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WATER ENERGY NEXUS IN URBAN WATER SOURCE SELECTION: A CASE STUDY FROM QINGDAO

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FOREWORD

Water and energy are important resources supporting socio-economic development and are main factors that must be addressed to achieve sustainable urban development. Through the years, a large amount of research has been conducted regarding resource shortages and rational resource allocation. The water-energy nexus, however, has rarely been studied. Because water and energy have been viewed in isolation, analyses and conclusions have not been sufficiently comprehensive.

The process of rapid urbanization faces serious water and energy challenges. It is necessary to comprehensively consider the impacts on energy consumption and greenhouse gas emissions when developing urban or regional water resource strategies. Therefore, the World Resources Institute's Sustainable and Livable Cities Initiative team conducted research in Qingdao and published the report *Water-Energy Nexus in the Urban Water Source Selection* to better understand the energy issues in the urban water system and the water-energy nexus.

Qingdao is a coastal city in northern China that severely lacks water but has diverse water sources. Currently, those water sources primarily consist of surface water, groundwater, transferred water from the Yellow River, recycled water and desalinated water. In addition, Qingdao receives Yangtze River water from the South-to-North Water Diversion Project. Optimizing the water sources portfolio, achieving reasonable allocation, ensuring urban water supply and reducing carbon emissions from the urban water supply system are all important for Qingdao's low-carbon development and the construction of a sustainable and livable city.

This report analyzes Qingdao's socio-economic development status; the status, use and supply potential of existing water sources; and risk features and energy consumption of all kinds of water sources. The report also forecasts Qingdao's water production consumption and greenhouse gas emissions in 2020 by examining trends in Qingdao's urban water demand and consequent energy consumption. The forecasts are used to provide recommendations to decision makers on how to achieve a sustainable, low-carbon water supply strategy and optimize the water sources portfolio.

We hope that this research can provide new insights about China's urban water resource plans, in addition to technical support for low-carbon urban design and construction. Such insights allow for urban water issues to be considered from the perspective of carbon emissions and climate change.

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EXECUTIVE SUMMARY

Water and energy are inextricably linked. Energy production depends on water, while the urban water system - particularly inter-basin water transfer or desalination - requires a large amount of energy. Thus, water supply is closely connected to a city's energy consumption. With increasing expectations on water quality and exploitation of unconventional water resources, the energy requirement of urban water systems may increase and subsequently raise greenhouse gas emissions.

Located on China's east coast, Qingdao faces a chronic water shortage; per capita water resources are only 12% of the national average. In order to meet its growing water demand, long-distance water transfer or the exploitation of unconventional water resources (such as desalination and reclaimed water) are already seen as a necessary step. Since the energy intensity of producing water from desalination, reclaimed water or long-distance water diversion is much higher than that for supplying water from conventional sources, Qingdao must work out how to allocate its various water sources so that it can ensure the security of its water supply while also reducing the urban water supply's carbon emissions, if it is to become a low-carbon, sustainable and livable city.

With financial support from the Caterpillar Foundation and the UKFCO Strategic Prosperity Fund, and the help of Qingdao's Development and Reform Commission, the Qingdao Water Supply Division, and the Qingdao Municipal Water Conservancy Bureau, the World Resources Institute and Atkins (UK) formed an international research team of specialists from China, the US and the UK, to help Qingdao analyze and find a water-energy resource balance for its urban water allocation mix.

The project team used a multi-pronged approach to identify the water supply potential and the advantages and disadvantages of using various types of water sources by analyzing Qingdao's naturally occurring water resources, predictions of the future trends in water use, and potential energy consumption of the urban water system, and then developing scenario analyses of the energy demand of the urban water supply system in 2020. We then used the analyses to provide recommendations to policymakers to develop strategies for a sustainable, low-carbon water supply, and to optimize the allocation of water resources.

CHARACTERISTICS AND UTILIZATION OF QINGDAO'S WATER SOURCES

Qingdao suffers from an acute water shortage. Its water resources are unevenly distributed, both temporally (inter-annual and intra-annual variations are large) and spatially (the urban center, which has the highest population density and the highest development density, is the area that has the worst water shortages). It is characterized by short periods of relatively plentiful water followed by prolonged droughts.

With decades of effort on water saving, Qingdao is now a national leader in industrial water efficiency and also has relatively low per capita domestic water use, meaning that any further improvement to its water efficiency is severely limited. Along with economic development and the continual rise in living standards, per capita water consumption may rise further, which means that the pressure on water supply will inevitably grow more intense. Reliance on alternative water sources, such as long-distance water transfer or desalination, which will drive up the urban water system's energy consumption and greenhouse gas emissions, will exert additional pressure on Qingdao to reduce its carbon emissions.

WATER DEMAND PROJECTION FOR QINGDAO IN 2020

By 2020, Qingdao's annual water demand will reach 1.48 billion m^3. Of this, industrial water demand will be about 301 million m^3, up 58% from 2011; agricultural water demand (including rural residents' water usage, water for livestock and for irrigation) will be about 486 million m^3, up 7% from 2011; domestic water demand (including householder use and urban public services) will be 583 million m^3, up 89% from 2011; and environmental water demand will be 110 million m^3, up 94% from 2011. We can see from this that the biggest water consumers in the future will be domestic consumers.

Based on the provincial water quotas scheme, Qingdao is expected to limit total annual water use to 1.47 billion m^3 by 2020, which is slightly lower than our projection. Therefore, Qingdao will need to further promote water conservation, and tap unconventional water resources (e.g. reclaimed wastewater, desalination), which are excluded from the government quotas.

RISKS CHARACTERISTICS, WATER SUPPLY POTENTIAL AND ASSOCIATED ENERGY INTENSITY OF VARIOUS WATER SOURCES IN QINGDAO

Qingdao's principal future exploitable water sources are: local surface water, local groundwater, water diversion from the Yellow River/Yangtze River, seawater desalination and reclaimed wastewater.

Table 0-1 shows the different types of risks associated with Qingdao's various water sources. For example, even though supplies of seawater for desalination are reliable, and desalination is not vulnerable to climate change, it consumes a lot of energy, requires a lot of investment, and has low public acceptance. For water diversion, factors such as the high investment needed, the environmental impact, and population resettlement also pose large risks.

Table 0-1 | **Risks Comparison of Different Water Sources**

INDICATORS	LOCAL SURFACE WATER (RESERVOIR)	LOCAL GROUND-WATER	WATER DIVERSION	SEAWATER DESALINATION	RECLAIMED WATER	RAINWATER
Water Quality	Medium	Medium	Medium	Low	Low-High	High
Water Continuity	Medium	Medium	Medium	Low	Low	High
Impact on Land Use	High	Low	High	Low	Low	Low
Investment	High	Low	High	High	Medium	Low
Energy Consumption	Low	Medium	High	High	Medium-High	Medium
Environmental Impact	High	Medium	High	Low	Low	Low
Population Resettlement	High	Low	Medium	Low	Low	Low
Public Acceptance	Low	Low	Medium	High	High	Medium
Vulnerability to Climate Change	High	High	High	Low	Low	High

Figure 0-1 shows the water supply potential and the energy consumption per unit of water supply of various water sources.

- Not including desalination, the maximum water supply potential of all available water resources is 2.285 billion m^3. Of this, the maximum available from local surface water and groundwater resources is 1.463 billion m^3. The utilization rate for surface water must not exceed 40% if Qingdao wants to maintain its water use at a sustainable level, while for groundwater it must not exceed 50%. In that case, the local water supply potential will be 1.104 billion m^3 (640 million m^3 from surface water and 464 million m^3 from groundwater). Therefore, for Qingdao to satisfy its 2020 demand for water, it must resort to water diversion, reclaimed water, and/or seawater desalination.
- Meeting drinking water quality standards, the energy consumption per unit of water supply of seawater desalination is the highest at about 4kWh/m^3, around 10 times higher than that for surface water, which has the lowest energy consumption. Arranged in order of energy consumption for unit water supply from the lowest to the highest, the water sources are: surface water < river diversion (Yellow River) < groundwater <reclaimed water (NEWater) < water diversion (Yangtze River) < brackish water desalination < seawater desalination.

Figure 0-1 | **The Water Supply Potential and Energy Consumption of Qingdao's Water Sources**

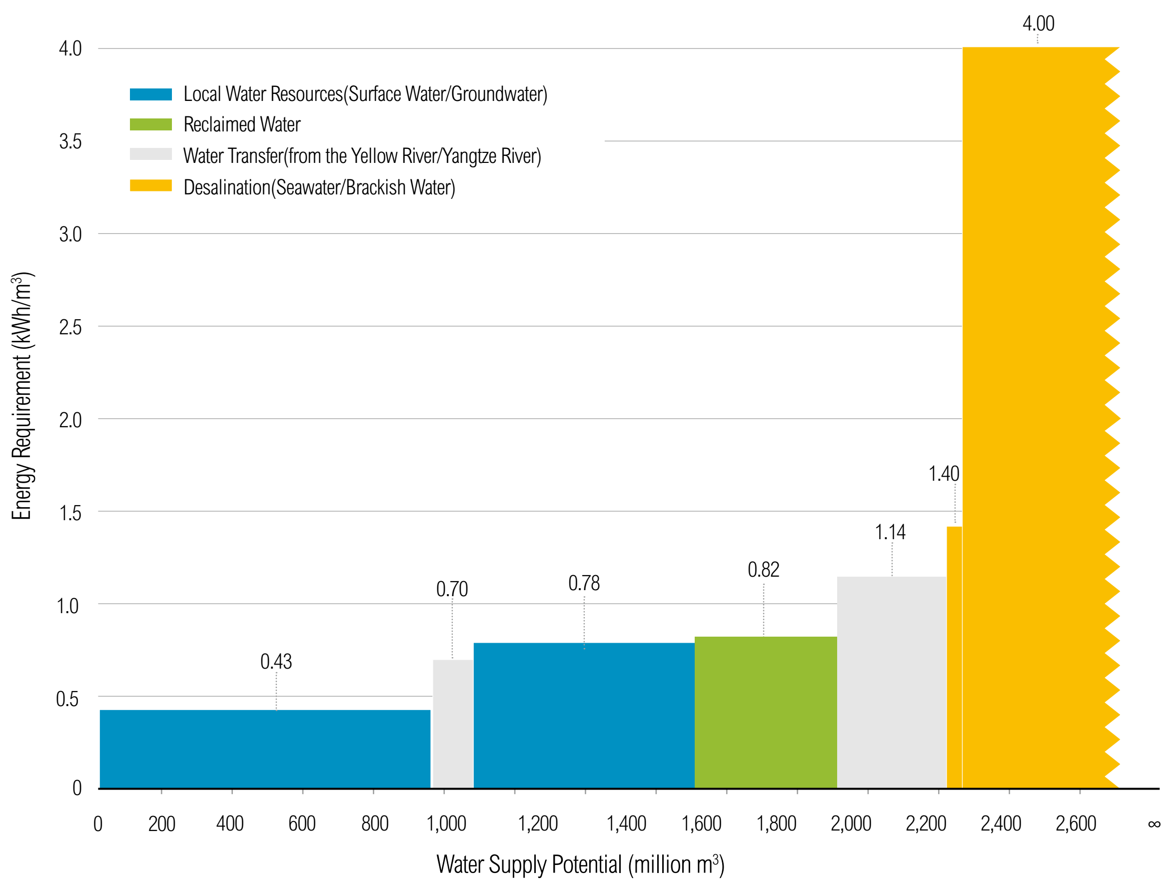


Table 0-2 | **Water Source Allocation Scenarios for Qingdao, 2020**

SCENARIO	TYPE OF WATER SOURCE	SEAWATER DESALINATION SUBSCENARIO WATER SUPPLY (100 million m^3)	RECLAIMED WATER SUBSCENARIO WATER SUPPLY (100 million m^3)	WATER DIVERSION SUBSCENARIO WATER SUPPLY (100 million m^3)
Surface Water 40 Baseline Scenario	Local Surface Water	6.4	6.4	6.4
	Groundwater	5.5	5.5	5.5
	River Diversion (Yellow River)	1.1	1.1	1.1
	River Diversion (Yangtze River)	0.78	0.04	1.91
	Seawater Desalination	1.53	0.4	0.4
	Low-Quality Reclaimed Water	0.37	0.37	0.37
	High-Quality Reclaimed Water	0	1.87	0
	Total	15.68	15.68	15.68
	TYPE OF WATER SOURCE	SEAWATER DESALINATION SUBSCENARIO WATER SUPPLY (100 million m^3)	RECLAIMED WATER SUBSCENARIO WATER SUPPLY (100 million m^3)	RIVER DIVERSION SUBSCENARIO WATER SUPPLY (100 million m^3)
Surface Water Red-Line Scenario	Local Surface Water	7.33	7.33	7.33
	Groundwater	5.34	5.5	5.5
	River Diversion (Yellow River)	1.1	0.21	1.1
	River Diversion (Yangtze River)	0	0	0.98
	Seawater Desalination	1.53	0.4	0.4
	Low-Quality Reclaimed Water	0.37	0.37	0.37
	High-Quality Reclaimed Water	0	1.87	0
	Total	15.68	15.68	15.68
	TYPE OF WATER SOURCE	SEAWATER DESALINATION SUBSCENARIO WATER SUPPLY (100 million m^3)	RECLAIMED WATER SUBSCENARIO WATER SUPPLY (100 million m^3)	RIVER DIVERSION SUBSCENARIO WATER SUPPLY (100 million m^3)
Surface Water 55 Scenario	Local Surface Water	8.8	8.8	8.8
	Groundwater	4.98	4.24	5.01
	River Diversion (Yellow River)	0	0	1.1
	River Diversion (Yangtze River)	0	0	0
	Seawater Desalination	1.53	0.4	0.4
	Low-Quality Reclaimed Water	0.37	0.37	0.37
	High-Quality Reclaimed Water	0	1.87	0
	Total	15.68	15.68	15.68

ENERGY CONSUMPTION AND GREENHOUSE GAS EMISSIONS FROM QINGDAO'S WATER SECTOR IN 2020

Based on prerequisites of (1) meeting the water use target of 1.473 billion m^3 by 2020; (2) prioritizing the exploitation of local water resources; and (3) when considering water diversion, it is preferable to divert from the Yellow River, we created three scenarios—one with a surface water utilization rate of 35% (current level, referred to as surface 35 scenario); one of 40% (keeping within sustainable exploitation and utilization limits, referred to as surface 40 scenario); and one of 55% (extreme condition, surface 55 scenario). Within these three scenarios we then created three subscenarios: one, which emphasizes seawater desalination, the second, which emphasizes reclaimed water, and the third, which emphasizes water diversion. In the desalination subscenario, we assume all of Qingdao's proposed desalination capacities are in place while the amount of reclaimed wastewater and transferred water remain the same as in 2011. Similarly, we assume half of Qingdao's municipal wastewater is reused in the reclamation subscenario and more transferred water from the Yangtze is used in the transfer subscenario.

Table 0-2 shows the various source water allocations under the different scenarios. For a more detailed explanation please see the full report.

By 2020, if Qingdao keeps the current surface water utilization rate of 35%, total energy use will see a significant increase. The desalination subscenario has the highest growth in energy requirement while the reclamation subscenario appears to be the lowest of the three. Greenhouse gas emissions from the water sector showed a similar upward trend, with the reclamation subscenario bringing the lowest emissions, or 40% lower than the desalination subscenario.

Under the surface 40 scenario, energy consumption of the reclamation subscenario will be the lowest, while seawater desalination has the highest energy consumption, rising 153% from 2011 level. In terms of greenhouse gas emissions, the desalination subscenario again dwarfs the other two subscenarios.

If Qingdao were to increase its surface water utilization rate to 55%, local surface water and groundwater would be expected to provide 1.43 billion cubic meters of water, only 50 million short from the total water demand. The scheme prioritizing water diversion will lead to a 34% increase in energy consumption compared to the 2011 baseline level, while the reclamation sub-scenario and desalination subscenario show potential increases of 34.3% and 41%, respectively. The desalination subscenario is still the most carbon intensive solution, causing 5% higher greenhouse gas emissions than the water diversion subscenario or the reclaimed water subscenario.

To compare the energy consumption of the above three scenarios, we find that the more local surface water that is used, the lower the energy requirement of the water supply system: surface 55 < surface 40 < surface 35 (Figure 0-2). Given Qingdao's elastic interannual variability, it's critical to close the demand-supply gap by choosing the least carbon intensive type of unconventional water.

Figure 0-2 | **Comparison of Energy Consumption of Water Supply under Different Scenarios**

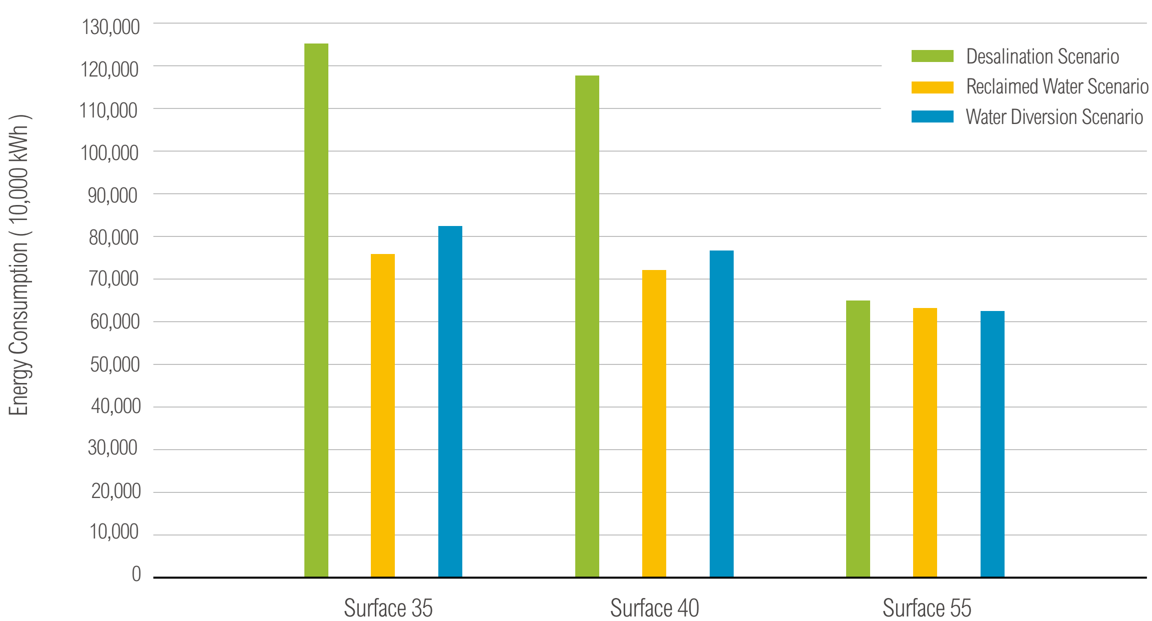
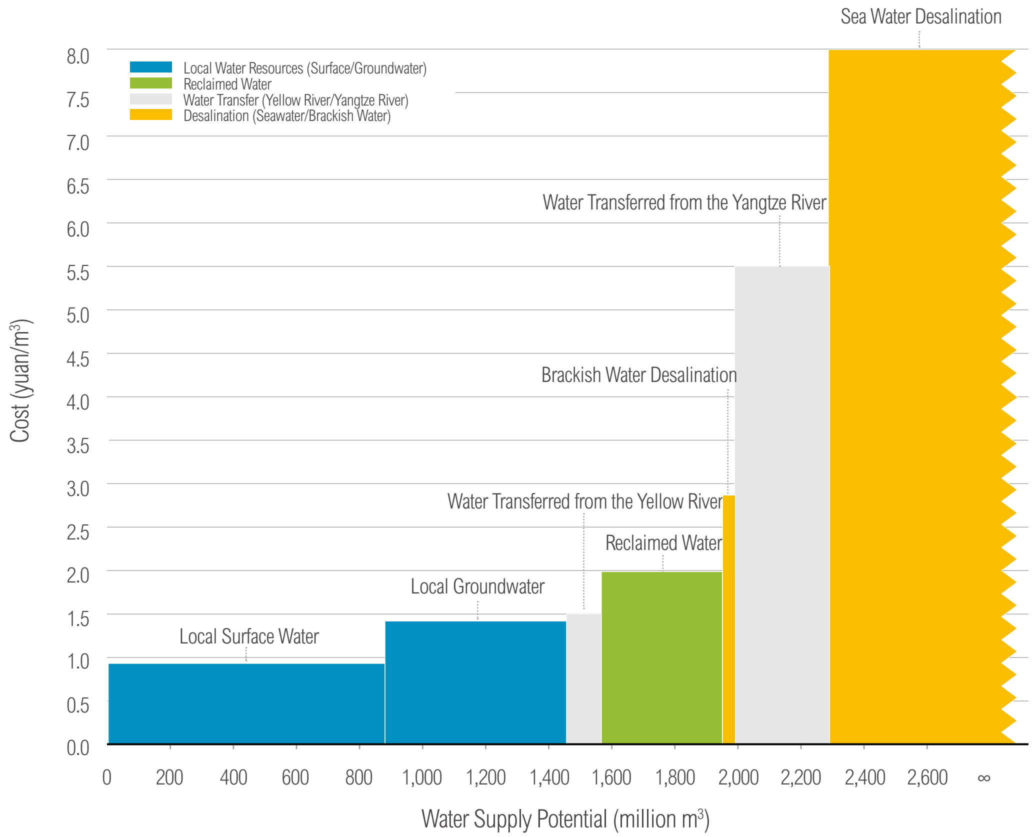


Figure 0-3 | **Costs of Qingdao's Water Sources**



A COST ANALYSIS OF QINGDAO'S WATER SUPPLY SOURCES

Figure 0-3 shows the water supply potential and the cost per unit of water produced for Qingdao's various water source options. We can see that current levels of technology, placed in order of increasing cost are local surface water < groundwater < water diversion (Yellow River) < NEWater< brackish water desalination < water diversion (Yangtze River) < seawater desalination. Of the conventional water sources, the cost advantages of NEWater are the most obvious; not only are they one-quarter that of seawater desalination, but they are even lower than water diversion (Yangtze River).

From a cost perspective, Qingdao should preferentially choose local water resources, followed by water diversion and then high-grade reclaimed water. The costs of water diversion (Yangtze River) and seawater desalination are both fairly high, and as they also increase carbon emissions, that adds to the costs of water supply.

Since Qingdao already has a desalination capacity of 133,000 m^3/day, from cost considerations, we recommend that seawater desalination should be used to supply water for industrial use. Although using current technology, seawater desalination is not cost effective compared to other water sources, since there is a stable supply of desalinated water and it is of good quality, irrespective of the time or weather, it is especially suited to those industries which require purified water, for example in the manufacture of electronics, chemicals, steel and microchips.

Similarly, the cost advantages of NEWater (reclaimed water) for industrial use are also clear. It costs about half as much to produce purified water from NEWater than from tap water.

CONCLUSIONS AND RECOMMENDATIONS

- The shortfall between Qingdao's water demand and water resources will continue to grow along with socio-economic development; the biggest contributor to this will be the growth in urban domestic water use. The speed of increase in domestic use and its proportion of all use will always be highest in urban areas and the speed of increase of use and the reason behind that increase will vary between districts. Water demand in Qingdao by 2020 is expected to reach 1.48

billion cubic meters, up 47% from 2011. The growth rate in industrial water demand will be 58%, agricultural water demand will grow 7% and urban domestic water demand (including urban public services) will grow by 89%. Urban domestic users will continue to be the principal water consumers, making up 40% of all society's water use. The percentage consumed by industry will remain stable, while the percentage used by agricultural consumers is expected to fall from 45% in 2011 to 33% by 2020.

- Qingdao must exploit unconventional water resources (including long-distance water diversion, reclaimed water, and seawater desalination) if it is to solve its water demand problem. Choice of water source allocation will have a direct impact on the energy consumption and carbon emissions of the urban water system. To meet drinking water quality standards, of the water sources available for Qingdao, the energy consumption is between 0.426 and 4 kWh per cubic meter. In order of increasing energy, the water sources are: local surface water < water diversion (Yellow River) < groundwater < NEWater < water diversion (Yangtze River) < desalination of brackish water < seawater desalination. As the most energy-intensive, seawater desalination has an energy consumption per unit of water supply which is 10 times larger than that of local surface water, which is the most energy intensive. Thus, which water source Qingdao chooses for its future water supply will have a direct impact on its urban water system's energy consumption and carbon emissions.

- Qingdao's urban water system faces an inevitable rise in energy intensity and carbon emissions. It must incorporate carbon accounting and energy management into its water supply planning to help it reduce the urban water system's carbon footprint allowing it to pursue low-carbon sustainable development. We estimate that greenhouse gas emissions from Qingdao's water sector will increase by 34% to 164% under different policy scenarios. The US and Europe are already aware of how changes to the structure of urban water resources and the demand for better quality water have caused urban water system energy intensity and carbon emissions to rise. These regions are now using carbon accounting when drawing up their urban water plans, with the aim of deriving a low-carbon water source allocation system. As Qingdao's economy develops, the energy consumption and carbon emissions of its urban water system will become fresh challenges. Especially since Qingdao is under pressure to follow a low-carbon development path and reduce its carbon emissions, we recommend that the city incorporate carbon accounting and energy management into its urban water source planning as soon as possible and build a low-carbon and sustainable urban water system.

- Of all the unconventional sources of water, reclaimed water is the best in terms of carbon emissions and cost. High-grade reclaimed water (NEWater) is not only relatively secure in terms of supply, but compared to other unconventional water sources, its carbon intensity and cost of production is also lower. According to our calculations, the energy consumption is 0.82 kWh, lower than water diversion (Yangtze River) and seawater desalination; while its cost is only one quarter that of seawater desalination, and also lowers than that of water diverted from the Yangtze River.

- Qingdao does not only need to consider factors such as cost and continuity of supply when deciding on a water source allocation mix, it also needs to thoroughly consider the type of water source, energy consumption per unit of water supply, carbon emissions, and environmental risks etc. There are many factors that need to be considered when deciding which water sources should be developed. As well as the quality of the water, continuity of supply and the costs involved, because of environmental protection and climate change, energy requirements, environmental impacts, and vulnerability to climate change are also elements that need to be considered when the city decides on a source water allocation mix.

- Customize water source use in accordance with local conditions. Qingdao should adjust the water source allocation mix for each district according to its individual water resources and water use requirements. Because water-intensive industries are relocating out of the eastern coastal districts, in the future, the focus of water supply will be on consumers from the domestic and service sectors. We recommend that local water resources and water diversion be used for domestic drinking water use; meanwhile, (low-grade) reclaimed water can be used for urban greening, residential toilets, and other non-contact and non-potable use. In the industrially-developed western coastal districts, which will experience a rapid expansion in population growth, we recommend high-grade reclaimed water for industry's main supply.

- Qingdao should reform its water tariff and continue prioritizing water saving measures. To date, the water tariff of Qingdao is at a relatively low level, considering that the city is among one of China's richest. Low water price hinders the city's endeavors to improve urban water service and water use efficiency. In the long run, it will be crucial for the water service sector to fully recover the cost and reflect the true cost of water. Qingdao should introduce increasing block tariffs to encourage water saving. This approach should consider social equity and ensure meeting the basic water needs of low income families. Public awareness of water efficiency could be improved through outreach activities backed up with incentives and subsidies given to deploy or upgrade water saving facilities.

CHAPTER 1

INTRODUCTION

Global demand for natural resources is growing because of rapid urbanization and population growth, prompting a potential resource depletion crisis. The reserves of non-renewable resources, such as coal, oil and natural gas, are in constant decline, while the functionality of renewable resources, such as water and land, is degraded due to unsustainable use. Human society and urban development now face various challenges related to water, energy, environment and economy.

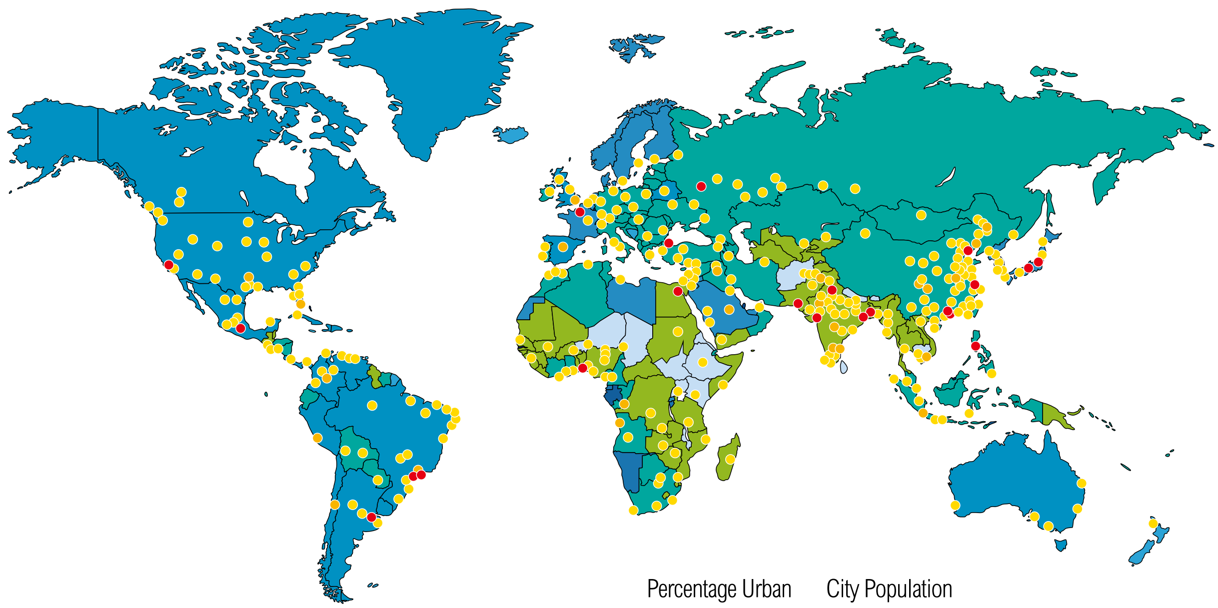
Urban population is growing in the 21st century. Roughly half the world's population lived in cities in 2008, a proportion predicted to reach 60% by 2030 (United Nations, 2008). Urbanization in developing countries is especially rapid. According to an analysis of the UN's Department of Economic and Social Affairs, an average of 5 million people in developing countries move from rural areas to urban areas every month. Currently, 15 out of 23 megacities with populations over 10 million are located in developing countries (see Figure 1-1), and four of them are located in China. By 2050, the estimated proportion of people living in cities in India will rise from 30% to 55%, while the proportion in China will rise from 50% to 73% (United Nations, 2012).

Compared to developed countries, China's urbanization started later and happened more rapidly (see Figure 1-2). It took China only 40 years to increase its urbanized population from 17% to 39%, while it took the U.S. 50 years and the UK 80 years to do the same thing[1]. Therefore, China's urbanization is facing unprecedented resource and environmental constraints. Various environmental and social problems caused by rapid urbanization must be resolved in a short period of time.

Cities are powerful economic drivers. But those intensive economic activities consume large amounts of natural resources. According to an analysis by the United Nations Human Settlements Programme (UN-HABITAT), cities account for 75% of the global energy consumption and 80% of global greenhouse gas (GHG) emissions. Ten percent of freshwater in the world is used for residential purposes and 20% is used for power generation (United Nations, 2008). It is estimated that by 2030, global energy demand will increase by 40%, most of which will come from cities and related industrial and commercial activities. Meanwhile, the demand for water in urban areas will continue to rise. According to the International Food Policy Research Institute, global domestic water consumption will be 75% higher in 2025 than it was in 1995. Ninety percent of that will come from cities in developing countries (IFPRI, 2002). Moreover, McKinsey & Company (2009) forecasted that total human demand for water will exceed predictable supply by 40% in the next 20 years.

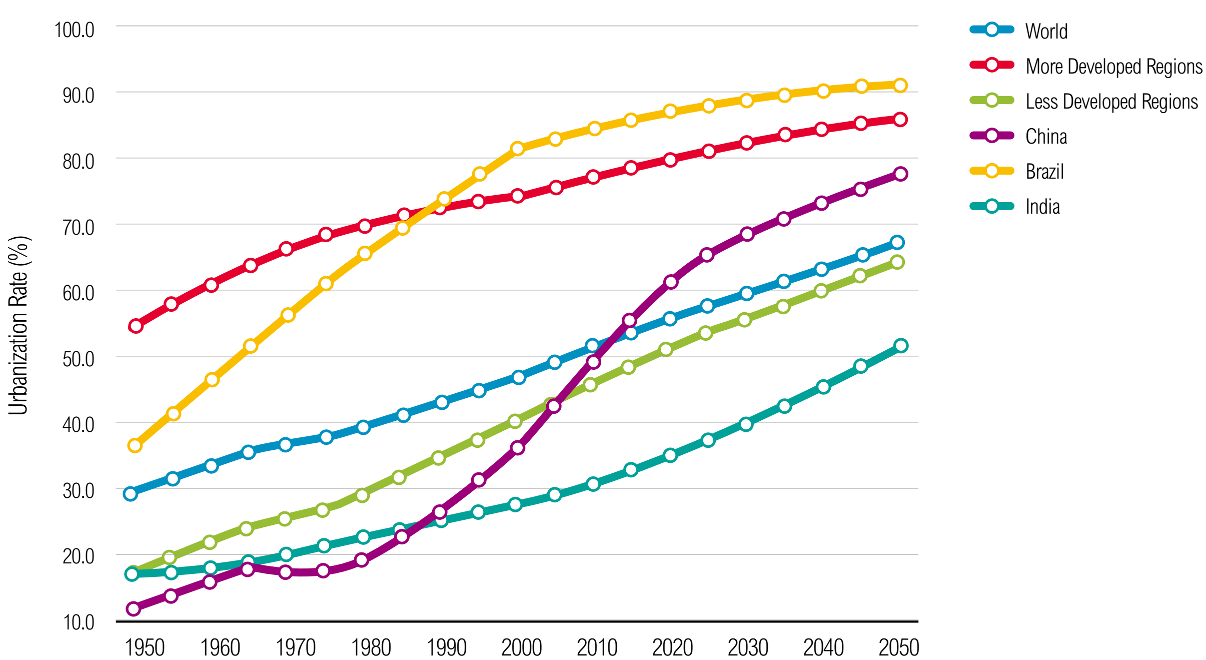
According to the Chinese Academy of Social Sciences, China has entered an urbanized era, leaving behind its older rural society. Globally, urbanization has resulted in increased resource consumption and carbon emissions. China is no exception. For instance, the electricity consumption of urban residents is four times higher than rural residents and the water consumption is three times higher[2]. This results in increased pressures on energy supply, resources, and the environment. China needs more energy to support its urban development. By 2020, the national capacity of electrical generation is expected to reach 1.59 billion kW, which is 0.62 billion kW more than in 2010 (EIA, 2013). The newly added capacity will mainly come from thermal

Figure 1-1 | **Global Urbanized Proportion and Urban Population**



Data Source: United Nations, 2012

Figure 1-2 | **Comparison of Urbanization Processes around the World (1950-2050)**



Data Source: United Nations, 2012

and hydropower, so more water resources will be required to support energy production. But limited water resources are already a serious challenge for the development of cities in China. Currently, two-thirds of cities in China have a lack of water, approximately 50 billion m^3. Water resources are overexploited in many regions and are far beyond their carrying capacities. For example, 76% of the Yellow River basin has been excessively used[3].

Coastal regions in China have seen the highest levels of urbanization and the fastest development, and they are suffering serious water shortages. Out of 52 coastal cities in 11 coastal provinces (including autonomous regions and municipal cities directly under the central government), nearly 90% face some kind of water shortage[4], whether extreme (18 cities), severe (10 cities), medium (9 cities) or slight (9 cities). Limited water resources have become a constraint on sustainable social and economic development in many coastal areas[11]. Qingdao is one of the northern coastal cities with the most severe water shortages. The amount of water supply per capita in Qingdao is only 313 m^3, which is less than the globally acknowledged absolute water shortage criteria (500 m^3 per capita). The amount of water per mu (approximately 667 m^2) of arable land is only 306 m^3, which is 15% of the national average.

In Qingdao, water diversion and unconventional water sources (such as desalinated seawater and reclaimed wastewater) have been considered as inevitable methods of resolving the severe water shortage. However, the energy required for seawater desalination, wastewater reclamation and water diversion are all higher than for tapping surface water and ground water resources. In some cases, the energy required can be 10 times higher. The energy consumption and related carbon emissions of Qingdao's urban water supply will be inevitably and directly impacted by the city's future water source portfolio. While Qingdao has committed to developing a sustainable and livable city with low carbon emissions, a rapid increase in the energy intensity of the water supply due to its portfolio makeup may weaken the city's ability to reduce carbon emissions. Therefore, in order to develop a livable and sustainable city with low carbon emissions, Qingdao needs to pay attention to and address how it will configure different water sources to ensure water supply security, as well as reduce water system-related carbon emissions.

Sponsored by the Caterpillar Foundation and the British Foreign and Commonwealth Office's Global Prosperity Fund, and with the support of the Qingdao Development and Reform Committee, Qingdao Municipal Utility Bureau and Qingdao Water Resources Bureau, World Resources Institute, Atkins (UK) and Qingdao Engineering Consulting Institute jointly formed a research team of Chinese, American and British experts to assist Qingdao in analyzing and identifying the water-energy balance in its urban water source configuration. The project focuses on the impacts of different water source portfolios on water supply cost, energy consumption and GHG emissions. The main contents include:

(1) Analysis of the energy consumption and cost of supplying water from various sources (including local surface water, ground water, water diversion, seawater desalination and wastewater reclamation) in Qingdao.

(2) Estimate of Qingdao's water demand in 2020 and prediction of the energy consumption and related GHG emissions of Qingdao's water supply in 2020, based on different water resource configuration scenarios.

(3) Identification of the water supply potential and pros and cons of various water resources in Qingdao, and recommendations for decision makers to develop a low-carbon sustainable water supply strategy and optimize the configuration of various water resources.

Chapter 2 discusses the relationship between the municipal water supply and its energy consumption, as well as GHG emissions. We then describe the status of Qingdao's economic and social development, water endowment and current water supply in Chapter 3. Qingdao's water demand in 2020 is estimated based on that information. We then analyze the characteristics and energy intensity of different water sources (Chapter 4), and predict the energy consumption and GHG emissions of Qingdao's water supply in 2020 based on analysis of various scenarios in Chapter 5. The conclusions and suggestions are provided at the end of the report.

Water shortages are growing more common. So, although this study focuses on Qingdao, other cities can refer to it to develop their own water supply strategies. The analysis and evaluation methods used in this study are applicable to most other Chinese cities as they incorporate issues at the water-energy nexus into the city planning process.

CHAPTER 2

THE WATER-ENERGY NEXUS IN URBAN WATER SYSTEMS

2.1 What Is the Water-Energy Nexus?

Historically, water and energy have been viewed and managed in isolation. Decision makers rarely take into account the impact of energy policies and development plans on water resources, including water supply and quality. Local water risks and water resource constraints are often neglected. At the same time, water policies and plans rarely take into account energy issues (such as energy consumption of different water sources) and energy management.

However, water and energy are interlinked in a complicated and subtle fashion. Water is necessary for energy extraction and power production – from coal extraction to thermal power generation. Additionally, energy is necessary for water extraction, transport, provision, wastewater treatment and reclamation. This interdependence between water and energy is called the "water-energy nexus".

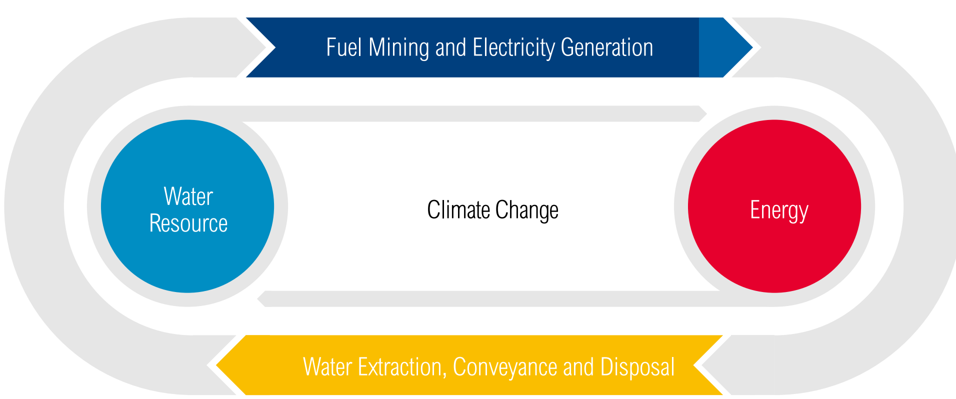
Climate change has intensified the interdependence between water and energy. Studies show that climate change has shifted the spatio-temporal patterns of precipitation, leading to more frequent extreme weather, such as floods and droughts (Table 2-1). The acceleration of these trends will influence the availability of water resources, directly and indirectly impacting energy production and power supply. For example, continuous drought in eastern and northern India in 2012 caused the shutdown of hydropower and thermal power plants, which in turn caused the most severe power outage in the country's history, impacting approximately 600 million people (Cleetus, 2012). Energy activities, especially the combustion of fossil fuels, will worsen climate change and its impacts, thus further changing the global water cycle and threatening the water supply security of human society. Because of climate change, the water-energy nexus can no longer be ignored (see Figure 2-1).

Table 2-1 | **Major Impacts of Climate Change on the World's Hydrology**

	CONFIRMED IMPACTS	PREDICTED IMPACTS IN 21ST CENTURY
Precipitation Amount	The global trend is not clear. However, precipitation has increased in northern areas between 30 and 85 degrees latitude, while it has decreased in southern areas between 10 and 30 degrees latitude.	The global precipitation amount will increase with different trends in different regions.
Precipitation Intensity	The amount of precipitation in extreme rainfall events has increased, as has the frequency of extreme weather globally.	Extreme rainfall events will increase 7% for each one-degree increase in global average temperature.
Drought	According to the Palmer Drought Severity Index, droughts around the world have increased. However, the droughts in some regions have eased to some extent.	The possibility of seasonal droughts will increase in some regions.
Glaciers	The global total volume of glaciers has decreased, the mountain snowlines in the Northern Hemisphere have retreated and glaciers now melt earlier than before.	The total volume of glaciers around the world will continuously decrease, and snowlines will retreat.
Sea Level	Sea level has increased 0.2 m in the 20th century.	Sea level will increase by 0.2 to 0.6 m by 2100.
Ocean Acidification	The ocean's average pH has dropped from 8.2 to 8.1.	The ocean's average pH will drop to between 7.7 and 7.8 by 2100.
Ocean's Surface Temperature	The ocean's surface temperature has increased 0.5 degrees since 1980 period	The ocean's surface temperature will keep increasing.

Data Source: UNEP, 2012

Figure 2-1 | **Illustration of the Water-Energy Nexus**



2.2 The Water-Energy Nexus in Urban Water Systems

Compared to other industries, the urban water sector's energy consumption is relatively low and therefore often overlooked by municipal administrations. This problem is especially pronounced in China. There aren't even statistics on urban water systems' energy consumption and rising energy consumption is not noticed due to the lack of information. However, as water shortages prompt more and more cities to incorporate unconventional water resources (such as desalinated seawater, reclaimed wastewater and transferred water) into their water portfolios, the energy consumption of urban water systems will increase. Moreover, different water sources will pose different environmental, ecological and health risks.

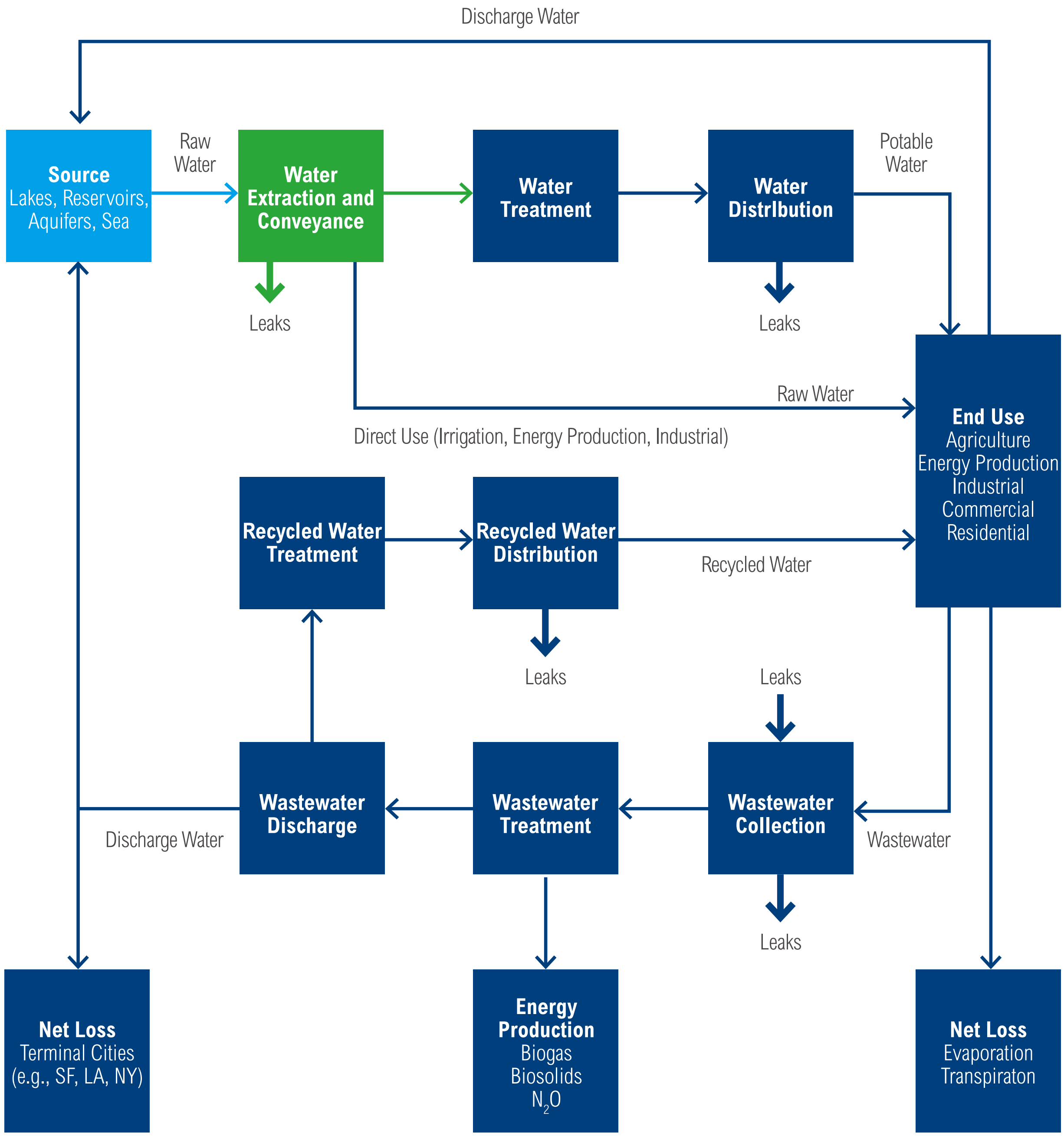
Energy is mainly consumed during the following aspects of the urban water cycle (see Figure 2-2):

(1) Raw water extraction and delivery: Most water sources (including surface water, ground water, seawater, reclaimed water and transferred water) require pumps to lift the raw water to the water supply plant. Elevation differences between the water collecting point and accepting point usually require a relatively high amount of energy to overcome. For example, the energy consumed during water transmission in coastal cities in California is about 2.5 kWh/m^3.

(2) Water production: Normal tap water plants purify the raw water through industrial processes such as sedimentation, filtration and sterilization to meet national drinking water standards. Pump stations lift the raw water to the reaction pond. Other water production processes also consume energy. The energy needed for seawater desalination and wastewater reclamation is higher than that of conventional water, due to different water production processes.

(3) Water distribution: Tap water to be delivered to users is pressurized at pump stations, which consumes energy.

Figure 2-2 | **Illustration of the Urban Water System**



Data Source: Revised Based on Water in the West (2013)

(4) Wastewater collection, treatment and discharge: Wastewater is delivered to wastewater treatment plants via wastewater pipe networks for physical and biochemical treatments. Pump stations, fans, biochemical treatments and other treatments (such as sterilization by ozone or UV and membrane treatments) consume energy.

The energy consumption and carbon footprint differ significantly for different water supply infrastructure systems. Due to limited data, this study only considers operational energy consumption in water extraction and production (hereafter referred to as water production energy consumption).

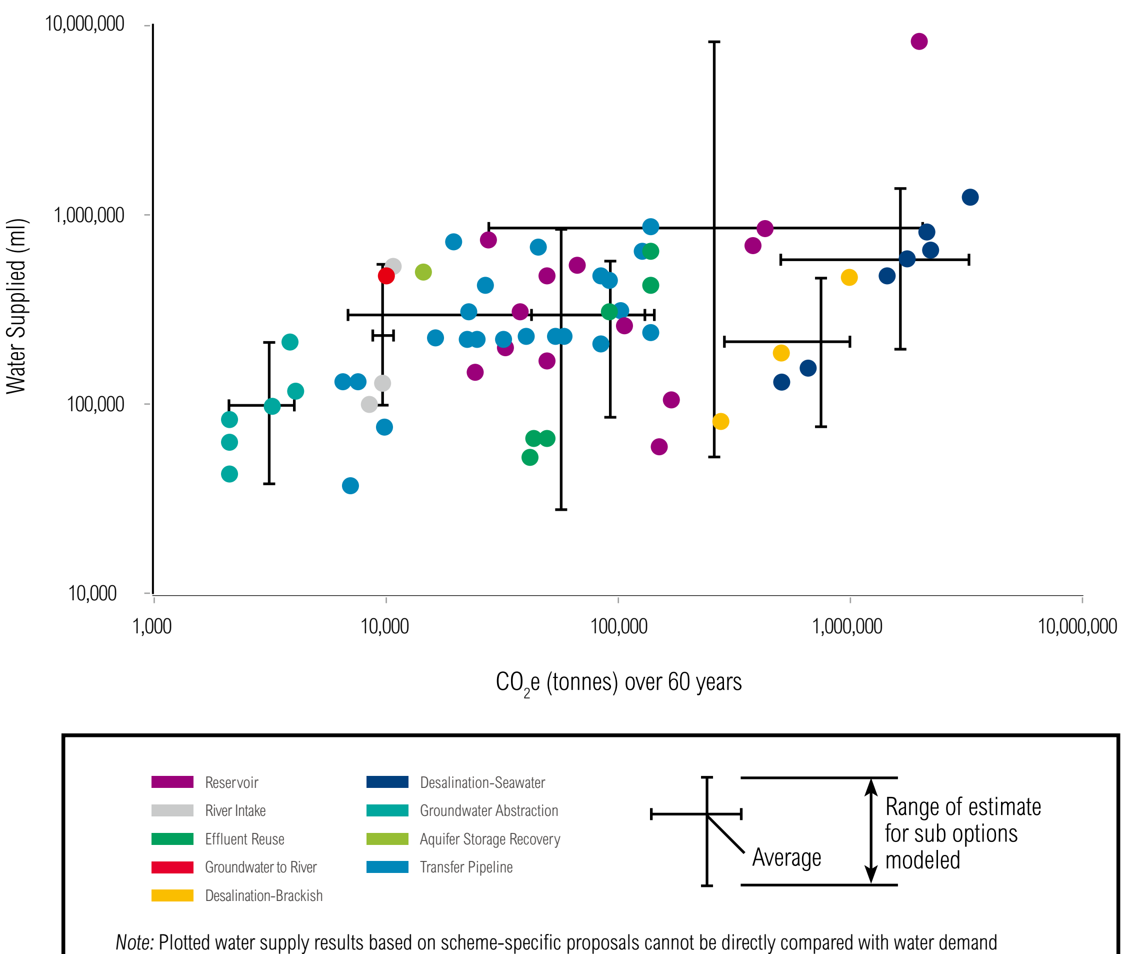
The energy consumption and management of urban water systems have raised concerns in western countries. For example, in the UK, the energy consumption of tap water production is typically about 0.12 kWh/m^3, and for wastewater treatment it is 0.21 kWh/m^3. Meanwhile, the energy consumed by residential water uses (mainly for heating water) is much higher and, at 2.66 kWh/m^3, accounts for 89% of the total energy consumption. Since 2008, the UK Office of Water Service has required cities to evaluate the energy consumption and carbon emissions of water supplies from different sources, with the goal of helping the country achieve its low-carbon development targets. To provide instructions on calculating life-cycle GHG emissions (including project construction, raw material production and other production processes), the UK Department of Environment issued the *Guide for the Red-Line Scenario Measurement and Calculation of the Greenhouse Gas Emission in Water Industry* (hereafter referred to as the *Guide*) and *Calculation Tools for Carbon Footprint in Water Resources*. The calculator uses multiple models to estimate the energy consumed by supplying water from conventional water sources (ground water and surface water) and unconventional water sources (seawater/brackish water desalination, utilization of rainwater and reclaimed water) as well as the distribution system (water distribution pressure, pipe network loss). The calculator automatically includes the cost of carbon emissions in a project's overall budget.

According to the calculator, water industry can both cut operational costs and help the government achieve its carbon emissions reduction plan by reducing its energy consumption, The UK's Southern Water Services used the water carbon footprint calculation tools in its 2010-2015 business development plan to estimate carbon emissions from its water supply in more than 70 scenarios (Box 1).

Box 1 | Carbon Footprint Calculation by UK's Southern Water Services

In 2008, the carbon footprint calculation tool (CFP calculator) was used by the UK's Southern Water Services to develop its water business development plan. Carbon emissions from different sources and methods of supplying water were assessed by the calculator. The following figure shows that within its 60-year life cycle, the energy consumption of seawater desalination is 1,000 times higher than that of a ground water proposal.

Similar methods can be used as a reference for Qingdao to calculate the energy consumption and carbon emissions of supplying water from different sources. There may be significant differences between the energy consumption of various methods of expanding Qingdao's water supply, and energy demand and carbon emissions can be included as criteria in evaluating the economic feasibility of various solutions.



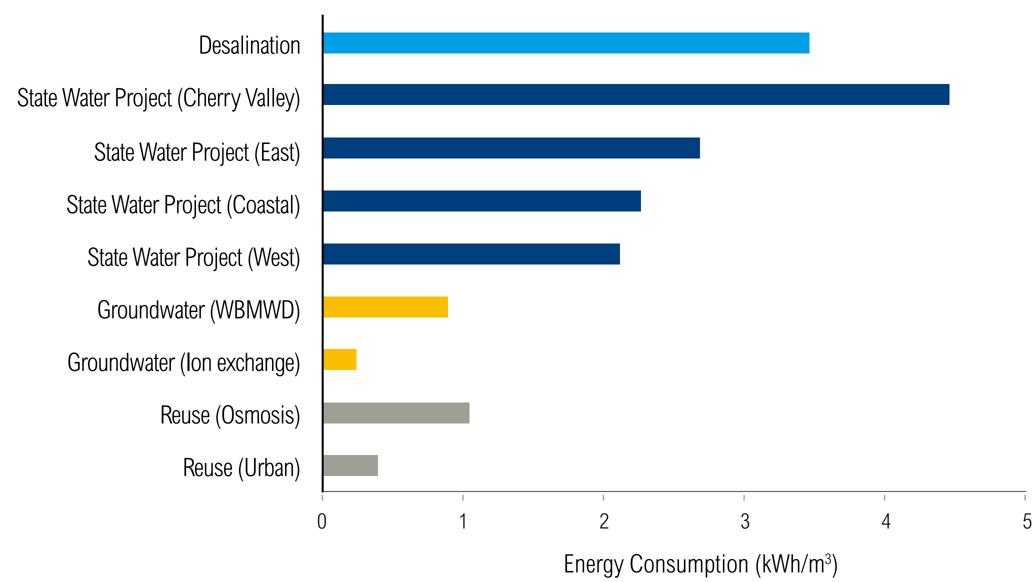
Note: Plotted water supply results based on scheme-specific proposals cannot be directly compared with water demand results based only on uptake by 1,000 households.

Whether by importing water or exploiting unconventional water resources, cities' water portfolio will change noticeably. Cities' water strategy will become more diverse and complex because of population growth and economic development. Importantly, changing urban water supply sources also impacts energy consumption and carbon emissions. Different water sources consume more or less energy. For example, seawater desalination consumes 5 to 10 times more energy per unit of water supplied than conventional surface water. A University of California analysis of the energy consumed by various water sources (Figure 2-3) indicates that the water production energy consumption of some water sources can be 10 times higher than others. Currently, 20% of California's electricity and 30% of its natural gas are used for water production, transportation and utilization[5]. The analysis suggests that the impacts of the urban water system on energy demand cannot be overlooked.

Therefore, selecting urban water sources is not only a water issue but an energy issue. Different combinations of water sources will have different impacts on cities' energy demands and GHG emissions. Water supply systems will become an indispensable and critical aspect of cities' low-carbon development, especially in cities with severe water shortages.

Bay cities facing water shortages, such as Qingdao, may be tempted to turn to water diversions and seawater desalination, but such sources could greatly increase total energy consumption. In Qingdao, water production energy consumption currently accounts for only 1% of overall electricity consumption (if water distribution and wastewater treatment are also included, the total power consumption of the urban water system is estimated at 4 to 5% of the city's electricity consumption)[6]. However, an unreasonable water configuration will cause the water supply system's carbon footprint to grow rapidly, which could intensify the conflict between the city's development and its water supply and energy consumption. Therefore, a study on the water-energy nexus of Qingdao's urban water source configuration is useful for thy city's low-carbon development, as well as for other cities facing water shortages.

Figure 2-3 | **Water Production Energy Consumption of Different Water Sources in Southern California**



Data Source: Wilkinson, 2010

CHAPTER 3

CURRENT STATUS OF QINGDAO'S WATER MANAGEMENT

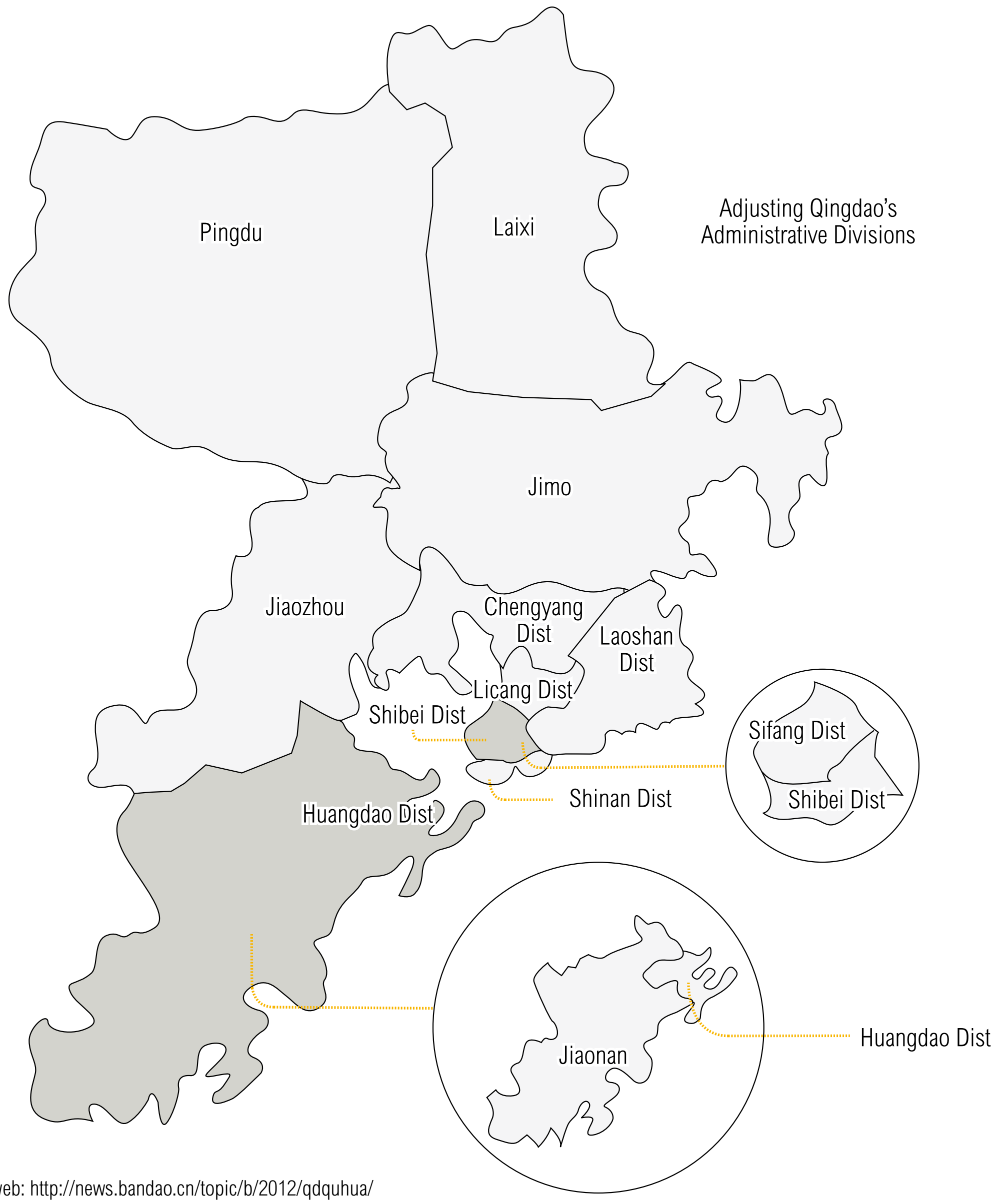
3.1 Basic Information on Qingdao

Qingdao is located in the southern part of the Shandong Peninsula, with the Yellow Sea to the southeast, the city of Yantai to the northeast, the city of Rizhao to the southwest and the city of Weifang to the west. Qingdao is a city specifically designated in the state plan and is among the first batch of opening coastal cities. It is also a coastal tourism city and an important international port.

Qingdao is a hilly city with higher elevation in the east, lower elevation in the west and hilly areas in the north and the south. The city's total area is 10,654 km^2, and it is 15.4% mountains, 25.1% hills, 37.8% plains and 21.7% depressions[7].

Since 1994, Qingdao has had 7 districts and 5 counties. At the end of 2012, the State Council approved Qingdao's application to reduce the number of administrative districts to six and county-level cities to four. Since then, Sifang District has been incorporated into Shibei District, and the Huangdao District and the county-level city Jiaonan have been merged into a new Huangdao District (see Figure 3-1)[8].

Figure 3-1 | **Adjustment of Administrative Divisions in Qingdao**

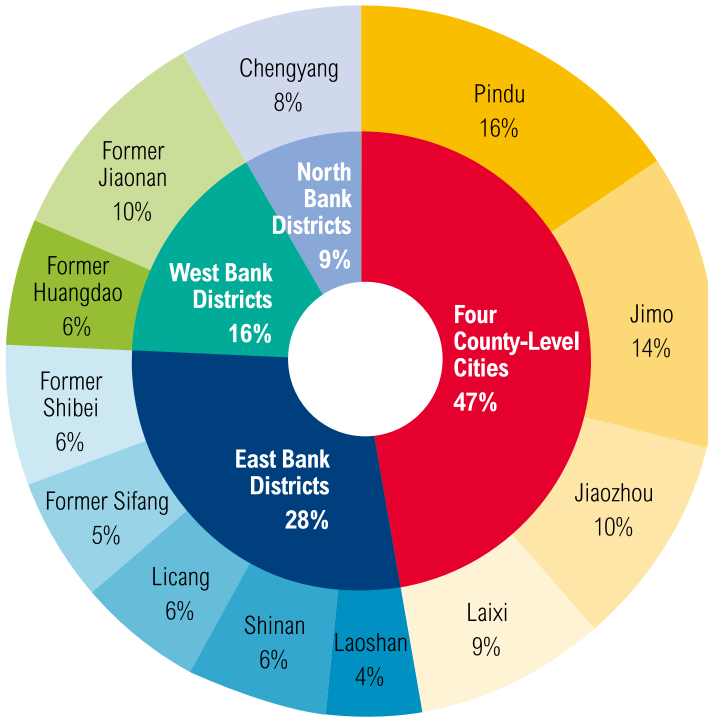


Data Source: Bandao web: http://news.bandao.cn/topic/b/2012/qdquhua/

Qingdao had a permanent population of 8,715,100 in 2010, of which 66% was urban (QDSB, 2011), according to the 6th national census. The population distribution in Qingdao is very unbalanced, with 39% of the permanent population concentrated on 16% of the land area in the east, north and west bank areas (not including the former Jiaonan county-level city and Laoshan District). In those areas, the population density is 1,873 people per km^2, which is 2.7 times higher than the city's average population density (see Figure 3-2) [9].

Qingdao's Conservation and Development around Jiaozhou Bay Plan calls for rapid economic and social development and urbanization. Based on the *12th Five-Year Plan of Economic and Social Development of Qingdao*, the city will have a permanent population of 9.5 million people by 2015 (a 9% increase from 2010), with the urbanized proportion of the population reaching 75% and GDP growth hitting 76%. Meanwhile, energy demands will rise 41% and water demands will rise 42% (see Table 3-1).

Figure 3-2 | Population Distribution in Qingdao (2010)



Data Source: Qingdao Statistical Yearbook 2011 (QDSB, 2011)

Table 3-1 | Qingdao's Economic, Social, Energy and Water Index in 2010 and 2015

	INDICES	2010	2015
	GDP (100 million RMB)	5,666	10,000
	Permanent Population (10,000 people)	871	950
	Urbanization Rate (%)	67	75
	Energy Demand (10,000 tons of standard coal)	3,968	5,606
	Water Demand (10,000 m^3/day)	139	198

Data Source: 12^{th} Five-Year Plan of Economic and Social Development of Qingdao

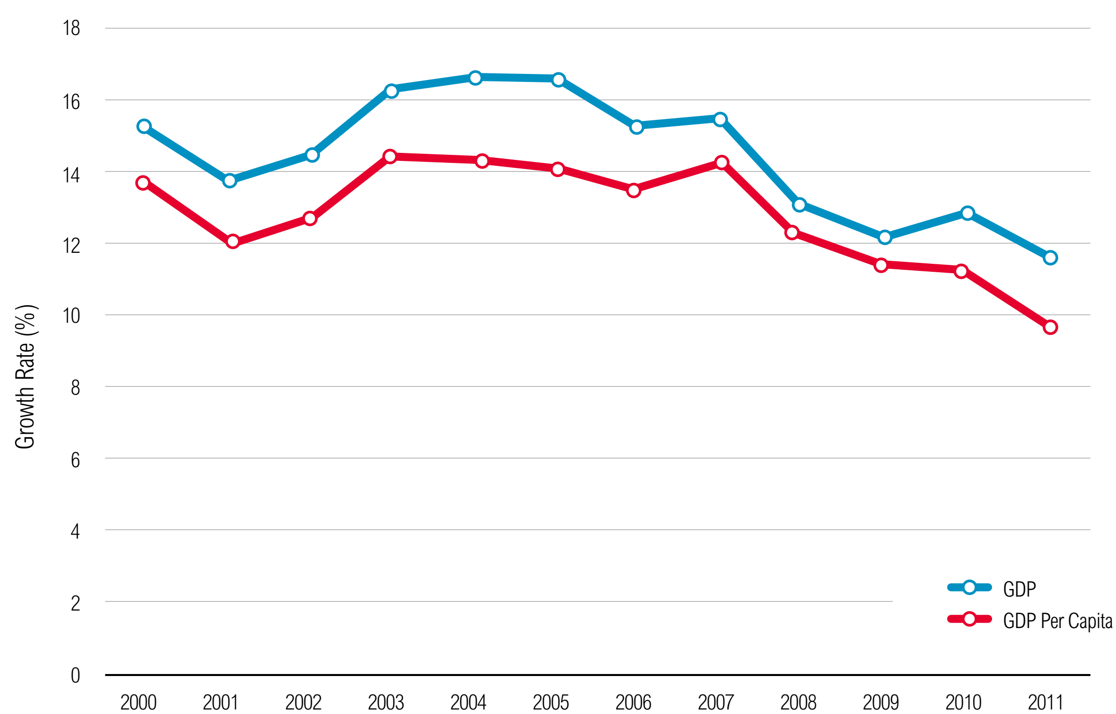
It is estimated that Qingdao's population will reach 12 million by 2020, with 80% of people living in urban areas. Development in the east bank area will reach the saturation point. The focus of the Development around Jiaozhou Bay strategy will move to the north and west bank areas. Chengyang and Huangdao Districts will face more difficulties due to future population growth.

Qingdao is the largest industrial city in Shandong Province, and it is also one of the cities in China with the fastest economic development (see Figure 3-3). Its GDP in 2010 was 661.56 billion RMB and the GDP per capita was 75,763 RMB, which was 2.16 times the national average (35,083 RMB) (QDSB, 2011). The shares of the primary industry, secondary industry and tertiary industry are 4.6%, 47.6% and 47.8% respectively. Several of the 10 industries in Qingdao with the highest industrial value-added rates are water-intensive: processing of farm and sideline products, chemicals, textiles and iron/steel.

It is estimated that Qingdao's GDP will reach 1 trillion RMB by 2015, and will exceed 2 trillion RMB by 2020. According to Qingdao municipal government plans, the east bank area will be home to modern service industries, such as finance, IT, business and tourism, while the north bank area will be home to secondary and tertiary industries such as the new high-tech industrial area. The west bank will be home mainly to secondary industries such as ports and manufacturing industry. Qingdao will be built into an ecological coastal city with a modular configuration.

Although agriculture's share of Qingdao's economy is dropping, the five county-level cities in Qingdao are all national bases for commodity grain production. Additionally, Jiaozhou, Jimo, Pingdu and Laixi are designated as primary grain production counties in the *National Plan for Adding 100 Billion Jin (500 grams) Grain Production Capacity*. Qingdao thus faces the challenge of securing water for agriculture and grain production (QDWRB, 2012).

Figure 3-3 | **Qingdao's GDP and GDP Per Capita Growth Rates (2000-2011)**



Data Source: Qingdao Statistical Yearbook 2011 (QDSB, 2011)

3.2 Current Status of Water Utilization in Qingdao

Qingdao is one of the northern coastal cities in China with a severe water shortage. On one hand, Qingdao's demand for water is growing rapidly. On the other hand, local water resources that can be developed are very limited. The city's dependence on transferred water is gradually growing and groundwater in some areas is overexploited. Competition among urban, industrial and agricultural uses of water is becoming increasingly fierce. Hence, Qingdao's water portfolio and utilization mode will have direct impacts on the city's social and economic development.

3.2.1 Total and Available Amount of Water Resources

Qingdao's long-term average annual precipitation is 688.2 mm, and the total amount of water resources is 2.21 billion m³. Long-term average surface water makes up 1.6 billion m³ per year, and groundwater makes up 0.929 billion m³ per year, with 0.319 billion m³ per year double-counted (see Table 3-2). The water amount per capita is 313 m³ (12% of the national average) and the amount per mu of land is 306 m³ (15% of the national average) (QDWRB, 2007b).

According to *Qingdao's 11th Five-Year Plan of Comprehensive Utilization and Development of Water Resources* (QDWRB, 2007b), the city's long-term average annual total amount of available water resources is 1.488 billion m³, which is 67% of its total water resource amount. And the long-term average available surface water is 0.905 billion m³ per year and developable groundwater is 0.583 billion m³ per year (after the double-counted 89 million m³ is deducted). The whole city's available water re-

Table 3-2 | **Qingdao's Long-Term Average Annual Total Amount of Water Resources**

ADMINISTRATIVE DIVISION	PRECIPITATION		SURFACE WATER RESOURCE (10^8 M³)	GROUNDWATER RESOURCE (100 MILLION M³)	DOUBLE-COUNTED (10^8 M³)	TOTAL WATER RESOURCE (10^8 M³)
	MM	10^8 M³				
Urban	728.1	1.03	0.34	0.18	0.13	0.39
Former Huangdao	737.1	2.08	0.51	0.21	0.09	0.63
Laoshan	861	3.35	1.46	0.66	0.41	1.71
Chengyang	698	2.92	0.83	0.47	0.16	1.14
Jiaozhou	686.1	8.30	1.52	1.06	0.41	2.17
Jimo	678.5	11.72	2.68	1.29	0.54	3.43
Pingdu	638.7	20.22	3.28	2.41	0.36	5.33
Laixi	678.8	10.33	2.13	1.36	0.37	3.12
Former Jiaonan	743.7	13.36	3.25	1.65	0.71	4.18
Whole Cities	688.2	73.32	16.0	9.29	3.19	22.1

Data Source: Qingdao's 11th 5-Year Plan of Comprehensive Utilization and Development of Water Resources (QDWRB, 2007)

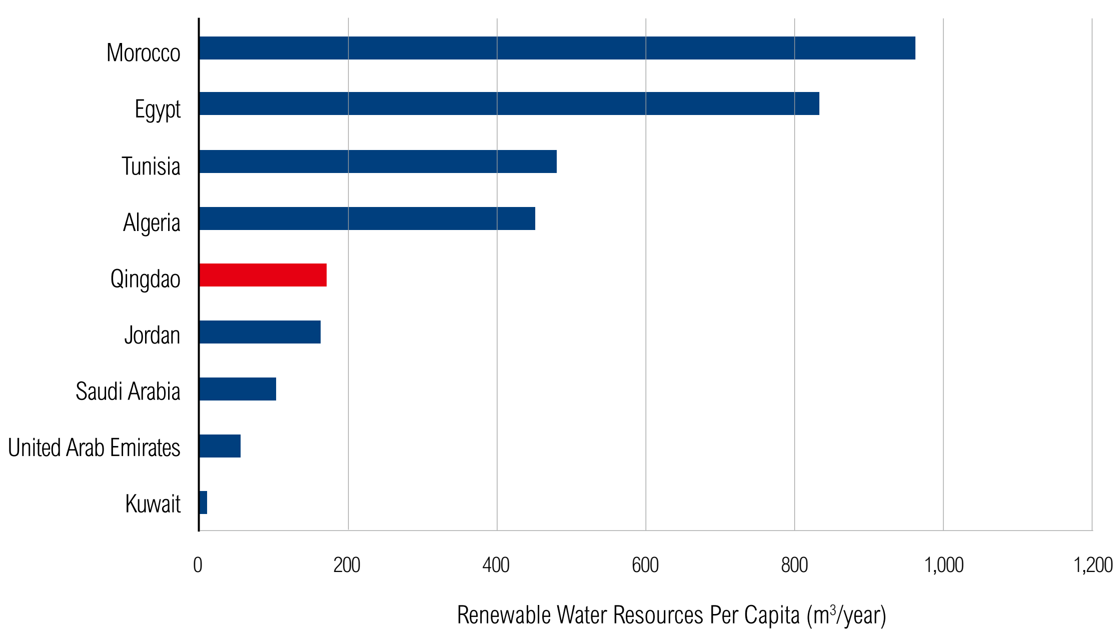
sources per capita are 171 m^3, which is less than that of many Middle Eastern countries (Figure 3-4). The available water resources per capita in the east bank area are only 3.4 m^3 per year, which is less than half of that in Kuwait (8 m^3/year).

Qingdao's water resources have the following characteristics:

1. Uneven Temporal Distribution of Water Resources

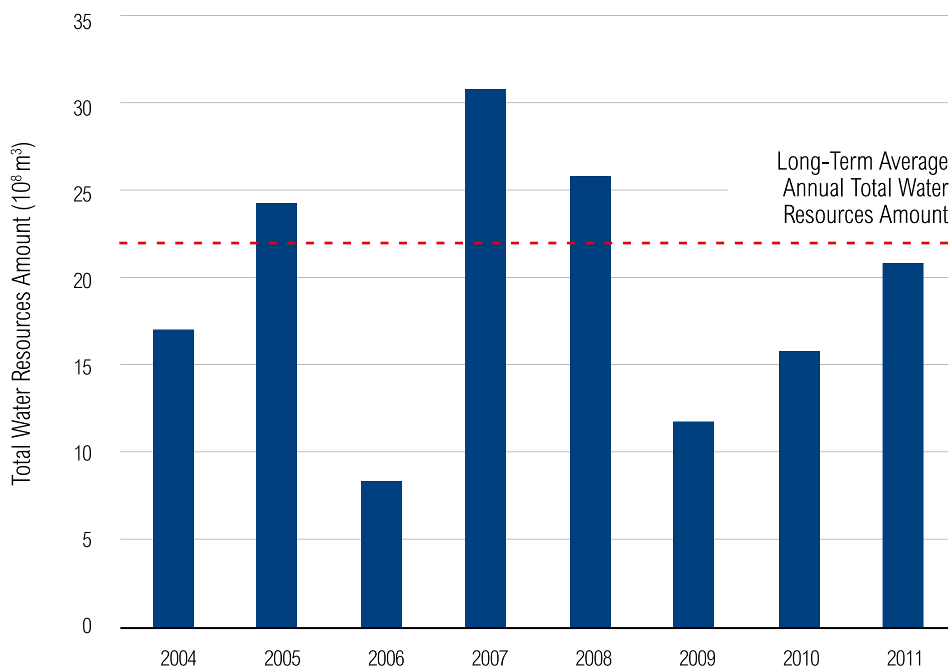
Year-to-year variations of water resources are significant. Qingdao's local water resource is mainly supplied by precipitation. Droughts occur 20% of the time and floods occur 17% (Chen, 2006), with major variations from year to year. As shown in Figure 3-5, between 2004 and 2011, 62.5% of the years fell below the long-term average annual water amount. Differences can be extreme, such as in 2006 when the total water amount was only 27% of that in 2007. Seasonal variations in precipitation are also significant. Between 70% and 75% of rainfall happens during flood season (June to September), and 50% happens in July and August. Consequently, it is difficult to capture and utilize rainwater (Figure 3-6).

Figure 3-4 | **Comparison of the Available Water Amount Per Capita in Qingdao and Middle Eastern Countries**



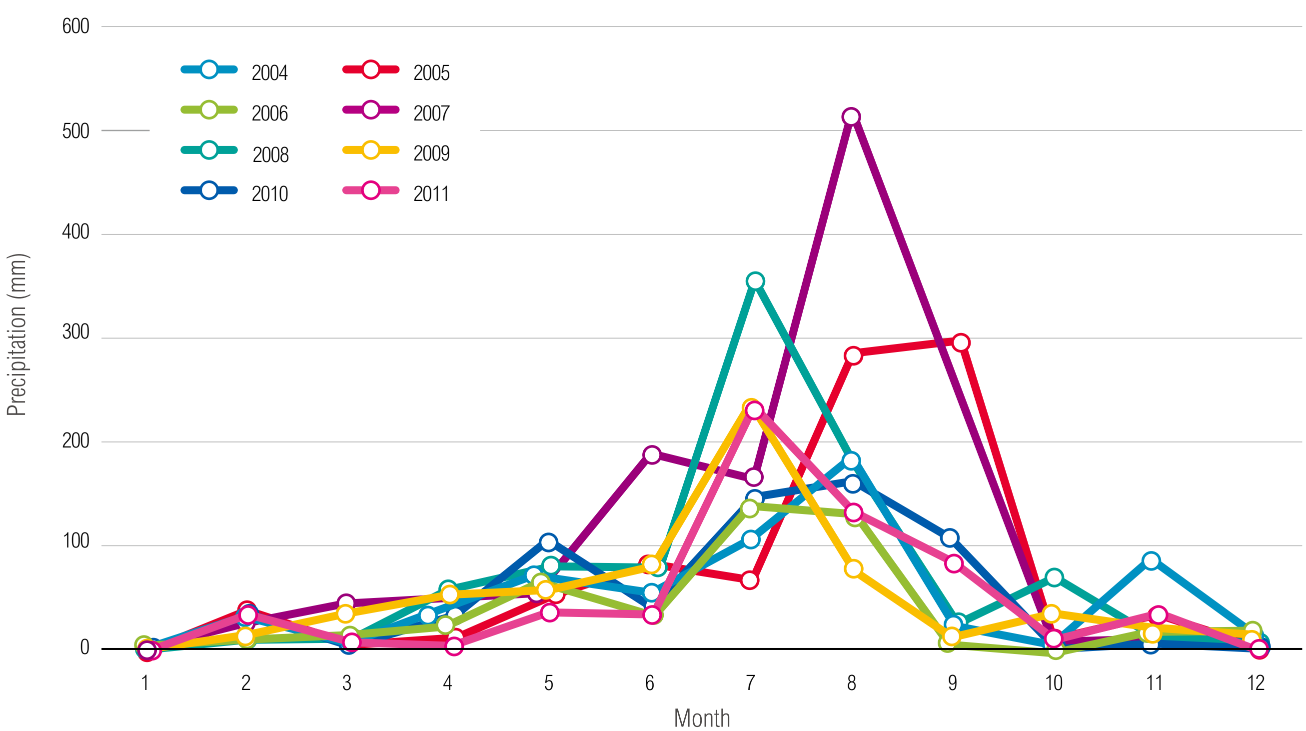
Data Source: FAO AQUASTAT 1998–2002

Figure 3-5 | **Change of Total Water Amount in Qingdao from 2004 to 2011**



Data Source: Qingdao Water Resources Bulletin 2004-2011 (QDWRB, 2005-2012)

Figure 3-6 | **Temporal Distribution of Precipitation in Qingdao from 2004 to 2011**



Data Source: Qingdao Water Resource Bulletin 2004-2011 (QDWRB, 2005-2012)

2. Uneven Spatial Distribution of Water Resources

Qingdao's people are concentrated in the central area (former Shibei, Sifang and Huangdao Districts, Shinan, Licang and Chengyang), which has the highest population density and degree of development. But that area has had only about 10% of the city's total water amount since 2004 (see Figure 3-7).

3. Continuous Wet and Continuous Dry Seasons

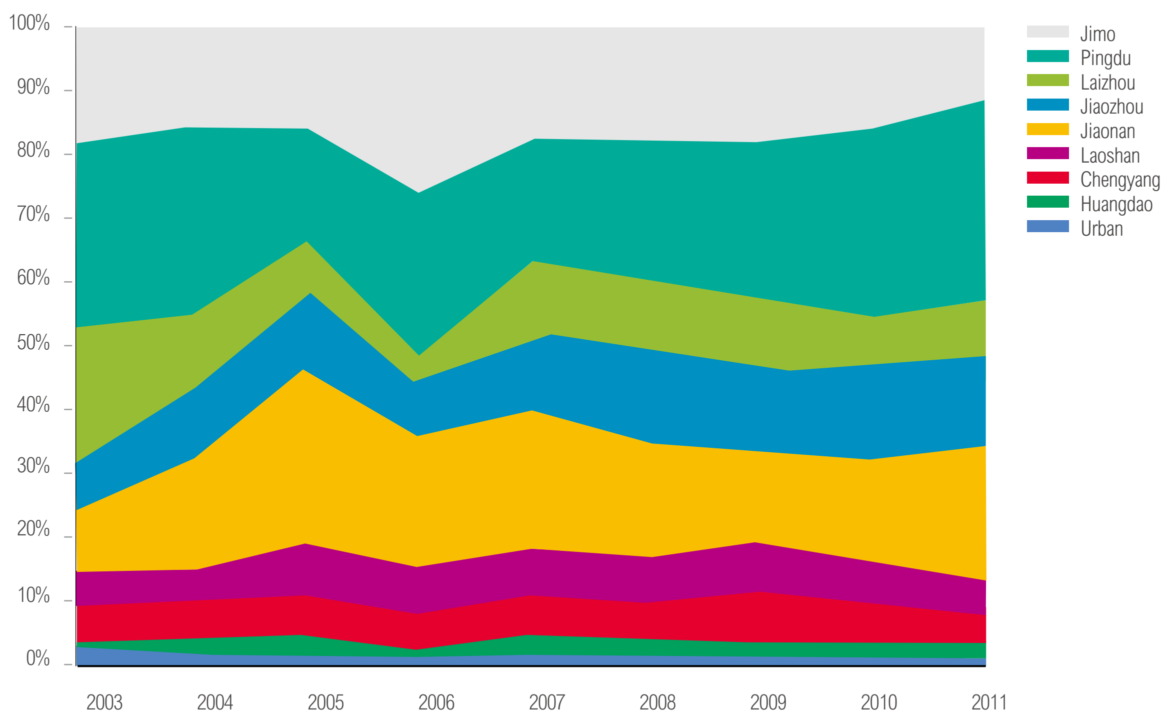
Precipitation data from the last century since 1899 indicates that Qingdao goes through 60-year wet-dry cycles, with 30 years of each. Currently, the city is in a lower precipitation stage of the wet period. It is estimated the precipitation will become above-normal around 2020 and the next dry season will start around 2036 (Wu, 1999).

3.2.2 Current Status of the Utilization and Development of Water Resources

Qingdao's water sources include surface water (both local surface water and water from trans-basin diversions), groundwater and others. The city has eased off exploiting groundwater since 2005 because of various environmental problems arising from overpumping. From 2005 to 2011, ground water's share of the total water supply dropped from 50% to 36% (see Figure 3-8). Up until 2011, about 45% of Qingdao's water supply came from local surface water. However, the potential to develop new local surface water is very limited. About 15% of Qingdao's water supply is transferred from elsewhere. Unconventional water resources are being developed quickly, with 40 times more water coming from those sources than in 2005.

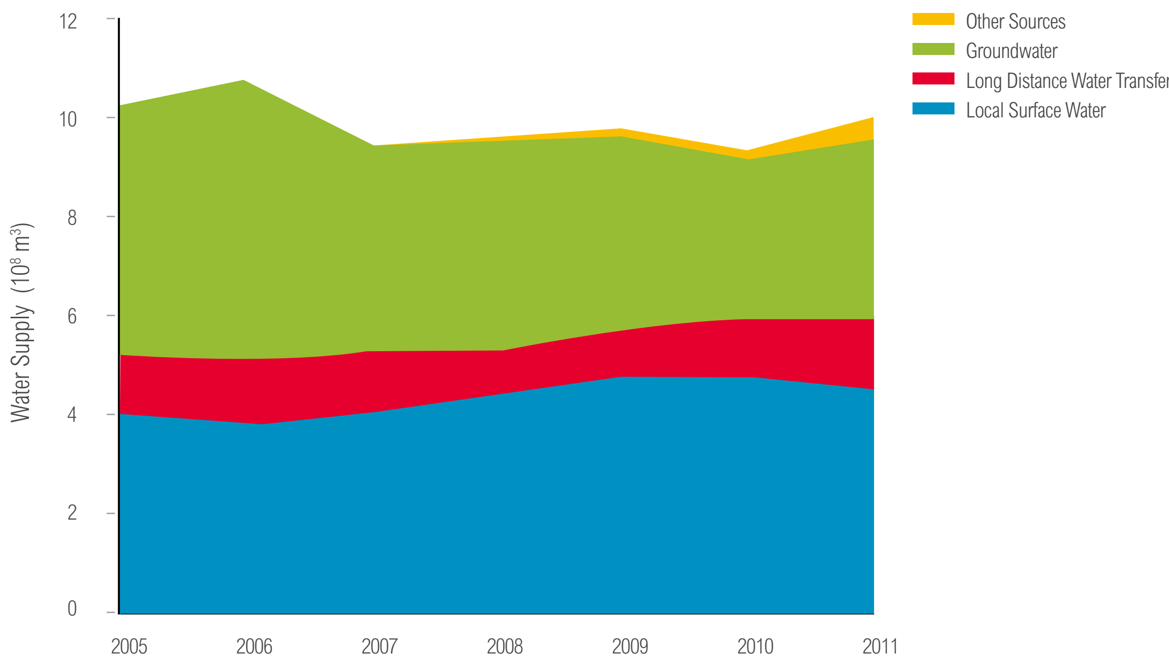
According to data from Qingdao's administrative divisions, more than 50% of the east bank area's water demand is met with transferred water. Unconventional water sources are used mainly in the north bank and east bank areas. The west bank area (former Huangdao and Jiaonan) already consumes more than the east bank area, with more than half of that water coming from the ground (see Figure 3-9).

Figure 3-7 | **Water Resource Amount in Each Administrative Division in Qingdao (2004-2011)**



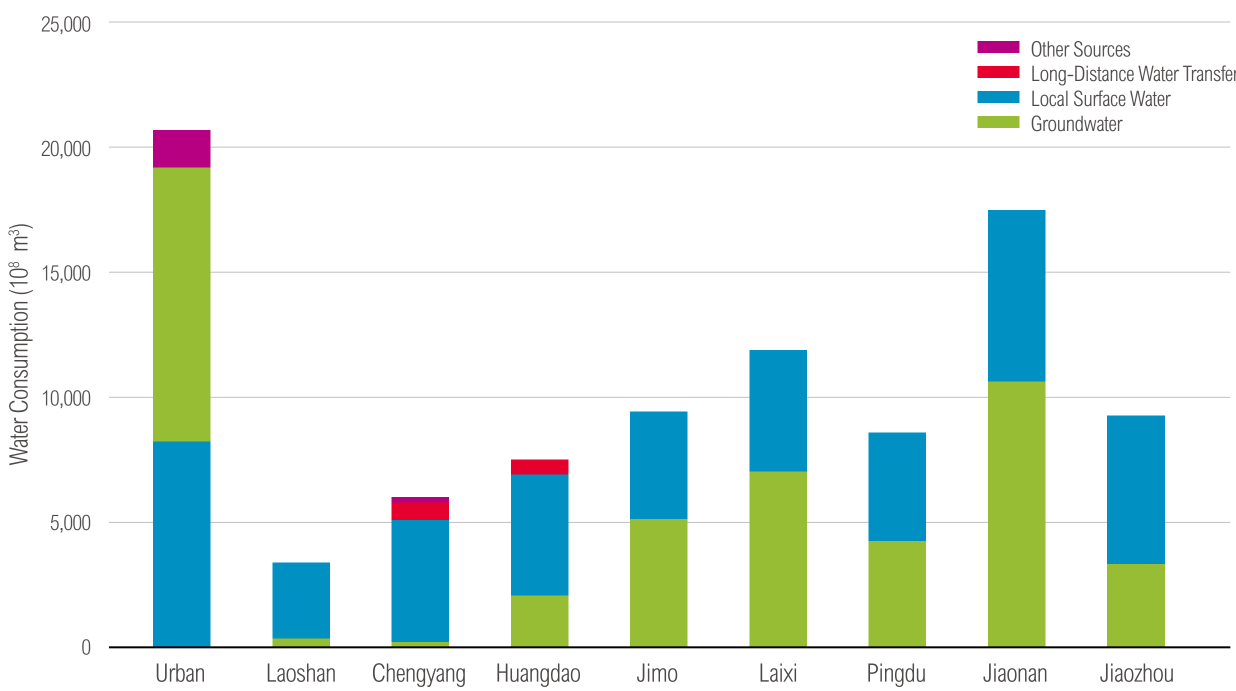
Data Source: Qingdao Water Resource Bulletin, 2004-2011 (QDWRB, 2005-2012)

Figure 3-8 | **Utilization of Various Water Resources in Qingdao from 2004 to 2011**



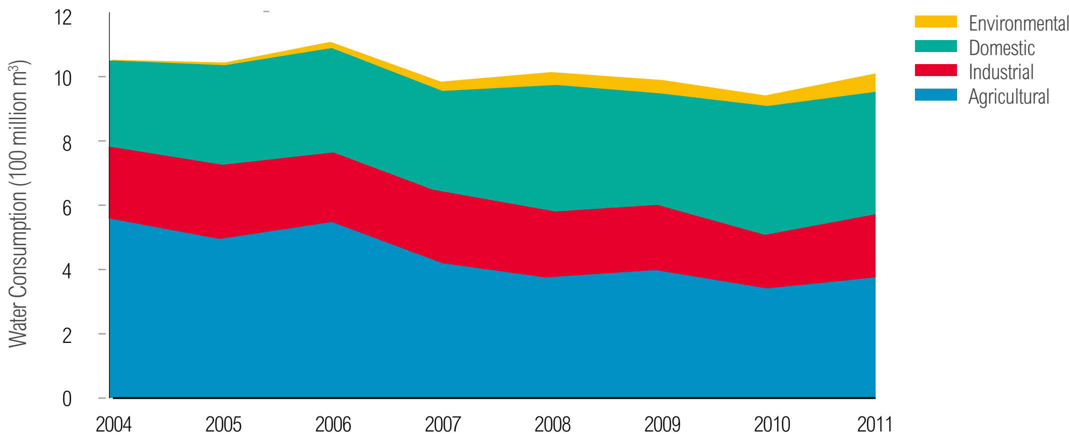
Data Source: Qingdao Water Resource Bulletin 2004-2011 (QDWRB, 2005-2012)

Figure 3-9 | **Water Consumption and Water Source by Administrative Division in Qingdao (2011)**



Data Source: Qingdao Water Resource Bulletin 2004-2011 (QDWRB, 2005-2012)

Figure 3-10 | **Water Consumptions in Different Sectors in Qingdao from 2004 to 2011**



Data Source: Qingdao Water Resource Bulletin 2004-2011 (QDWRB, 2005-2012)

Water is used for agricultural, industrial, domestic (including municipal) and environmental and ecological purposes, as shown in Figure 3-10. A few key points:

(1) Total water consumption peaked in 2006 and decreased slightly afterwards to around 1 billion m^3.

(2) Agricultural water use decreased significantly (by 24%) between 2004 and 2011.

(3) Industrial water use makes up about 20% of the total and has been mostly stable with only a slight decrease.

(4) Domestic water use is growing every year and accounts for a rising share of total water use. Domestic water consumption rose 75% between 2004 and 2011.

(5) The amount of water reserved for the environment and ecology is growing steadily.

Urbanization is undoubtly an important driver of the rapid growth in Qingdao's domestic water demand. According to an analysis of sectoral water use in different administrative divisions (Figure 3-11), domestic water use in the east bank area (which has the highest level of urbanization) makes up as much as 71% of total use, while in the former Jiaonan county-level city, it makes up only 19%. Industrial water use makes up a high proportion of total use in Chengyang District (48%) and the former Huangdao District (41%). Other districts have much less industrial use, with the former Jiaonan county-level city and Jiaozhou county-level city both around 5%. Water for agriculture is negligible in the east and north bank areas, but it makes up the lion's share (73%) in the former Jiaonan county-level city. Now that the former Jiaonan county-level city has been incorporated into Huangdao District and become the focus of development in the west bank area, the type and amount of water use may see significant changes.

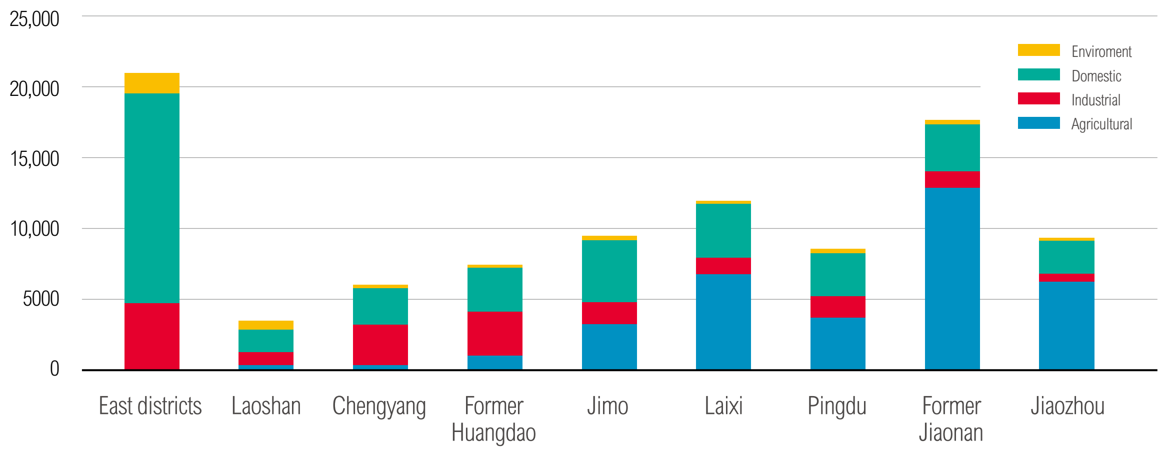
3.3 Overview of Water Resource Management Policies in Qingdao

To resolve urban water shortages and make water supplies secure, Qingdao has commited to saving water, developing unconventional water resources (such as desalinated seawater and reclaimed wastewater) and transferring water, all while formulating the relevant policies and regulations.

3.3.1 Water Management Goals in Qingdao

In 2012, the State Council issued "Three Red-Line" targets on the utilization and development of water resources, the control of water use efficiency and the allowable limit of wastewater in water functional areas. Afterward, the Shangdong provincial government issued the *Implementation Opinions on the Enforcement of the Strictest Water Resource*

Figure 3-11 | **Sectoral Water Use by Administrative Division in Qingdao (2011)**



Data Source: Qingdao Water Resource Bulletin 2004-2011 (QDWRB, 2005-2012)

Table 3-3 | **Comparison of the 3 Red-Line Targets in Water Resource Management of China, Shandong Province and Qingdao**

CATEGORIES		UTILIZATION AND DEVELOPMENT OF WATER RESOURCES	WATER USE EFFICIENCY			LIMIT ON WASTEWATER IN WATER FUNCTIONAL AREAS
Index		Total Water Consumption Amount	Water Consumption Per Industrial Value Added at 10,000 RMB	Water Consumption Per 10,000 GDP	The Effective Irrigation Water Utilization Factor	Meeting Rate of Water Functional Areas
Unit		100 million m^3	m^3	m^3		
2011	Qingdao [b]	10.08	6.83	15.24	0.58 (2010)	
2015	China [a]	6350	<63	<105	0.53	60%
	Shandong [c]	250.6	<15	<60	0.64	60%
	Qingdao [c]	12.58	15.7	17.6	0.66	80%
2020	China [a]	6700	65		0.55	80%
	Shandong [c]	276.59	<13		0.65	0.8
	Qingdao [c]	14.73	10.1		0.68	85%
2030	China [a]	7,000	40		0.6	95%
	Shandong [c]	301.84				
	Qingdao [d]	19.67	9.5		0.7	95%

Data Sources:

a. Opinions on the implementation of the Strictest Water Resource Management, No. 3 Policy Paper of the State Council, 2012.01.12

b. The 12th Five-Year-Plan of the Circular Economy Development in Qingdao, Qingdao Development and Reform Committee, 2011.

c. Notice about the issuance of assessment methods on the implementation of the strictest water management mechanism in Shandong Province, No.14 Policy Paper of the General Office of Shandong Government, 2013.

d. Opinions on the Implementation of the Strictest Water Resources Management , No. 5 Policy Paper of Qingdao Government, 2013.

Management Required by the No.3 Policy Paper of the State Council in 2012 (No.25 Policy Paper of Shandong Government , 2012) and established "red-line" targets on water management for the whole province. In 2013, Shandong Province approved the *Notice about the Issuance of Assessment Methods for the Implementation of the Strictest Water Management in Shandong Province (No.14 Policy Paper of Shandong Government, 2013)* and established the "Three Red-Line" targets for Qingdao's water management. The targets addressed total water consumption, water use efficiency and water quality reaching the standard in water functional areas[10]. Table 3-3 shows that water management targets in Qingdao are stricter than China and Shandong Province as a whole. Qingdao's industrial water efficiency has already reached globally advanced levels. In 2011, the amount of water consumed per RMB of actual industrial value added was already lower than the target for 2020.

3.3.2 Management of Development and Utilization of Transferred Water Resources

Since local water is very limited in Qingdao, the city's development is to some extent dependent on transferred water. Water started flowing from the project "Yellow River to Qingdao" on November 25, 2011 and relieved a lot of pressure on Qingdao's water supply.

Additionally, the east line project of the South-to-North Water Diversion Project started working at the end of 2013, and could help to further secure Qingdao's water supply. But the price of the transferred water may prove to be challenging for Qingdao[11]. According to a document issued by the National Development and Reform Committee ("Notice about the policy on water price in the initial operation phase of the main project of the East-line Phase I of South-to-North Water Diversion[12]"), the overall water price of raw water in the Qingdao line (east of Dongping Lake) is 1.65 RMB/m^3. That price is much higher than local surface water (0.35 RMB/m^3) or ground water (0.8 RMB/m^3). Based on an estimate by the Construction Management Bureau of the South-to-North Water Diversion Project in Shandong Province, the average price for the end user is about 6 RMB/m^3.[13] Additionally, the raw water quality may also impact enthusiasm in Qingdao for using transferred water from the Yangtze River due to the pollution that occurs along the transfer route.

3.3.3 The Utilization and Development of Unconventional Water Resources

Unconventional water resources, such as seawater, reclaimed water and direct rainwater capture, can be used to supplement conventional water resources. Therefore, unconventional water resources have strategic importance in addressing the disparity between urban water demand and supply, and maintaining sustainable economic development. Such sources are especially critical to Qingdao, a city with severe water shortages.

(1) Seawater Desalination

According to the *12th Five-Year Development Plan for Circular Economy in Qingdao* (QDDRC, 2011), Qingdao is required to desalinate and use 1.5 billion m^3 of seawater per year and 250,000 to 300,000 m^3 per day (at the end of 2010, the two targets were set at 1.3 billion m^3/year and 30,000 m^3/day). Qingdao's Baifa desalination project was completed at the end of 2012 and is the largest seawater desalination project for urban water supply in China, producing 100,000 m^3/day.

(2) Reclaimed Water

Qingdao has two main methods of utilizing reclaimed water: centralized and distributed. Centralized reclaimed water projects use the water discharged by wastewater treatment plants as raw water. As of 2012, three wastewater treatment plants in Qingdao had installed deep treatment facilities for reclaimed water. The facilities use conventional processing as the primary treatment method and membrane processing as the supporting method. (Additionally, a 187 km pipeline capable of transporting 55,000 m^3/day of centralized reclaimed water has been installed.) Distributed reclaimed water projects use wastewater generated by enterprises or residents as the raw water. Currently, Qingdao has more than 70 distributed reclaimed water facilities, with a total capacity of 108,000 m^3/day.

In 2011, 25% of wastewater in Qingdao was reclaimed (Zhang, 2011), which surpassed the target of reclaiming 20% by 2015, as detailed in the *12th Five-Year Development Plan for Circular Economy in Qingdao*. Qingdao will add another 370,000 m^3/day of wastewater reclamation capacity during the 12th Five-Year period, plus 40 km of pipes to distribute the water. Moreover, policies to coordinate wastewater treatment and construction of infrastructure to allow the use of reclaimed water will be studied to improve the utilization rate of reclaimed water.

(3) Rainwater

Due to its medium latitude monsoon climate, Qingdao's precipitation is uneven from season to season and varies significantly from year to year. Additionally, the hilly topography makes storing and collecting rainwater difficult. Currently, Qingdao does not prioritize rainwater as an unconventional water source. Plans to utilize rainwater were only briefly outlined in the *Plan of Qingdao's Reclaimed Water Utilization*.

3.3.4 Management Policy and Potentials on Water Saving

The Qingdao municipal government has long focused on conserving water due to the city's poor water endowment. A Water Conservation Office was set up in 1964 to coordinate and manage water conservation efforts across the city, and to gradually establish and improve multiple methods of saving urban water. The city has enacted mandatory water saving policies such as total volume control, quota management, market permits, punitive water price and the Three Same-Time regime. Qingdao was honored with the "National Water Saving Model City" award three times, in 1983, 1990 and 1995 and was listed among the first batch of 10 water-saving cities in China in 2002.

In the early 1980s, Qingdao clearly stipulated that water-intensive industrial projects would not be approved. In 2011, the total volume of industrial water use in Qingdao was 0.191 billion m^3, and the water use per 10,000 RMB of industrial value added was only 6.83 m^3 [14], making Qingdao one of the cities with the highest industrial water efficiency rates in China. Qingdao's water use index values are not only lower than the national targets set for 2020 and 2030, but also lower than the rates of developed countries, such as Japan and some European countries (see Appendix 1). Meanwhile, Qingdao requires thermal power generators to use desalinated water and once-through cooling systems to meet water demands. In Qingdao, water use for thermal power generation only makes up 5.3% of industrial water use, which is far below the national average of about 40%. Therefore, Qingdao's industrial water saving potential is very limited.

To conserve urban domestic water, Qingdao has focused on water metering, promoting water-saving appliances, price leveraging and reducing water pipe leakage[15]. Qingdao's domestic water use was 0.212 billion m^3 in 2010, which was 2.4% lower than in 2005[16]. The average domestic water use per person in the downtown area is 178.05 L/day, which is slightly less than the average in Eastern Chinese regions where people use 184.53 L/day[17]. However, Qingdao's domestic usage is still higher than that in Beijing, Shanghai, Tianjin, Jinan and other cities. Therefore, Qingdao still has room to improve domestic water use rates.

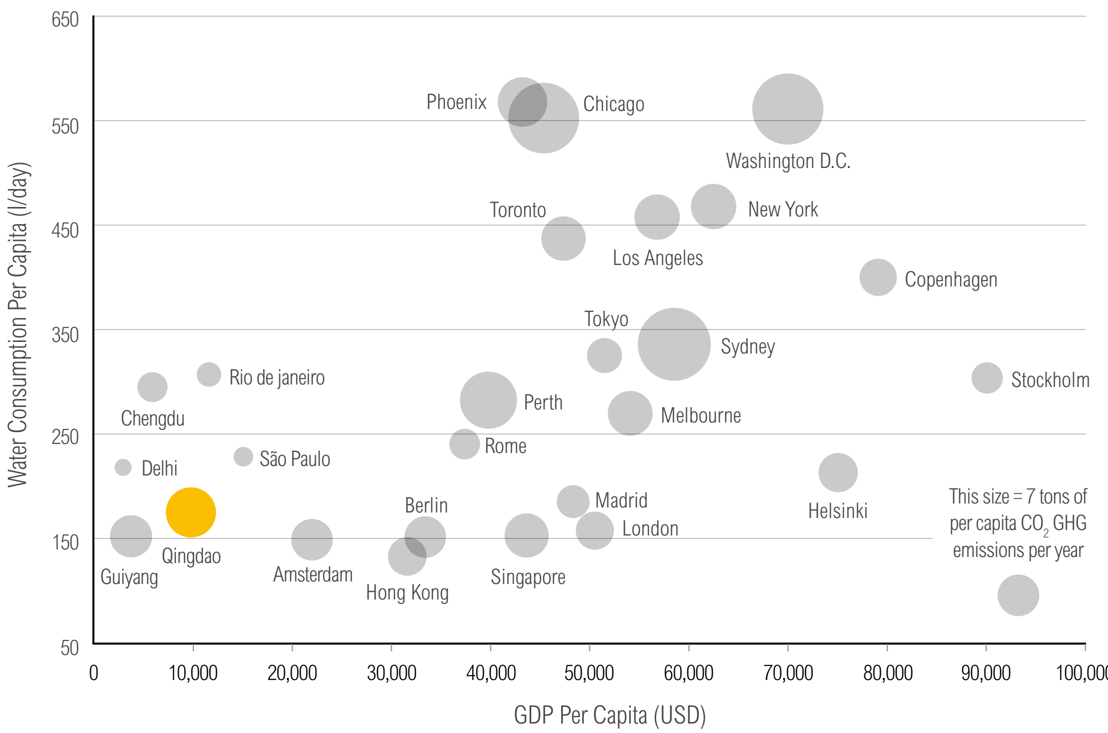
Qingdao's agricultural water efficiency rate is better than the national average, at 0.58 compared to 0.5. According to the *12th Five-Year Plan for Water-Saving Irrigation*, the efficient water-saving irrigation area is planned to reach 2.47 million mu by the end of the 12th five-year period. Of that, 716,000 mu will be newly added (pipe irrigation will be installed for 617,100 mu, sprinkling irrigation for 37,000 mu and drip irrigation for 61,900 mu). Qingdao's agricultural water use is expected to stay stable because of targets set by Shandong Province in "Zero growth on agricultural water use."

3.4 Prediction of Qingdao's Water Demands in 2020

3.4.1 Comparison of Domestic Water Use Per Capita, GHG Emissions and Economic Development

WRI has conducted a comparative analysis of the GHG emissions, domestic water use and GDP per capita for 26 major cities in the world. The results are shown in Figure 3-12. The x-axis represents the GDP per capita,

Figure 3-12 | **GHG Emissions and Water Uses in 26 Cities in the World**



Data Sources: China City Construction Statistical Yearbook, 2010; Latin-American Green City Index, 2011; Asian Green City Index, 2011; US and Canada Green City Index, 2010; European Green City Index, 2007; World Bank, 2011

and the y-axis is the domestic water consumption per capita. The size of the bubble corresponding to each city represents its GHG emissions per capita.

A few key points:

(1) Chinese cities' current average domestic water consumption per capita is still at a low to medium level, but the average GHG emissions per capita are already near those of developed countries. As for Qingdao, its GDP per capita is USD 9,725, which is 20% less than the standard for high income (USD 12,476), according to the World Bank. Qingdao still has large potential for economic development. The city's average domestic water consumption per capita is 178 Liters/day, which is lower than many foreign cities, and its average GHG per capita are 9.6 tons/year, which are about 40% higher than China's average. Therefore, emissions should be reduced.

(2) The data suggest that cities follow one of two development routes: carbon-and-water-intensive (Type I, such as North American cities), and low-carbon-and-water (Type II, such as European cities and Hong Kong and Singapore). It is noteworthy that some Type II cities, such as London, have high incomes and high living standards, while also having lower average water consumption and GHG emissions than China.

(3) Long-term water conservation work has contributed significantly to the relatively low average domestic water consumption per capita in Qingdao today. Unfortunately, that also means the potential to further improve efficiency is limited. Future average water consumption may increase because of continued economic development and living standard improvements, thus inevitably increasing pressure on water supplies. At the same time, dependence on imported water or desalinated water will increase energy consumption and carbon emissions from the water system, thus making future carbon reductions more difficult.

3.4.2 Prediction of Qingdao's Water Demands by Industrial, Agricultural, Domestic and Ecological Uses in 2020

This report predicts that, by 2020, Qingdao will use more water than today for a variety of industrial, agricultural, municipal domestic and ecological uses. See Appendix I for the detailed calculations.

It is estimated that Qingdao's total water demand will reach 1.48 billion m^3 by 2020, with significant growth from 2011 levels. Of that, industrial uses will take 301 million m^3, agricultural uses (including water for rural households, livestock and irrigation) will take 486 million m^3, domestic uses (including water for urban households and municipal use) will take 583 million m^3 and ecological uses will take 110 million m^3. Industrial use will be 58% higher than in 2011, agricultural use 7% higher, domestic use 89% higher and ecological use 94% higher. Domestic water use will be the biggest water user in the future, while agricultural water use will stay the same.

Table 3-4 shows estimates of future water demand by administrative division. All the districts see some kind of growth in demand by 2020, except for the east bank area (Shinan, Shibei and Licang), where water demand will drop 8% compared to 2011. Water demand will grow the most in Chengyang District, where demand will be 154% higher than 2011. Urban development in the north bank area and rapid population growth are driving the increased demand. Huangdao District (including the previous Huangdao District and Jiaonan County-Level City) has the second highest growth rate at 85% (with 152% in the previous Huangdao area and 48% in the previous Jiaonan area). Development in the east bank area and increased demand for domestic and agricultural uses due to the industrial shift are driving the overall demand growth. The growth rates in other regions are between 25% and 70%. The driving forces are mainly industrial and agricultural development.

By 2020, Qingdao aims to cap the water demand at 1.473 billion m^3, according to the *Notice about the Issuance of Assessment Methods for the Implementation of the Strictest Water Resource Management Mechanism in Shandong Province (No. 14 Policy Paper of Shandong Government, 2013)*. That is 7 million m^3 less than the estimates of related studies. The difference suggests that Qingdao will face severe future water challenges. The city must not only reinforce water conservation work and improve water use efficiency across sectors, but also develop new, unconventional water resources (such as reclaimed water, rainwater and desalinated seawater) that are not included in the total water consumption target.

Table 3-4 | **Total Water Demand in Qingdao in 2020 (in 0.1 billion m^3)**

	URBAN	LAO-SHAN	CHENG-YANG	HUANG-DAO	JIAO-NAN	JIAO-ZHOU	JIMO	PINGDU	LAIXI	SUBTO-TAL
Industrial	0.13	0.09	0.32	0.51	0.49	0.42	0.41	0.38	0.25	3.01
Domestic	1.58	0.29	1.15	0.93	0.39	0.37	0.30	0.55	0.28	5.83
Rural Households	0.00	0.00	0.01	0.00	0.15	0.12	0.14	0.15	0.11	0.67
Livestock	0.00	0.00	0.01	0.00	0.04	0.03	0.04	0.07	0.09	0.28
Irrigation	0	0.01	0.02	0.02	0.51	0.47	0.67	1.51	0.69	3.9
Ecological	0.40	0.17	0.06	0.08	0.07	0.10	0.09	0.07	0.06	1.10
Total	14.8									

CHAPTER 4

ANALYSIS OF THE CHARACTERISTICS OF DIFFERENT WATER SOURCES AND WATER PRODUCTION ENERGY INTENSITIES IN QINGDAO

Currently in Qingdao, municipal and industrial water uses mainly rely on local surface water and externally transferred water, while agricultural use mainly relies on local groundwater. Since the end of 1980s, the Yellow River to Qingdao Water Diversion Project has largely relieved the pressure on Qingdao's water supply. The project diverts water from the Yellow River that is 290 km far away from Qingdao and the head lift is 33.5 m (Jiang, 1999). The energy consumption per ton for Yellow River water is much higher than local surface water because of the energy needed by pumps that lift the water.

Unconventional water resources (including seawater desalination and utilization of reclaimed water) have recently received more attention because of their ability to improve urban water supply security. Two industrial seawater desalination projects (the Huangdao Power Plant and the Qingdao Soda Ash project) have already started operating. And the construction of Baifa, the first project in China to introduce desalinated seawater into the municipal water supply, has finished. Reclaimed water utilization projects have been installed in the Tuandao Wastewater Plant and the Haibohe Treatment Plant to provide alternative sources of non-drinking water to industrial enterprises, the building industry and residents. However, the energy required to desalinate seawater and reclaim wastewater is relatively high.

The following section analyzes and compares the characteristics of different water sources, their potential to provide new supplies and the energy each consumes.

4.1 Comparison of Characteristics and Risks of Different Water Sources

Cities need to consider various factors when selecting water sources, including the guarantee rate, economic cost and water quality. More and more cities are starting to explore using unconventional water sources to solve their water shortages, especially in the context of increased environmental protection and climate change. The energy consumed by water production, ecological and environmental impacts and climate change risks need to be taken into account when selecting water sources.

By reviewing the literature, this report is able to compare the risks of different water sources from nine perspectives, including water quality, water source guarantee rate, land use, capital investment and energy consumption. The results are shown in Table 4-1 (see Appendix II for a detailed explanation).

Table 4-1 | **Comparison of Water Supply Risks from Various Water Sources**

INDICATOR	LOCAL SURFACE WATER (RESERVOIR)	LOCAL GROUNDWATER	WATER DIVERSION	SEAWATER DESALINATION	RECLAIMED WATER	RAINWATER
Water Quality	Medium	Medium	Medium	Low	Low-Medium[18]	High
Water Source Guarantee Rate	Medium	Medium	Medium	Low	Low	High
Impact on Land Use	High	Low	High	Low	Low	Low
Investment	High	Low	High	High	Medium	Low
Energy Consumption	Low	Medium	High	High	Medium-High	Medium
Environmental Impact	High	Medium	High	Low	Low	Low
Population Resettlement	High	Low	Medium	Low	Low	Low
Public Acceptance	Low	Low	Medium	High	High	Medium
Vulnerability to Climate Change	High	High	High	Low	Low	High

- Local surface water in Qingdao mainly comes from reservoirs. The advantages are good water quality and low energy consumption, but the disadvantages include large land occupation, resident resettlement and high capital investment. Additionally, reservoirs' ability to deal with climate change is weak.
- Currently, groundwater mainly serves agricultural uses. The advantages are low land occupation and low capital investment. However, it is hard to restore groundwater after overexploitation, and groundwater also has weak ability to deal with climate change.
- Externally transferred water (including from the Yellow River and the Yangtze River) can help mitigate the stress on local water withdrawal which may be good for local water conservation. However, the supply is impacted by the season and climate of the exporting area, resulting in different water guarantee rates under wet or dry conditions. Moreover, transferred water requires large amounts of land and high capital investment, and consumes a lot of energy. Raw water quality can also suffer because of illegal discharges, traffic accidents and natural disasters along the banks of the water transport channels.
- The advantages of seawater desalination are its high water supply guarantee rate and robust ability to deal with climate change. The disadvantages are readily apparent: high cost, high energy consumption and the low public acceptance of drinking desalinated water.
- Reclaimed water can be categorized into either general municipal miscellaneous water (with deep treatment) or high-quality pure water (such as the "NEWater" of Singapore). Both have high water supply guarantee rates and a strong ability to deal with climate change. The disadvantage is that the energy consumption for NEWater is relatively high.
- The biggest advantages of utilizing rainwater are low land occupation, capital investment and energy consumption. However, its main disadvantage in Qingdao is an extremely low guarantee rate. Therefore, this study does not examine the utilization of rainwater.

4.2 Energy Consumption of Withdrawing and Producing Water from Different Sources

4.2.1 Local Surface Water Resources

The local surface water in Qingdao mainly comes from three river basins:

(1) Dagu River: As the largest river in the Jiaodong Peninsula, the Dagu River originates in Yantai City of Shandong Province and flows from north to south into the sea. The total length of its main stream is 179.9 km and the total basin area is 6131.3 km^2. Of that, 4781 km^2 are within the Qingdao area. The river flows through Laixi, Pingdu, Jimo, Jiaozhou and Chengyang District. There are two large reservoirs (Chanzhi Reservoir and Yifu Reservoir) upstream of Qingdao, with a total storage of 0.563 billion m^3 the reservoirs are Qingdao's most important local water sources.

(2) North Jiaolai River: Originating in Pingdu and flowing into Laizhou Bay via Weifang City, the total length of the North Jiaolai River's main stream is 100 km and the total basin area is 3979 km^2. The main tributaries in Qingdao include the Ze River, Longwang River, Xian River and Baisha River.

(3) Coastal river systems: The Baisha River, Moshui River, Feng River, Baima River, Jili River, and Zhoutong River (Lianyin River) are all coastal systems that flow independently into the sea and have a total basin area of 3960 km^2.

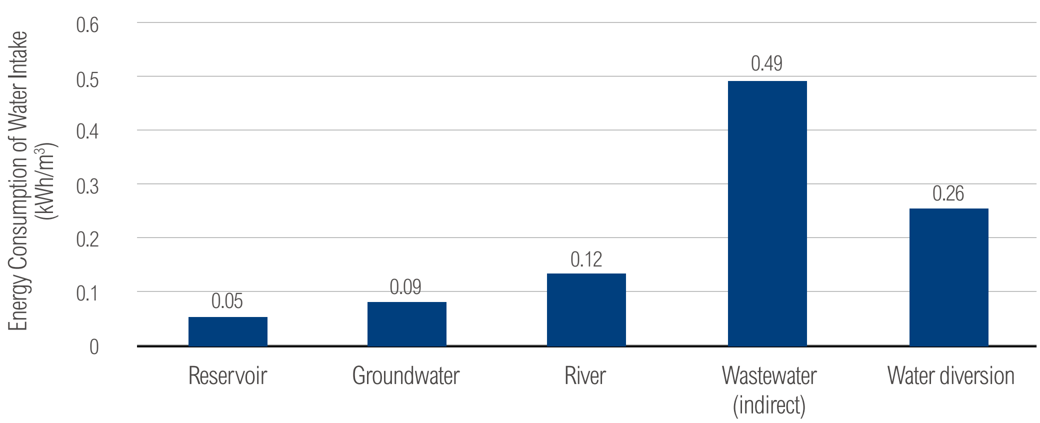
Qingdao utilizes surface water mainly through water storage projects (reservoirs). In 2011, the water supply from reservoirs accounted for 66.35% of the total surface water supply. Another 24.28% came from trans-basin water diversions[19]. The reservoirs are mainly located in the mountainous and hilly areas upstream of Qingdao. After pump stations withdraw the raw water, gravity power delivers it to tap water plants using the natural height difference. Therefore, the energy consumption of both water withdrawal and transmission are relatively low. A study by the UK Environment Agency shows that reservoirs in the UK consume the least energy for water withdrawal and transfer (0.05 kWh/m³) (see Figure 4-1).

Once raw water is delivered to the tap water plant, it is purified to meet the national standard for drinking water using various methods such as sedimentation, filtration and sterilization. Water purification is an energy-intensive process. The energy consumption mainly occurs at the pump stations, so the efficiency of the pump station has a direct impact on the electricity consumed by water delivery. At the Baisha River Water Plant, for example, electricity is the largest cost, making up about 40% of the total cost (including construction cost)[20]. The installation of high-efficiency water pumps at Baisha River resulted in water production energy consumption dropping 23% from 0.34 kWh/m³ to 0.26 kWh/m³.

Currently, the average water production electricity consumption of all tap water plants in Qingdao is 0.376 kWh/m³. There is still plenty of potential to save energy and reduce emissions.

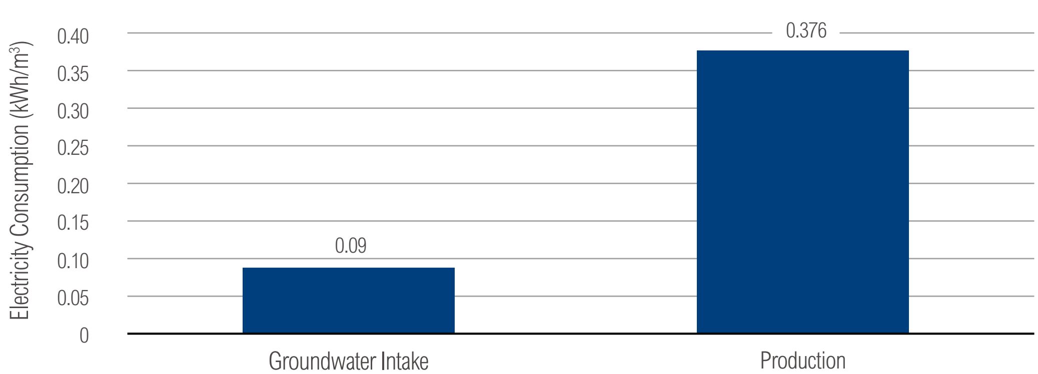
Currently, Qingdao does not measure the energy consumption of pulling water from its reservoirs, and thus there is no detailed data available. For this report, we relied on studies from the UK that determined the average energy consumption of withdrawing and transferring water from reservoirs is 0.05 kWh/m³. Based on the average electricity consumption of water production in Qingdao, we determined that the electricity consumption of water intake and production from local surface water sources is 0.426 kWh/m³ (Figure 4-2).

Figure 4-1 | **Comparison of the Water Intake Energy Consumption from Various Sources in the UK**



Data Sources: The UK Environment Agency, 2008

Figure 4-2 | **Energy Consumption of Water Intake and Production from Local Surface Water Sources in Qingdao**



4.2.2 Groundwater Resources

Groundwater in Qingdao is mainly used for agricultural irrigation and livestock. Only a small amount is for municipal, domestic and industrial uses. Since neither Qingdao's water resources departments nor its agriculture departments collect statistical data on the energy consumption of groundwater pumping, we used fieldwork (interviews with rural households in Pingdu and Jiaozhou and electricity bills paid by farmers) to estimate the electricity consumption of withdrawing groundwater to be 0.4 kWh/m^3 [21].

The quality of raw water has little impact on the electricity consumption of water production, according to interviews with workers from tap water plants. Assuming the electricity consumption of water production from groundwater is the same as local surface water (i.e. 0.376 kWh/m^3), then we can conclude that the energy consumption of water production from groundwater is 0.4 kWh/m^3 if it is used only for agriculture (water production and distribution are not required), while the energy consumption of water production from groundwater is 0.776 kWh/m^3 if it is used for municipal purposes (Figure 4-3).

4.2.3 Transferred Water Projects in Qingdao

4.2.3.1 Yellow River to Qingdao Water Diversion

The Yellow River to Qingdao Water Diversion Project is an important component of Shandong's T-shape water diversion project. Construction on the project started on April 15, 1986 and the project started delivering water on November 25, 1989.

The total length of the Yellow River to Qingdao project is 290 km, including 253 km of lined open channel and 22 km of covered channel with a total designed lift of 33.52 m. Water from the Yellow River is diverted from the Dayuzhang Gate in Binzhou in Shandong Province and flows through four cities (Binzhou, Dongying, Weifang and Qingdao) and 10 counties (county-level cities or districts) before reaching Qingdao's Baisha water plant. A de-silting basin is at the beginning of the channel with four pump stations (Songzhuang, Wangru, Tingkou and Jihongtan) and a large plain reservoir, Jihongtan (Figure 4-4). The project is designed to supply 300,000 m^3/day of water to Qingdao at the guaranteed rate of 95%.

Figure 4-3 | **Energy Consumption of Water Intake and Production from Groundwater in Qingdao**

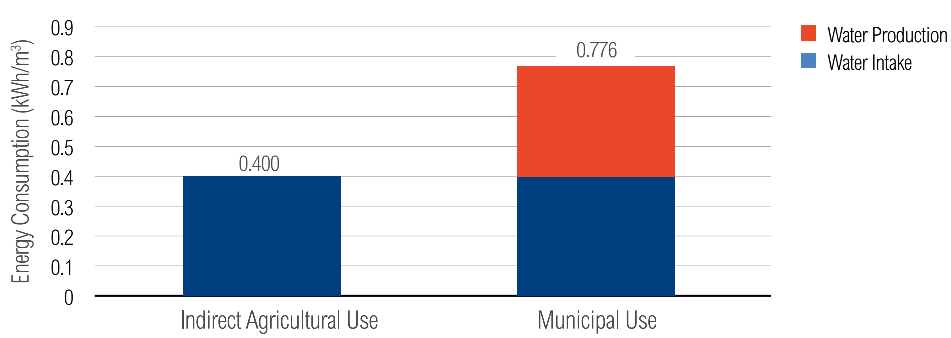


Figure 4-4 | **Project Route of Yellow River to Qingdao Project**

Data Sources: South-to-North Water Diversion Office

Since there is no public data for the Yellow River to Qingdao project's energy consumption, we estimated it based on the electricity price and bills per ton of water. According to the *Study on Overall Cost of Various Water Sources and Optimization of Water Supply Structure in Qingdao* and based on the commodity price level in 1992, the electricity cost of raw water withdrawn from Jihongtan Reservoir is 0.079 RMB/m^3, and the electricity price is 0.25 RMB/kWh. Therefore, the electricity consumption of water transmission is calculated to be around 0.32 kWh/m^3. Once delievered to the tap water plant, the average electricity consumption of water production is 0.376 kWh/m^3. Overall, the energy consumption of water intake and production from the Yellow River to Qingdao Water Diversion Project is 0.696 kWh/m^3 (Figure 4-5).

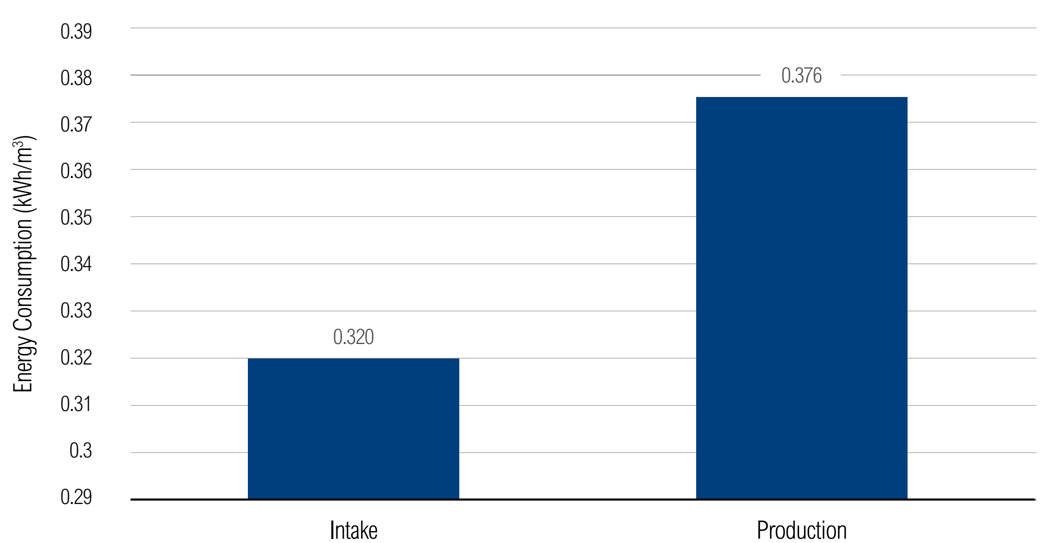
4.2.3.2 East Line of South-to-North Water Diversion

The South-to-North Water Diversion Project is an important cross-basin water diversion project to relieve the severe water shortages in Northern China. The Eastern Line is an important component of the overall project layout and it supplies water to the eastern part of the Huang-huai-hai Plain and Jiaodong region. The total area is divided into three sections: South of Yellow River, Jiaodong Region and North of Yellow River[22]. Qingdao benefits from the water transfer on the main stream in Jiaodong region (Figure 4-6).

The east line project withdraws water from the main stream of the Yangtze River close to Yangzhou, Jiangsu Province. The water is pumped to the north along the route of the Jing-Hang Grand Canal and it parallels rivers at each stage. Lake Hongze, Lake Luoma, Lake Nansi and Dongping Lake act as regulating reservoirs. There are 13 cascade pumping stations between the Yangtze River and Lake Dongping, with a total lift of 65 meters (Figure 4-7). After the water is pumped into Dongping Lake, it is divided between two routes: one flows north into Tianjin after crossing the Yellow River, while the other flows east through the new water transmission main stream in Jiaodong region, which runs 240 km from Dongping Lake to the Yellow River to Qingdao Project and provides water via project channels to the Jiaodong area, including Qingdao (Huang, 2004). The Eastern Line Phase I Project started to supply water to Shandong Province in 2015.[23] In 2016, Shandong Province transferred 0.6 billion m^3 of water from the Yangtze River.[24]

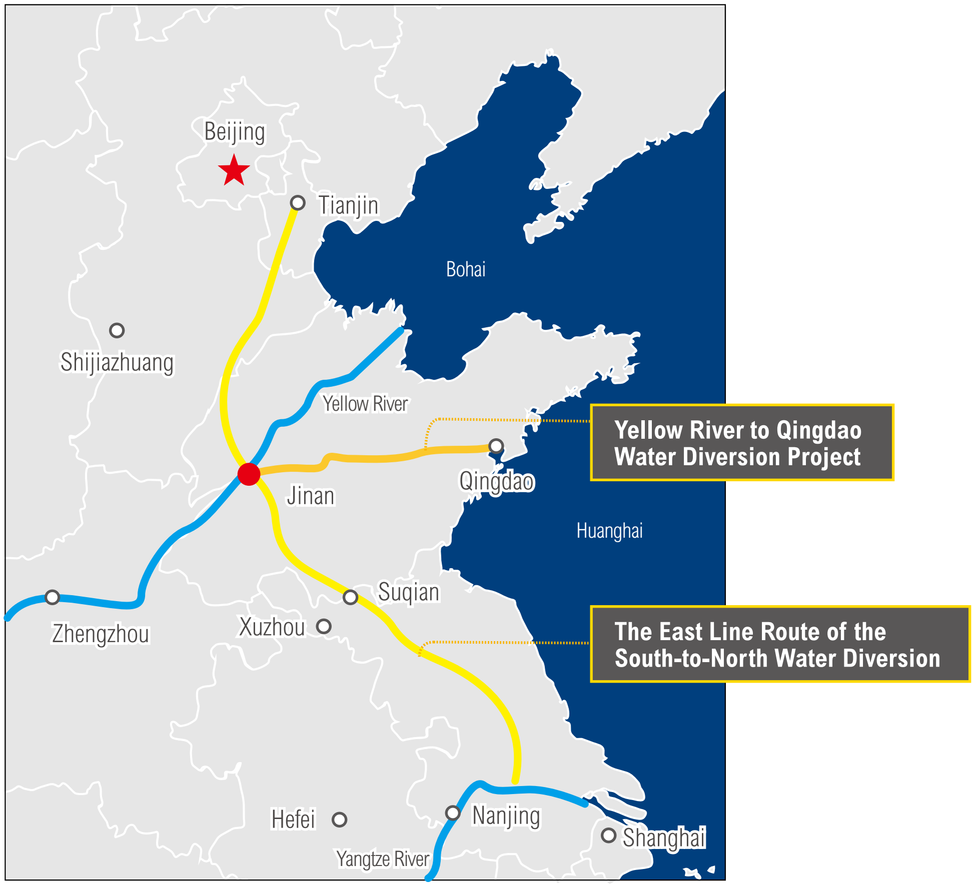
Estimating the water intake energy consumption for water coming from the South-to-North Water Diversion Project to Qingdao requires two separate calculations. For the first section running from the East Line to Lake Dongping, the electricity cost is 0.22 RMB/m^3 and the electricity price is 0.5 RMB/kWh. Therefore, the electricity consumption is 0.44 kWh/m^3 (Mery, 2005). For the second section

Figure 4-5 | **Energy Consumption of Water Intake and Production from the Yellow River to Qingdao**



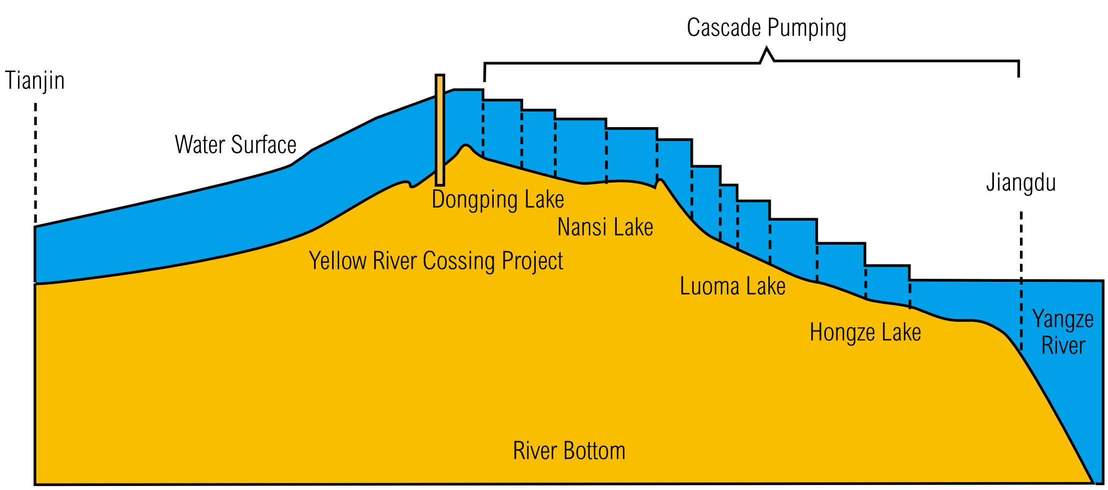
Data Sources: South-to-North Water Diversion Office, Introduction of East-Line Project

Figure 4-6 | **Illustration of the East Line Route of the South-to-North Water Diversion Project**



Data Sources: South-to-North Water Diversion Office, Introduction of East-Line Project

Figure 4-7 | **Illustration of Cascade Water Pumping in the East Line of the South-to-North Water Diversion Project**



Data Sources: Ministry of Water Resources, East line Project running from Dongping Lake to the channel of the Yellow River to the Qingdao project, the electricity consumption is 0.32 kWh/m^3, according to our calculations. Therefore, the total water transmission energy consumption from the South-to-North Water Diversion Project to Qingdao is estimated to be 0.76 kWh/m^3. Once the water is delivered to tap water plants, the average electricity consumption of water production is 0.376kWh/m^3. Therefore, the total energy consumption of water intake and water production from the South-to-North Water Diversion Project is approximately 1.136 kWh/m^3 (Figure 4-8).

4.2.4 Desalinated Water

4.2.4.1 Seawater Desalination

The phrase "desalinated water" refers to both seawater and brackish water from which salts and minerals have been removed. Many years of innovation and improvement have made seawater desalination technology an important solution to global freshwater shortages. As of 2012, the total seawater desalination capacity of all the facilities around the world had reached 74.8 million m^3/day. About 62% was for municipal water use (IDA, 2013).

Figure 4-8 | **Electricity Consumption of Water Intake and Production from the South-to-North Water Diversion Project**

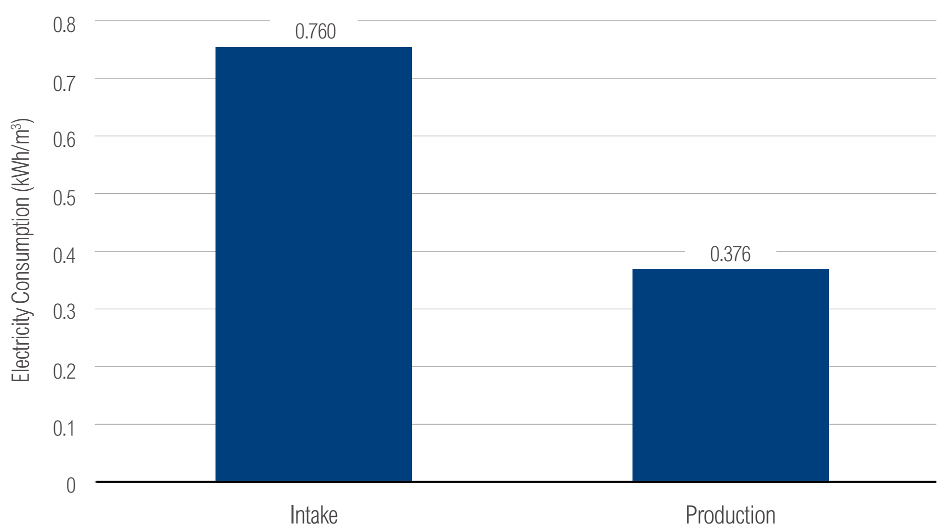
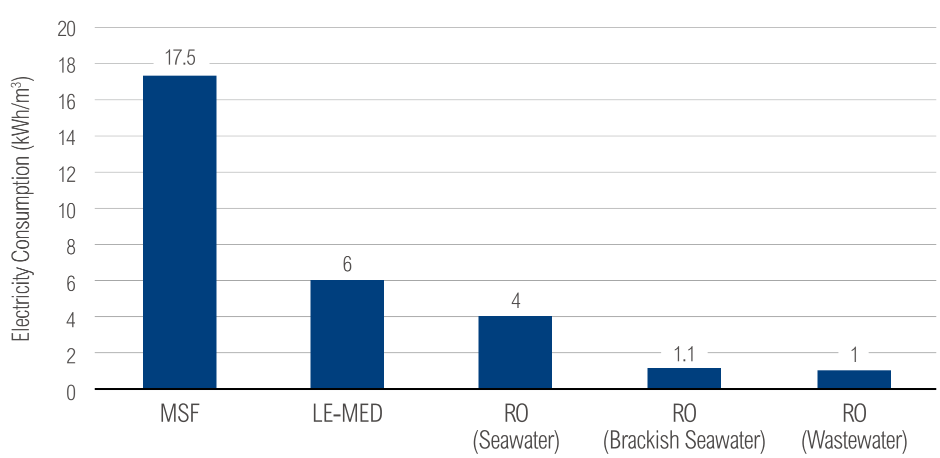


Figure 4-9 | **Comparison of Energy Consumption of Various Seawater Desalination Techniques**



Sources: Amy, 2009

In contrast to natural water resources, the energy needed for water intake accounts for only a small part of the total energy consumed for desalinated water. Instead, the water production process consumes most of the energy. Currently, the primary seawater desalination methods are thermal methods and reverse osmosis (RO), and the energy consumption differs significantly for each (see Figure 4-9).

The main thermal seawater desalination methods are Multi-Stage Flash (MSF) and low temperature/multi-effect desalination (LE-MED). For both methods, thermal (heat) energy accounts for the majority of the energy consumption, while electricity provides supporting energy. Since LE-MED only requires low temperatures, the method can take advantage of cheap thermal energy sources, such as residual heat and waste heat, while keeping electricity consumption low. For example, it takes only 1.65 kWh to process 3,000 m^3 of water per day at the LE-MED unit in the Shandong Huangdao Power Plant. Even when steam consumption is included, the total energy cost remains low at 6 kWh/m^3. However, the economic advantage of LE-MED has faded in recent years with rising fuel costs, and the LE-MED units in the Huangdao Power Plant have been idled. In contrast, the fuel cost of MSF is higher and the comprehensive energy consumption is nearly 18 kWh/m^3.

RO technology requires high osmotic pressure to ensure quality produced water and electricity is the only type of energy consumed. Energy is the biggest contributer to the total cost. The energy consumption of RO depends on the salinity of the incoming seawater. More energy is needed for seawater of higher salinity, so there are differences in energy consumption between regions. China has only recently started developing RO, so facilities are new and small in number. The electricity consumption is around 4.2 kWh/m^3 of water.

Currently, Qingdao has two RO seawater desalination units for industrial water uses. The unit energy consumed by the RO units at Qingdao's Soda Ash industry is 3.5 kWh/m^3, while at the Huangdao Power Plant it is 5 kWh/m^3. The Baifa plant, which has been built but is not operating yet, is designed to use 4 kWh/m^3. Based on these current examples of desalination, the energy consumed by water intake and production at seawater desalination plants in Qingdao is about 4 kWh/m^3.

Although important for addressing water shortages in coastal cities, desalinated seawater is generally used as a backup water source in European cities (for example, London) because of its high cost and energy consumption. In inland sea or bay areas with limited water circulation, the impact of strong brine discharges on the marine environment needs to be thoroughly considered. (Box 2 discusses the case study of seawater desalination-salt chemical co-production of the Qingdao Soda Ash Group.) Additionally, planners need to carefully consider issues. For instance, problems can arise when desalinated water is mixed with regular surface water sources.

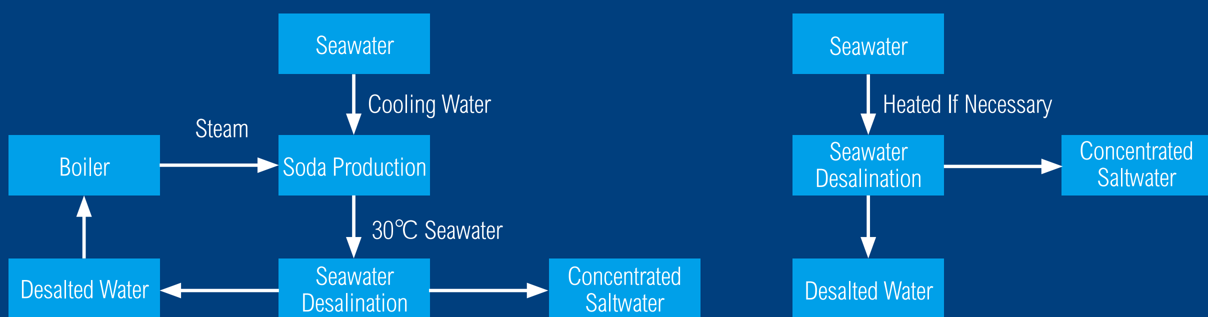
4.2.4.2 Brackish Water

Desalination technology can also be used on brackish water. The amount of total dissolved solids (TDS) in brackish water is between 1,000 and 10,000 mg/L, or roughly 3% to 28%[25] that of seawater. The energy consumed by RO for brackish water is also lower than seawater, between 0.3 and 1.4 kWh/m^3 (Cohen, 2004). Pingdu, a county-level city in the northeast region of Qingdao, has a severe water shortage but has abundant brackish water. Desalinating brackish water has advantages over desalinating seawater in both cost and energy consumption. The energy consumed by water intake and production for brackish water is 1.4 kWh/m^3.

Box 2 | Comprehensive Utilization of Seawater Desalination and Strong Brine

Seawater desalination results in a byproduct of strong brine, which has total dissolved solid (TDS) levels that are 40% to 350% higher than seawater. Brine is disposed of mainly by discharging it into the deep sea. Currently, the seawater desalination industry is mainly located in China's northern coastal area, especially next to the Bohai Sea and Jiaozhou Bay, where the seawater circulation is relatively weak. As seawater desalination plants expand, direct brine discharge may damage the local marine ecology. The consequent marine pollution cannot be ignored.

The Qingdao Soda Ash Group's seawater desalination project has adopted a method of producing soda from brine that not only solves the environmental problem of discharging strong brine, but also reduces the energy consumption of seawater desalination, and thus improves the overal profitability of the enterprise. Unlike other seawater desalination projects, the Qingdao Soda Ash Group uses cooling water discharged during the soda production process (i.e., lukewarm seawater that's around 30°C). About 45% of the lukewarm seawater from the cooling system becomes fresh water after RO treatment, becoming high-quality water for industrial boilers after deep treatment. About 55% of the seawater becomes strong brine that's fed into the current brine workshops for salt dissolving. The figure below compares this technology and common seawater desalination technologies.



Comparison of the seawater desalination technology in Qingdao Soda Ash Group and other conventional seawater desalination technologies

The main advantages of this project are:

The project uses waste heat from the cooling system, thus reducing energy consumption. RO systems work best at a temperature of around 30 degrees. The study by Abdulgader indicates that energy consumption can be significantly reduced and fresh water yield rates improved by raising the temperature of the incoming water. The waste heat is utilized fully by Qingdao Soda Ash Group and the electricity consumption per ton of water is between 3 and 3.5 kWh, which is 12.5% to 25% less than conventional RO systems.

Desalinated water is used as boiler water, thus reducing the demand for fresh water, as well as the cost. The Qingdao Soda Ash Group desalination plant can save up to 2.5 million m^3 of fresh water per year. The water production cost is around 8 RMB/m^3, which is 20-30% less than the cost of using tap water as boiler water. (Softening treatment is required when using tap water, resulting in higher costs.)

Both the environment and profitability win when concentrated seawater is recycled and reused. By using concentrated seawater salt dissolving methods, the soda production process can save 60,000 tons of industrial salt that would otherwise cost nearly 20 million RMB. Additionally, the temperature of concentrated seawater stays at around 30 degree throughout the year, so no additional heating is needed, further reducing the energy consumed by the production process.

The concentrated seawater resulting from desalination projects can be used directly for the production of salt, reducing over 50% of the salt production cycle time, and therefore saving large areas of valuable land in coastal regions. The possibility of extracting elements such as K, Br, Mg and Li from the concentrated seawater is also being studied.

Source: Investigation and interview in Seawater Desalination Plant in Qingdao Soda Ash Group by Project Team; Abdulgader A. Maghrabi. EFFECT OF HIGH FEED TEMPERATURE ON NANOFILTRATION AND RO MEMBRANE PERFORMANCE. 2005

4.2.5 Reclaimed Water

Qingdao was one of the first cities in China to utilize reclaimed water. As early as 2003, the city had issued and implemented two planning documents, *Management Regulations on Utilization of Urban Reclaimed Water in Qingdao* and *Reclaimed Water Utilization Plan in Qingdao*. Today, two centralized reclaimed water utilization projects have been built in the city. The treatment capacity of the Hai-bo-he Reclaimed Water Utilization Demonstration Project is 40,000 m^3/day, with a pipe network of 43 km. The treatment capacity of the Tuandao Reclaimed Water Utilization Project is designed to be 5,000 m^3/day, with a pipe network of 14 km. The reclaimed water is mainly used for industrial cooling, production processes, greenbelt irrigation, municipal cleaning, urban parks and rivers, domestic toilet flushing, infrastructure construction and water-heating pumps.

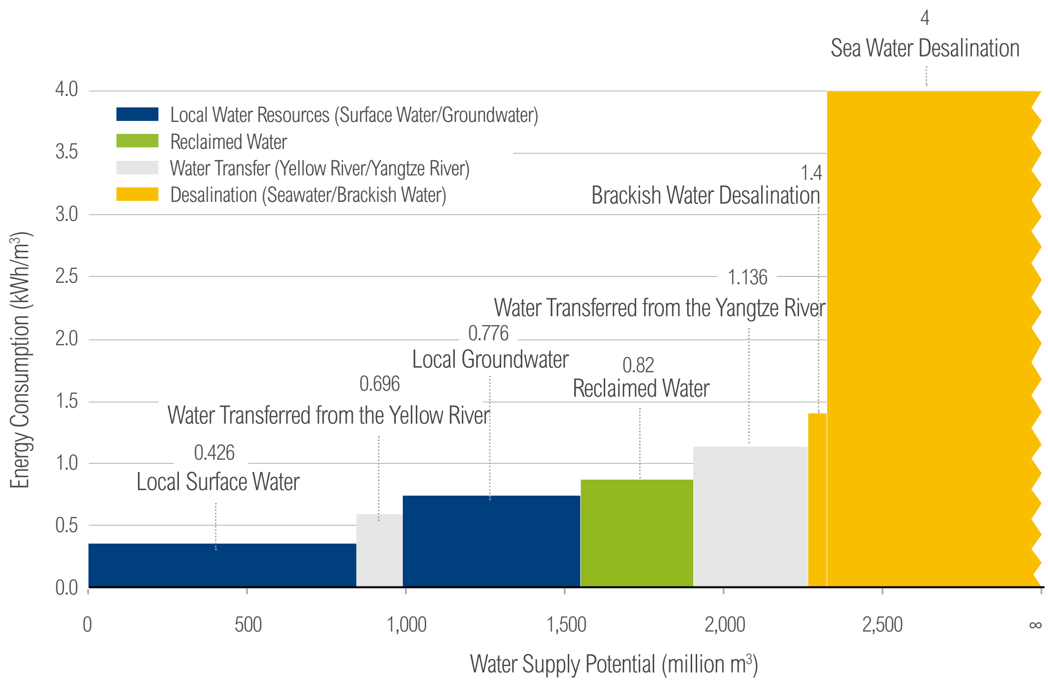
Reclaimed water's energy consumption depends on the treatment process and the quality requirements of the produced water. When the produced water is used as non-drinking/non-contact water, then biochemical treatment processes such as the Membrane Bio-Reactor (MBR) can be used. The energy consumed by MBR ranges from 0.45 to 0.91 kWh/m^3 (Wang, 2012). Membrane separation technologies such as ultrafiltration (UF) are more suitable for treating secondary wastewater discharged from treatment plants. They consume about 0.1 kWh/m^3 (Shi, 2011). For example, in the Hai-bo-he reclaimed water utilization demonstration project, a biological filtration tanks and UF are used to treat the water of Level 1 Standard A that is discharged by upstream wastewater treatment plants. According to an interview and analysis, the energy consumption of the biological filtration tank is around 0.255 kWh/m^3 (National wastewater treatment information system). When the UF treatment is included, the total energy consumed by the system is 0.355 kWh/m^3.

RO technology can also be used to produce high-quality reclaimed water (NEWater). According to data on energy consumed by Singapore's NEWater system, the energy consumed to produce high-quality reclaimed water is about 0.72 to 0.92 kWh/m^3, or roughly a quarter of that of seawater desalination. So far, Singapore has built NEWater production facilities with a total capacity of 460,000 m^3/day[26]. High-quality water is produced from wastewater treatment plant discharge and is processed using UF and RO. The water is mainly used for industrial production (such as computer chip manufacturing). Additionally, about 6% of the reclaimed water is mixed with water from reservoirs and is used indirectly as a drinking water source. Reclaimed water meets the equivalent of 1% of Singapore's drinking water demand[27].

4.3 Water Supply Potentials from Various Water Sources in Qingdao

The main water sources available for Qingdao in the future include: local surface water, local groundwater, transferred water from the Yellow River and the Yangtze River, desalinated seawater and reclaimed water. Figure 4-10 shows the results of an analysis of different water sources' supply potential and water production energy consumption. Each column represents one kind of water source. The width indicates the annual water supply potential and the height indicates the energy required to produce water that meets the drinking water standard.

Figure 4-10 | **Water Supply Potential and Water Intake and Production Energy Consumption Curves for Different Water Sources in Qingdao**



A few conclusions from the analysis:

1. Not including seawater desalination, the total water supply potential of all other water resources is 2.285 billion m³, with local surface water and groundwater together accounting for 1.463 billion m³. To improve local aquatic ecology health, exploitation rates of surface water should be less than 40% and groundwater should be less than 50%. Hence, the water supply potential from local water sources is only 1.104 billion m³ (assuming surface water provides 0.64 billion m³ and ground water provides 0.464 billion m³). That is far less than Qingdao's water demand. Therefore, Qingdao must utilize transferred water, reclaimed water or desalinated seawater to fill the gap between water demand and supply.

(1) Surface water resources: The internationally acknowledged maximum safe utilization rate of river surface water is 40%. Wang and Zhang (2008) concluded that the maximum water utilization rate for the seven large rivers in China should be between 0.31 and 0.45. However, due to Northern China's water shortage, the surface water utilization rate is far past that threshold. For example, 90% of the Hai River has been utilized (Jia and Zhang, 2003). Generally, when the surface water utilization rate exceeds 55%, the ecological system faces high risks[28]. If the development and utilization rate is kept at 55%, then Qingdao's long-term average surface water supply potential will be 0.88 billion m³ [29].

(2) Groundwater resources: Qingdao has 0.583 billion m³ of exploitable groundwater, according to *Qingdao's 11th 5-Year Plan for the Comprehensive Utilization and Development of Water Resources (2007)*. That is also the groundwater supply potential.

(3) Transferred water: Water administrators ranked higher than city officials approved the amount of water diverted to Qingdao. According to the water diversion and distribution plan of Qingdao, the amount diverted from the Yellow River is 0.11 billion m³, and the amount from the Yangtze River will be 0.302 billion m³. [30]

(4) Utilization of reclaimed water: Qingdao's urban residents will consume 0.583 billion m³ water in 2020, thus generating 0.467 billion m³ of domestic wastewater. After accounting for a reclaimed water production loss of 20%, the maximum reclaimed water supply potential is 0.374 billion m^3.

(5) Brackish water: Due to lack of data on brackish water supply, we made an estimate based on Qingdao's brackish water desalination capacity. The Xinhe Chemical Park plans to set up a brackish water desalination plant with a capacity of 100,000 m^3/day in the park, according to planning information. The maximum water supply potential will be 36 million m^3.

2. Seawater desalination consumes the most energy, 4 kWh/m^3, to produce water that meets the drinking water standard. That is nearly 10 times that required from local surface water, which needs the least energy. From lowest to highest, the order of energy needed to produce water from different sources is: local surface water < transferred water from the Yellow River < groundwater < reclaimed water (NEWater) < transferred water from the Yangtze River < brackish water desalination < seawater desalination.

3. Some water transfers are more energy-efficient than others. Yellow River diversions require only 60% of the energy needed to divert water from the Yangtze River, which is why Qingdao prioritizes Yellow River water.

4. Reclaimed water not only has large supply potential, but also has the lowest water production energy consumption of the unconventional water sources. The energy consumed for water production for high-quality reclaimed water (NEWater) ranges from 0.72 to 0.92 kWh/m^3 (Bodik, 2013), which is even less than that of transferring water from the Yangtze River (1.136 kWh/m^3).

5. In Pingdu, where water is especially scarce, developing brackish water can be prioritized, and then supplemented by seawater desalination. Pingdu is rich in brackish water resources, which only take 1.41 kWh/m^3 of energy to desalinate and produce. That is just a quarter of the energy needed to desalinate and produce seawater.

CHAPTER 5

SCENARIO ANALYSIS OF QINGDAO'S WATER SOURCE SELECTION AND ENERGY CONSUMPTION IN 2020

5.1 Base Year: Analysis of Qingdao's Water Source Configuration and Water Production Energy Consumption in 2011

5.1.1 Water Source Configuration in Each of Qingdao's Administrative Divisions in 2011

Qingdao's total volume of water supply in 2011 was 1.0082 billion m^3. Of that, 0.9677 billion m^3 was fresh water, 3.5 million m^3 was desalinated seawater and 37 million m^3 was reclaimed wastewater. Figure 5-1 shows a Sankey diagram of the distribution and utilization of Qingdao's water sources in 2011. A few key points:

Local surface water supplied 0.455 billion m^3, or 28% of the total long-term average surface water amount. Local groundwater supplied 0.3668 billion m^3, or 39% of the total long-term average ground water amount. Transferred water (the Yellow River to Qingdao) supplied 0.146 billion m^3 of water.

The municipal water supply (including centralized rural water supply) used 0.5301 billion m^3. Of that, 0.4376 billion m^3 was utilized directly without any treatment. Meanwhile, industrial recycled water use was 0.9199 billion m^3 and urban recycled domestic wastewater use was 37 million m^3.

About 8 million m^3 of water in the municipal supply network entered the environment directly without being used because of leaking and damaged water distribution pipes. The rest went to urban residential and municipal use (0.23 billion m^3), industrial use (0.159 billion m^3) and rural residential use (60.9 million m^3). Among the direct water uses, 0.311 billion m^3 was used for agriculture irrigation, 69.5 million m^3 was used for forest, stock, side-occupations and fisheries, and about another 56.8 million m^3 was used for the ecological environment.

Figure 5-1 | **Sankey Diagram of the Distribution and Utilization of Water Resources in 2011 in Qingdao**

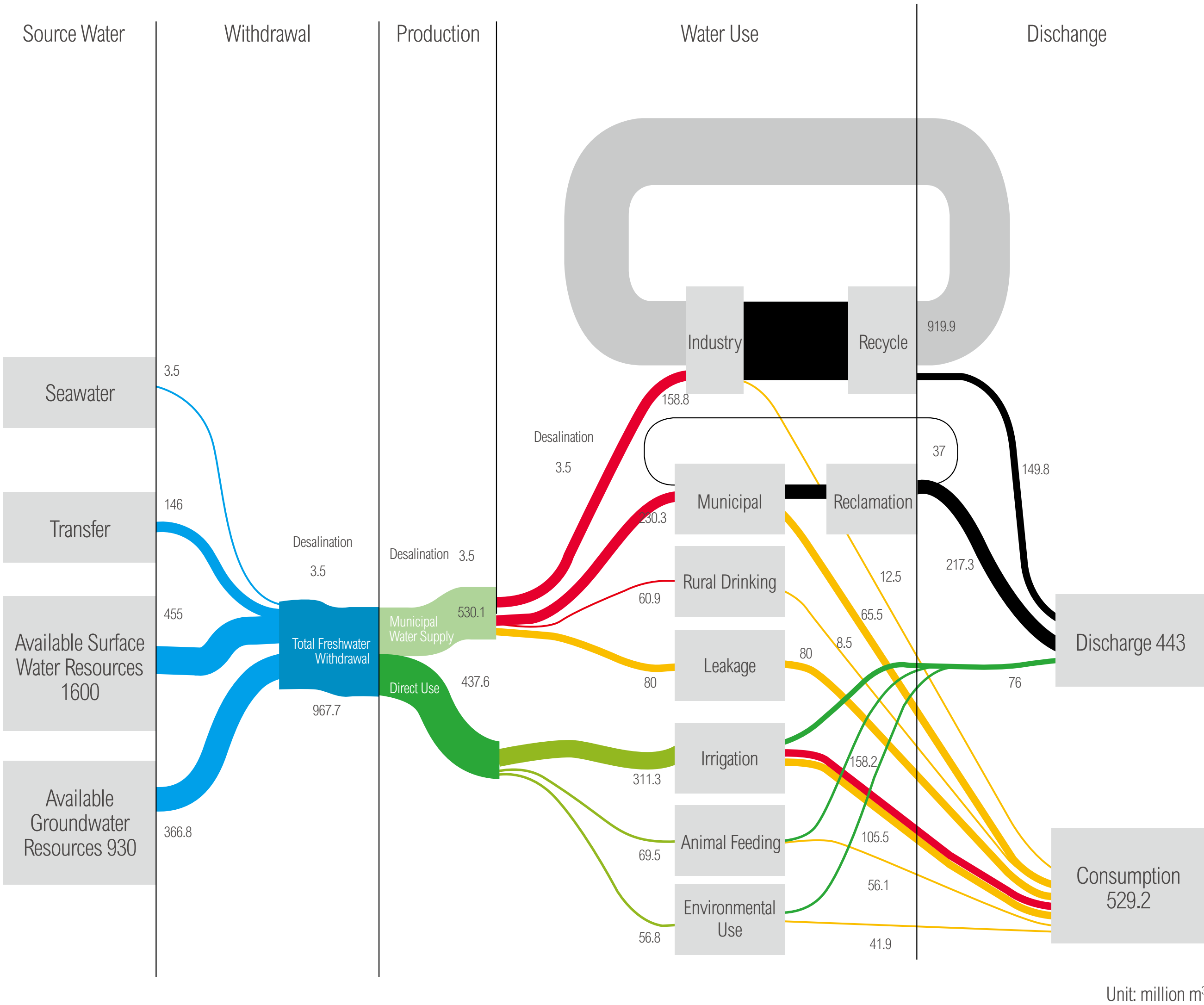
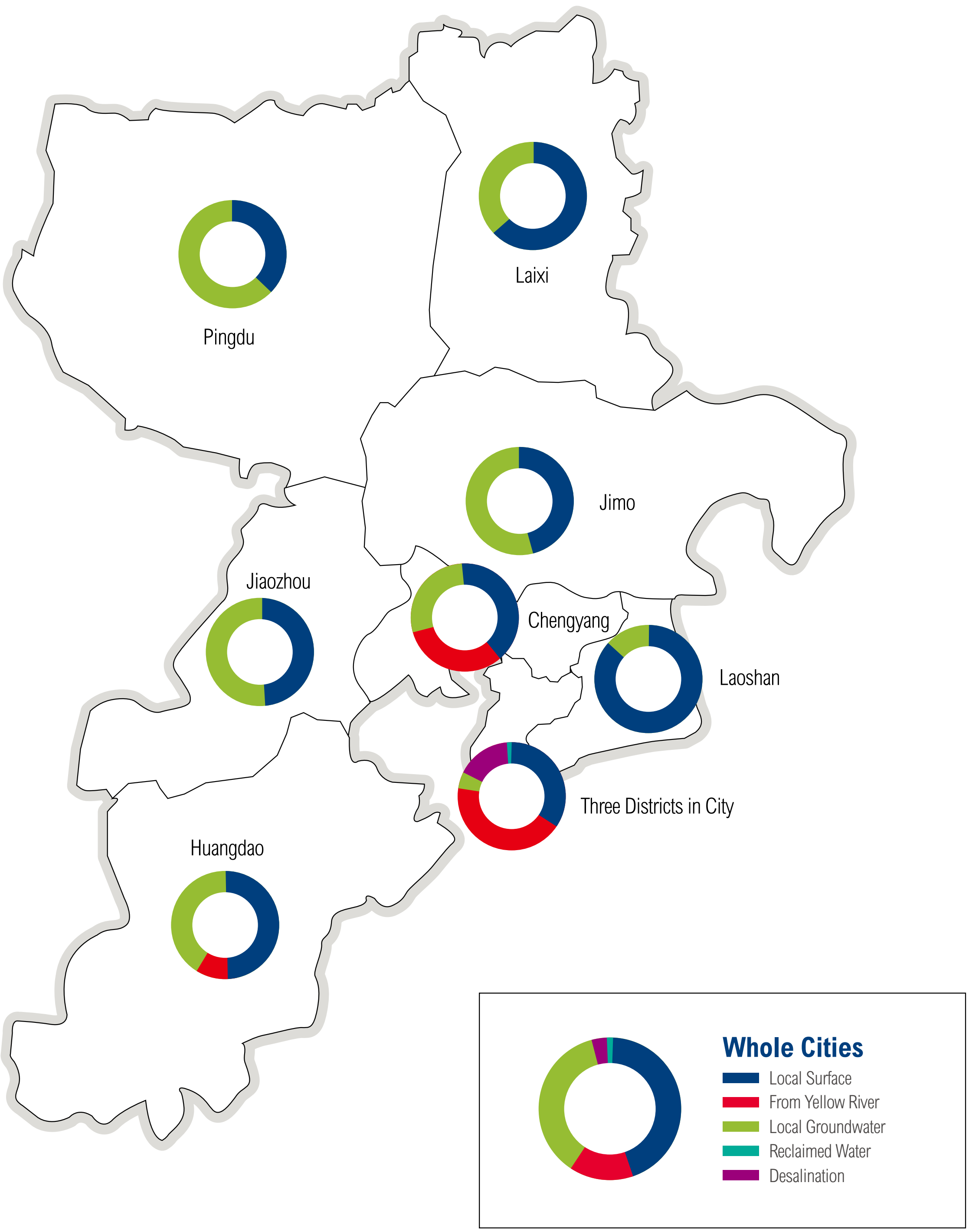


Figure 5-2 shows the sources of Qingdao's water by district in 2011. Transferred water and local surface water were the largest sources for the downtown area. Reclaimed water, which is currently low quality (suitable only for irrigation and road washing etc), was used only in the downtown area, accounting for 15% of total water consumption. Huangdao District and Chengyang District were partly using the transferred water from the Yellow River. Pingdu, Laixi, Jimo and Jiaozhou mainly depended on their local surface water and groundwater.

5.1.2 Analysis of Qingdao's Water Production Energy Consumption in 2011

As indicated in Section 2.2, this study focuses on the energy consumption of water intake and water production processes (thereafter referred to as water production energy consumption), which is directly related to the type of water source. Water meant for ecological purposes can come from diverse sources. It can be either treated low-quality reclaimed water that takes energy to produce, or untreated groundwater or surface water that only consumes energy

Figure 5-2 | **Qingdao's Water Supply Sources by District in 2011**



for water intake, not production. Since it is difficult to assign the water consumption for ecology to different water sources, the energy consumption by ecology water is omitted in this analysis.

Table 5-1 shows Qingdao's sectoral water consumption, and Table 5-2 shows water sources by administrative divisions.

Qingdao's water production energy consumption in 2011 is calculated to be about 0.469 billion kWh (see Figure 5-3) based on the energy consumed by water production from various sources (see Section 4.2).

Most water sources accounted for similar proportions of total water supplied and total energy consumed: local surface water (45.1% of water supplied and 41.3% of energy consumed), transferred water from the Yellow River (14.5% and 21.7%), ground water (36.4% and 31.3%), reclaimed water (3.7% and 2.8%) and desalinated seawater (0.3% and 3%).

The downtown area accounted for the lion's share of water production energy consumption, followed by Pingdu, which had the largest irrigation water use. Laoshan District had the lowest energy consumption (see Figure 5-4).

Table 5-1 | **Water Supply for Municipal, Industrial and Agricultural Uses in 2011 in Qingdao (in 10,000 m^3)**

	URBAN	LAOSHAN	CHENG-YANG	HUANG-DAO	JIMO	LAIXI	PINGDU	JIAONAN	JIAO-ZHOU	TOTAL
Irrigation	0	57	400	140	2,729	5,605	13,852	5,087	3,258	100,821
Forestry, Livestock and Fishery	0	355	240	86	595	3,225	978	910	562	
Industrial	5,423	1,086	2,859	3,270	1,716	533	1,357	1,278	1,576	
Municipal	4,498	348	536	489	794	453	941	607	643	
Domestic	9,311	1,507	1,998	2,036	3,776	1,839	2,561	3,042	2,581	
Ecological Environment	3,739	218	150	110	350	271	311	225	310	
Total	22,971	3,571	6,183	6,131	9,960	11,926	20,000	11,149	8,930	

Data Source: Qingdao Water Resources Bulletin 2011 (QDWRB, 2012)

Table 5-2 | **Qingdao's Water Supply Sources by District in 2011 (in 10,000 m^3)**

	URBAN	LAOSHAN	CHENG-YANG	HUANG-DAO	JIMO	LAIXI	PINGDU	JIAONAN	JIAO-ZHOU	TOTAL
Local Surface Water	7,640	3,090	2,368	4,188	4,574	7,525	7,416	4,328	4,368	100,821
The Yellow River	10,950	0	2,000	1,650	0	0	0	0	0	
Local Groundwater	465	481	1,815	162	5,386	4,401	12,584	6,821	4,562	
Reclaimed Water	3,700	0	0	0	0	0	0	0	0	
Seawater Desalination	216	0	0	131	0	0	0	0	0	

Data Source: Qingdao Water Resources Bulletin 2011 (QDWRB, 2012)

Figure 5-3 | **Proportion of Water Supply and Water Production Energy Consumption from Different Water Sources in Qingdao (2011)**

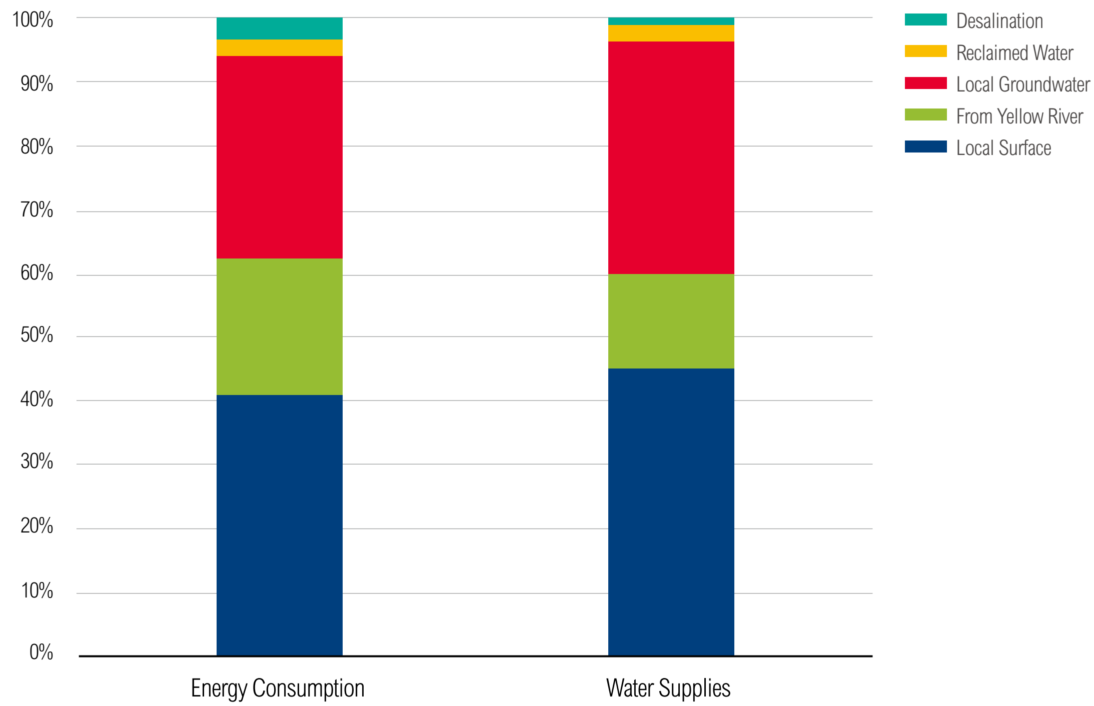


Figure 5-4 | **Qingdao's Water Production Energy Consumption by District in 2011**

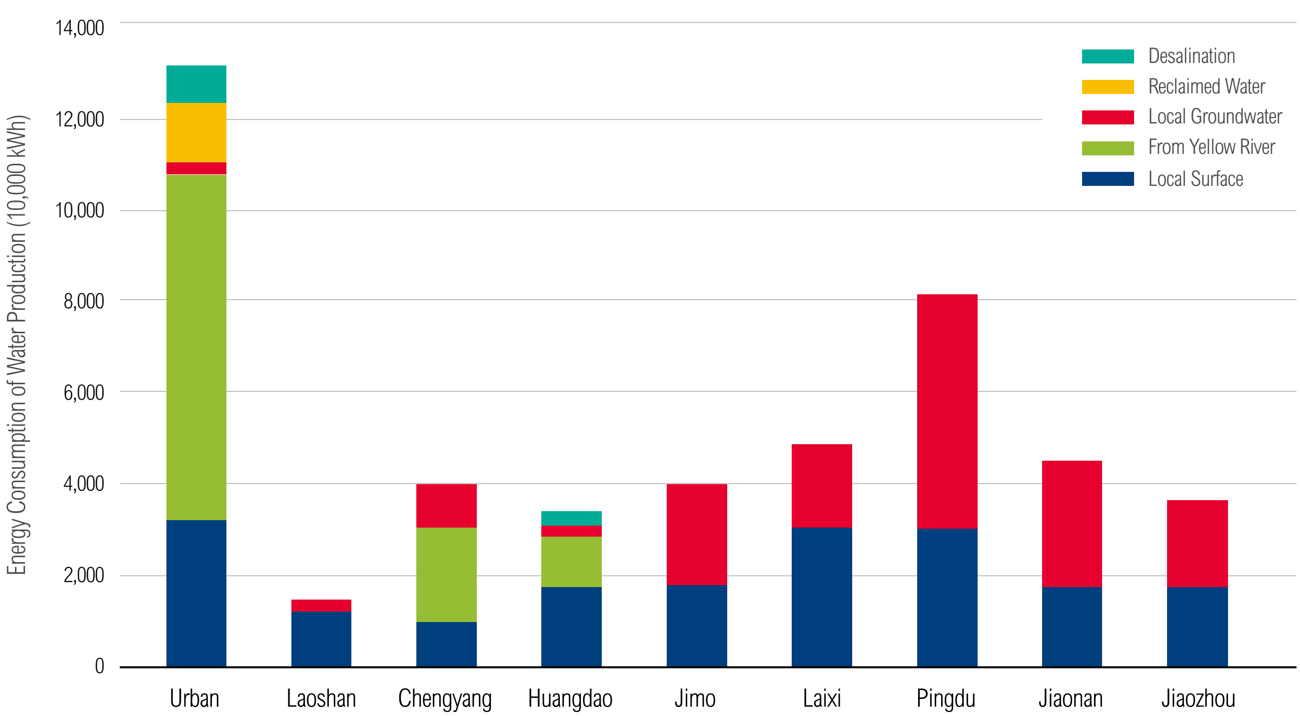


Figure 5-5 | **Water Production Energy Consumption by District in 2011 in Qingdao**

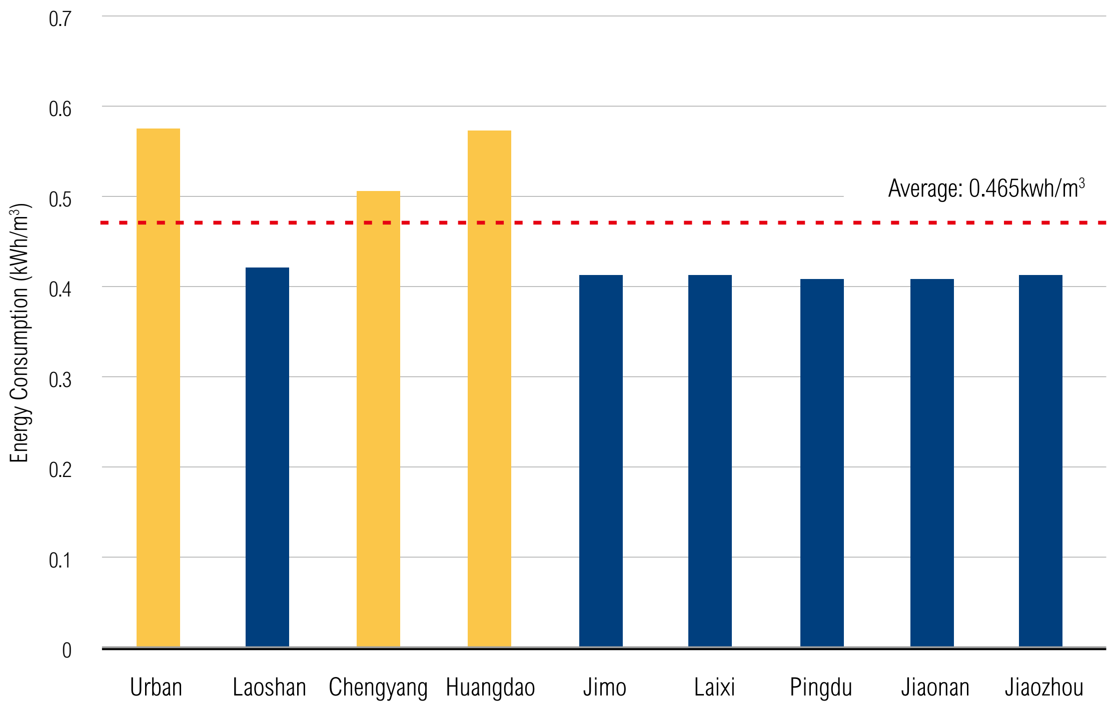


Figure 5-5 compares the average water production energy consumption in different districts. The average water production energy consumption of the downtown area, Chengyang and Huangdao were higher than the city's average of 0.465 kWh/m^3. Those areas used more transferred water, desalinated water and reclaimed water, which all consume more energy.

5.1.3 Analysis on Qingdao's GHG Emissions in Water Production System in 2011

Qingdao is within the North China power grid and has a carbon dioxide emission factor of 0.8845 kg CO2/kWh, according to *Average Carbon Dioxide Emission Factors of Regional and Provincial Power Grids in 2010 in China*. Since coal-fired power will likely remain China's dominant power source, we predict that the carbon dioxide emission factor will remain the same in 2020. Our analysis uses that factor to calculate the carbon emissions from the water supply system in 2020.

In 2011, the emissions from Qingdao's water supply system were 0.415 million tons CO2e. Of that, 190,000 tons, or 46% of total emissions, came from the water intake process of conventional water sources (local surface water, ground water and transferred water). Another 200,000 tons, or 48% of total emissions, was from related water production processes. Unconventional water sources (desalinated seawater and reclaimed water) only contributed 6% of total emissions because those sources are rare.

5.2 Scenario Settings of Water Source Configuration in 2020 in Qingdao

We estimate that Qingdao's total water demand will reach 1.48 billion m^3 in 2020 (see Section 3.4 and Appendix 1). That is slightly higher than Qingdao's red-line target (1.473 billion m^3) for 2020, and it means Qingdao must focus on developing and utilizing unconventional water resources (Note: unconventional water resources are not included in the red-line targets).

We followed several principles when determining possible water source configurations for 2020:

(1) Ensure total water consumption is lower than the state-assigned red-line target (1.473 billion m^3).

(2) Prioritize local water resources.

(3) Priortize Yellow River water for water diversions, up to the quota.

We established three basic scenarios based on the principle of prioritizing the development of local water resources: “Surface 35” (Qingdao’s surface water utilization rate reaches 35%, which is 1% more than in 2011), “Surface 40” (Qingdao’s surface water utilization rate reaches 40%, which is the upper limit of reasonable utilization) and “Surface 55” (Qingdao’s surface water utilization rate reaches 55%, which is the limit of the surface water development and utilization in Qingdao). Since Qingdao is located on the coast and no cities are downstream, excessive water withdrawals result in little impact on the downstream ecology. Therefore, Qingdao can reasonably use more local surface water without damaging the estuary ecology. However, transferred water or unconventional water resources must supplement local sources that are in short supply in Qingdao. Therefore, we added additional scenarios to the basic scenarios, variously prioritizing reclaimed water, desalinated seawater and diverted water.

5.2.1 Surface 35-Basic Scenario

1. Surface 35 with Priority on Seawater Desalination Scenario

Apart from local surface water, this scenario (hereafter referred to as “Surface 35 seawater desalination scenario”) prioritizes seawater desalination for 2020. The 2011 levels of water supplies from reclaimed water (37 million m^3) and the Yellow River diversion (0.11 billion m^3) are kept the same.

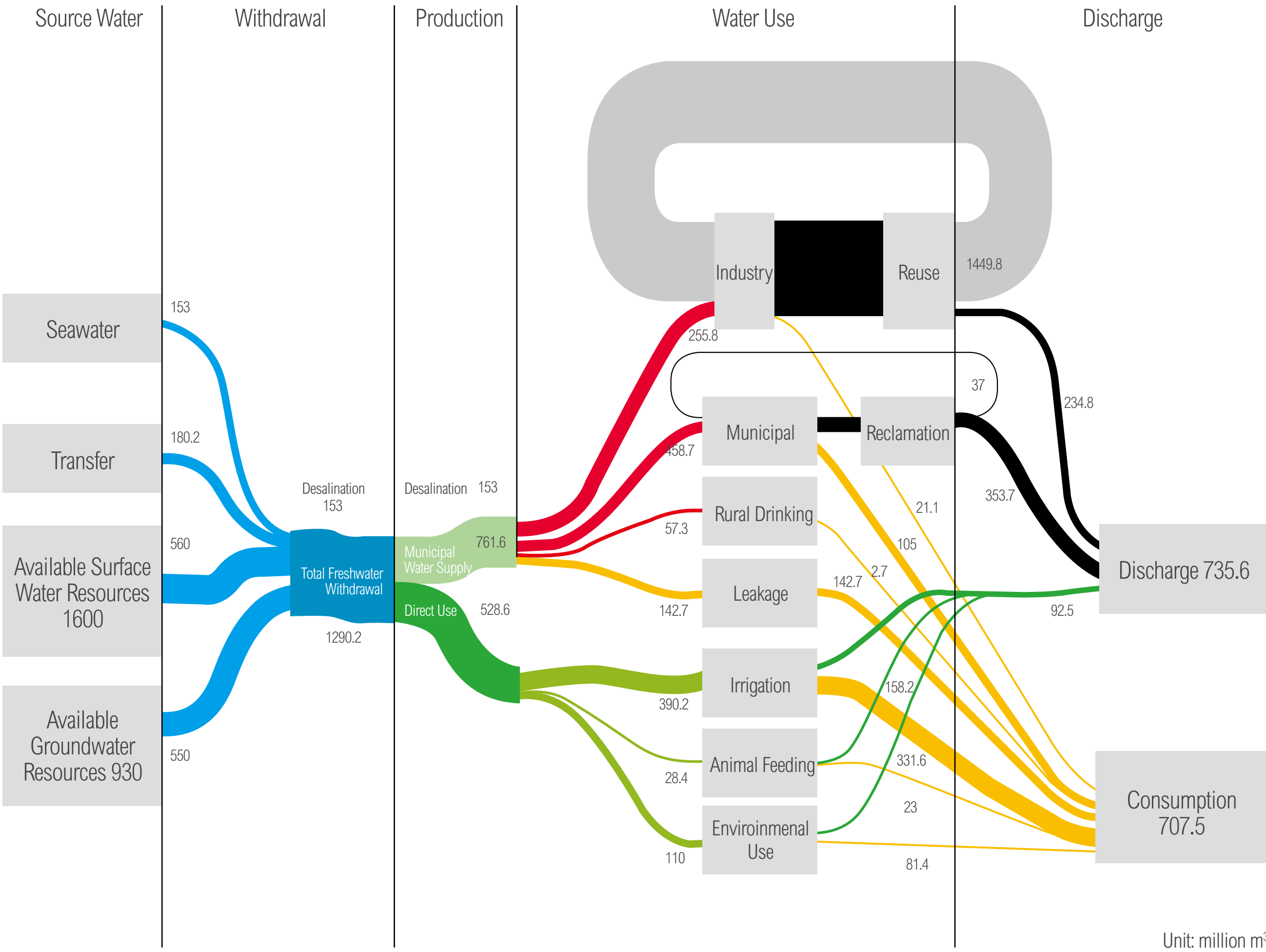
Plans call for building seawater desalination facilities capable of producing 400,000 m^3/day by 2020 (QDDRC, 2005), with 62% of the new capacity

Table 5-3 | **Table of Qingdao’s Planned Seawater Desalination Projects**

ADMINISTRATIVE DIVISION	PLANNING PROJECT	DESIGN ABILITY (10,000 M^3 PER DAY)	USAGE
Huangdao	Huangdao Power Plant	10	Industrial and Civil Use
	Huangdao North Seawater Desalination Factory	2	Civil Use
Urban	Qingdao Power Plant and Soda Production	8.5	Industrial Use
Jiaonan	Dongjiakou	10	Industrial and Civil Use
	Lingshanwei	1	Industrial and Civil Use
	Langya	1	Civil Use
	Tianheng	0.8	Civil Use
Chengyang		4	Industrial and Civil Use
Jimo		1	Civil Use
Laoshan	Wanggezhuang	0.8	Civil Use
Pingdu	Xinhe	0.5	Civil Use
Huangdao		0.4	Civil Use
Total	40	40	

Data Source: Seawater Desalination Development Planning of Qingdao (QDDRC, 2005)

Figure 5-6 | **Sankey Diagram on Qingdao's Water Source Configuration and Utilization under "Surface 35 Seawater Desalination Scenario"**

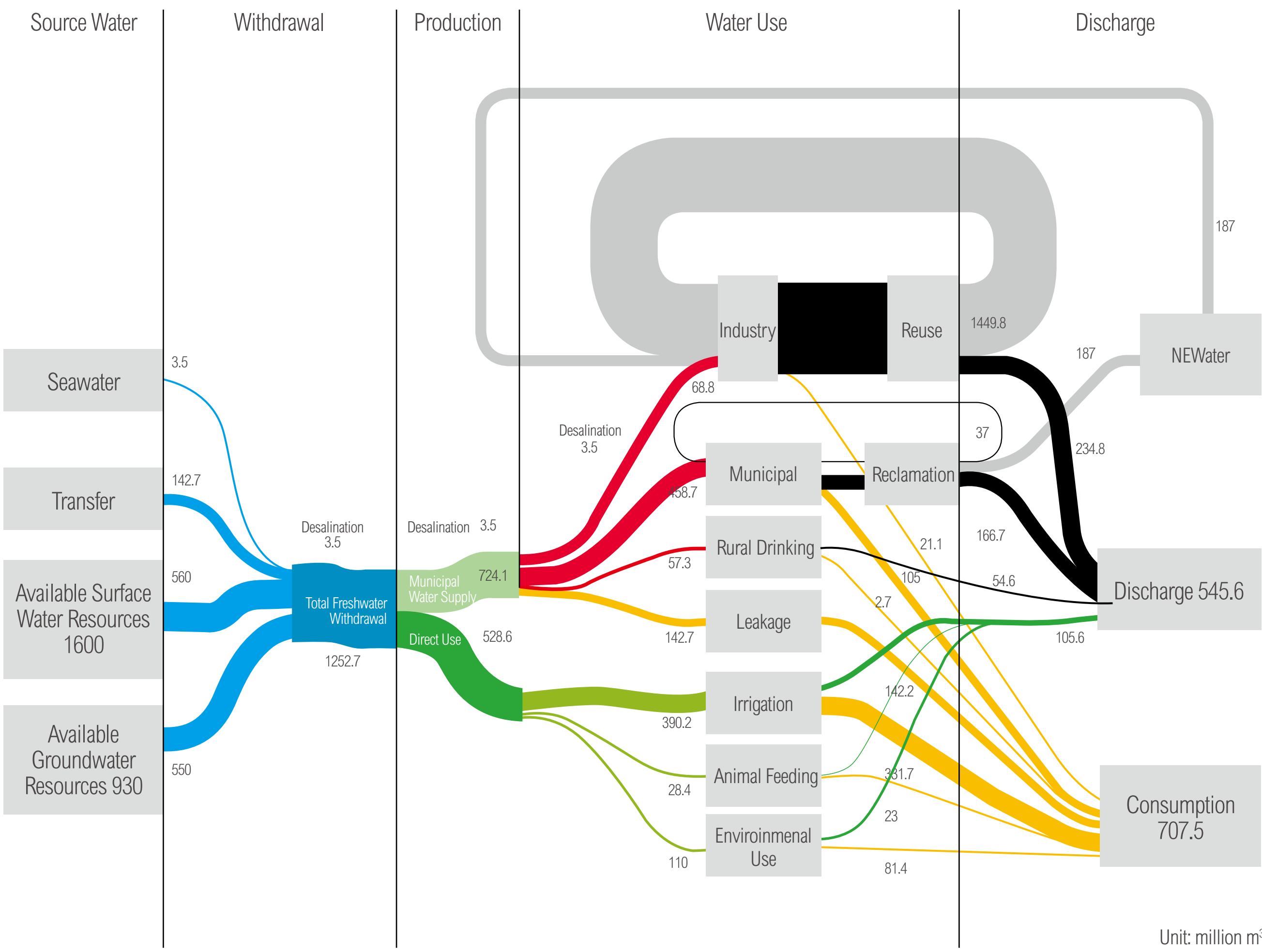


located in the new Huangdao District (see Table 5-3). If the desalination units operate at an 80% load factor, then Qingdao would have 0.153 billion m³ of desalinated water in 2020, or enough to meet about 50% of industrial water demand. Another 70 million m³ of diverted water from the Yangtze River would meet demand for the whole city. The Sankey diagram in Figure 5-6 demonstrates "the Surface 35 Seawater Desalination Scenario".

2. Surface 35 with Priority on Reclaimed Water Scenario

As technology has developed and costs have fallen in recent years, deep treatment and wastewater reclamation have gained more attention. Qingdao has a large potential to utilize reclaimed water (see Section 4-2), with a potential maximum reclaimed water supply of 0.374 billion m³, based on domestic urban water demand in 2020. Reclaimed water's water production energy consumption is not only the lowest among unconventional sources (producing high-quality reclaimed "NEWater" consumes a quarter of the energy needed for seawater desalination), but also lower than transferred water from the South-to-North water diversion. The water production energy consumption of low-quality reclaimed water (for miscellaneous municipal uses) is even lower, or only

Figure 5-7 | **Sankey Diagram on Qingdao's Water Source Configuration and Utilization under "Surface 35 Reclaimed Water Scenario"**



about 9% that of seawater desalination.

Under the Surface 35 scenario with a priority on reclaimed water (hereafter referred to as "Surface 35 Reclaimed Water Scenario"), we assume that the amount of low-quality reclaimed water holds steady at 37 million m³, while the production capacity of high-quality reclaimed water (NEWater) increases to 50% of its maximum water supply potential in 2020 (i.e., 0.187 billion m³). That water can meet about 62% of the industrial water demand. We assume that 2011 levels of seawater desalination (3.5 million m³) and transferred water from the Yellow River (0.11 billion m³) stay the same. As a result, the remaining demand can be met by an additional 32.70 million m³ of transferred water from the Yangtze River.

Figure 5-7 shows a Sankey diagram of Qingdao's water source configuration and utilization under "Surface 35 Reclaimed Water Scenario."

3. Surface 35 with Priority on Transferred Water

For the Surface 35 scenario with priority on transferred water (hereafter referred to as "Surface 35 Transferred Water Scenario"), the 2011 levels of reclaimed water (37 million m³) and seawater desalination (3.5 million m³) remain the same.

Additionally, 0.11 billion m³ is transferred from the Yellow River and and 0.22 billion m³ is transferred from the Yangtze River.

Figure 5-8 shows a Sankey diagram of Qingdao's water source configuration and utilization under "Surface 35 Transferred Water Scenario."

Table 5-4 shows the distributions of different water sources under different Surface 35 scenarios. Based on the water demand prediction, 0.11 billion m³ of water is estimated and reserved for ecology in 2020 in Qingdao.

Figure 5-8 | **Sankey Diagram of Qingdao's Water Source Configuration and Utilization under "Surface 35 Transferred Water Scenario"**

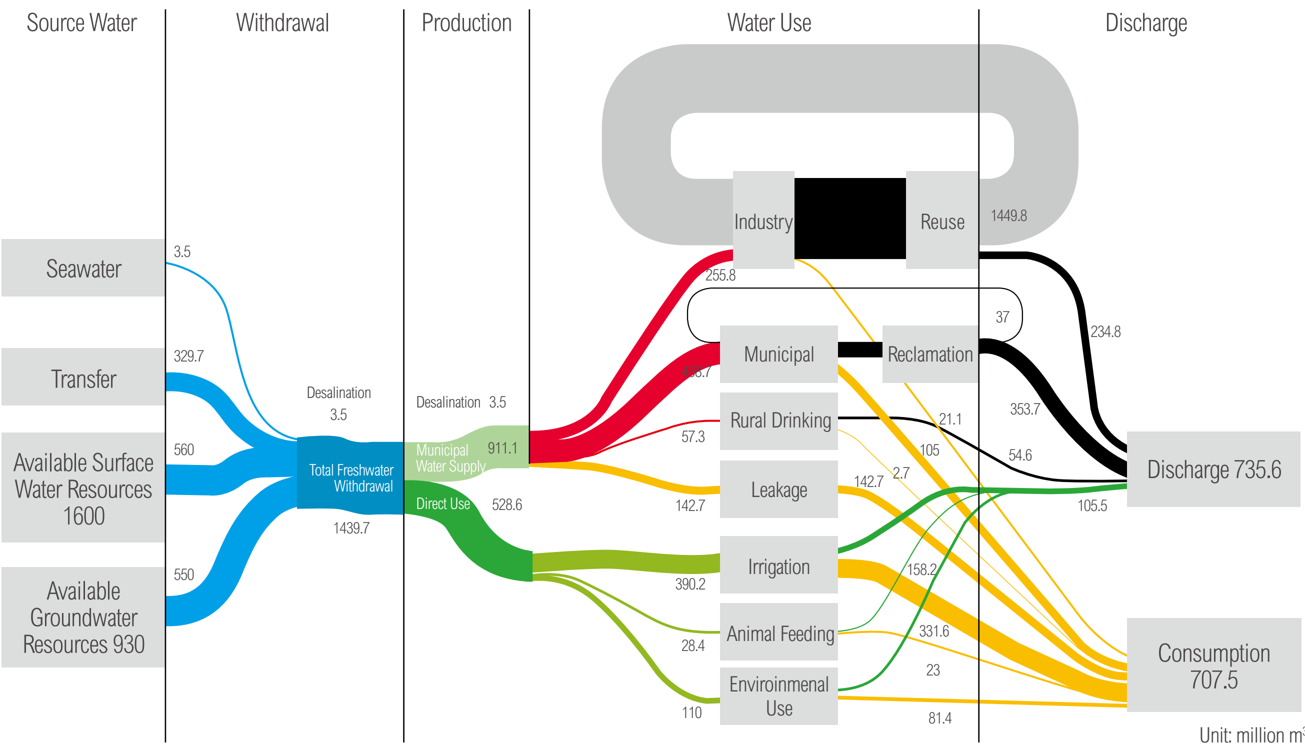


Table 5-4 | **Distributions of Different Water Sources under Different Surface 35 Scenarios**

TYPE OF WATER SOURCE	WATER SUPPLY WITH PRIORITY ON SEAWATER DESALINATION SCENARIO (100 MILLION M³)	WATER SUPPLY WITH PRIORITY ON RECLAIMED WATER SCENARIO (100 MILLION M³)	WATER SUPPLY WITH PRIORITY ON TRANSFERRED WATER SCENARIO (100 MILLION M³)
Local Surface Water	5.60	5.60	5.60
Groundwater	5.50	5.50	5.50
From Yellow River	1.10	1.10	1.10
From Yangtze River	0.70	0.33	2.20
Desalination	1.53	0.04	0.04
Low-Quality Reclaimed Water	0.37	0.37	0.37
High-Quality Reclaimed Water	0.00	1.87	0.00
Total	14.80	14.80	14.80

5.2.2 Surface 40 and Surface 55 Basic Scenarios

For the Surface 40 scenarios, we kept groundwater use at 0.55 billion m^3, while increasing the use rate of surface water to 40%, which is about 0.64 billion m^3.

We established three sub-scenarios (with priority on seawater desalination, reclaimed water and water diversion) for both the Surface 40 and Surface 55 scenarios. The detailed settings are similar to those for the Surface 35 scenarios, and also consider the available water amount (see Table 3-2) and the estimated sectoral demands in each district (see Appendix 1).

Table 5-5 shows the water amount distribution protocols for the Surface 40 scenarios.

Qingdao will withdraw 0.88 million m^3/year of surface water at the utilization and development limit of 55%. See Table 5-6 for the water amount distribution for the Surface 55 scenarios.

Table 5-5 | **Water Amount Distribution of Different Water Resources under Three Surface 40 Scenarios**

TYPE OF WATER SOURCE	WATER SUPPLY WITH PRIORITY ON SEAWATER DESALINATION SCENARIO (100 MILLION M^3)	WATER SUPPLY WITH PRIORITY ON RECLAIMED WATER SCENARIO (100 MILLION M^3)	WATER SUPPLY WITH PRIORITY ON TRANSFERRED WATER SCENARIO (100 MILLION M^3)
Local Surface Water	6.40	6.40	6.40
Groundwater	5.50	5.50	5.50
From Yellow River	1.00	0.63	1.10
From Yangtze River	0.00	0.00	1.40
Desalination	1.53	0.04	0.04
Low-Quality Reclaimed Water	0.37	0.37	0.37
High-Quality Reclaimed Water	0.00	1.87	0.00
Total	14.80	14.80	14.80

Table 5-6 | **Water Amount Distribution of Various Water Resources under Three Surface 55 Scenarios**

TYPE OF WATER SOURCE	WATER SUPPLY WITH PRIORITY ON SEAWATER DESALINATION SCENARIO (100 MILLION M^3)	WATER SUPPLY WITH PRIORITY ON RECLAIMED WATER SCENARIO (100 MILLION M^3)	WATER SUPPLY WITH PRIORITY ON TRANSFERRED WATER SCENARIO (100 MILLION M^3)
Local Surface Water	8.80	8.80	8.80
Groundwater	5.50	5.50	5.50
From Yellow River	0.00	0.00	0.10
From Yangtze River	0.00	0.00	0.00
Desalination	0.13	0.04	0.04
Low-Quality Reclaimed Water	0.37	0.37	0.37
High-Quality Reclaimed Water	0.00	0.10	0.00
Total	14.80	14.80	14.80

5.3 Analysis of Qingdao's Water Production Energy Consumption under Surface 35 Scenarios in 2020

5.3.1 Water Production Energy Consumption for Surface 35 Scenarios

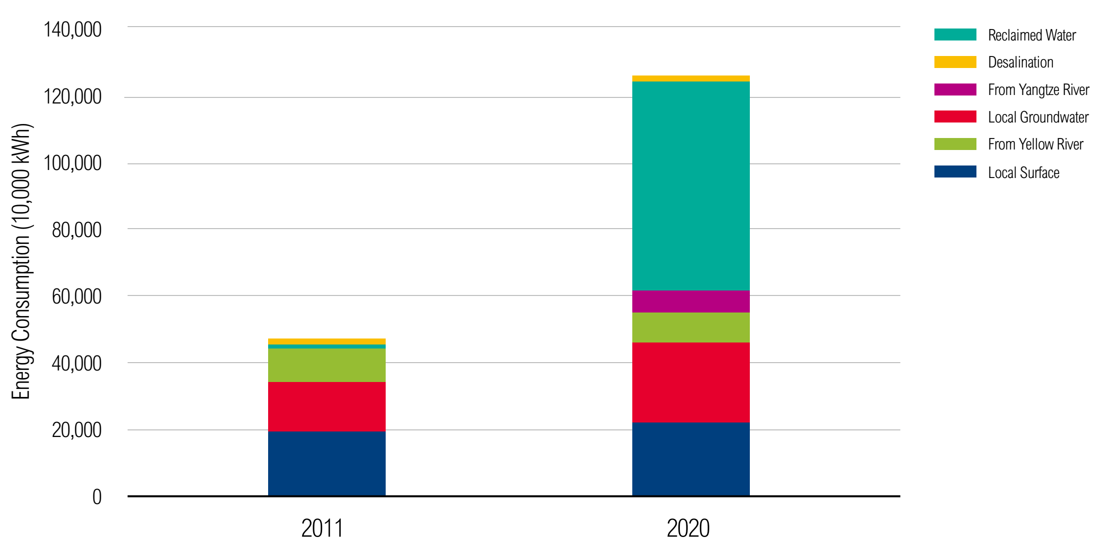
1. Priority on Seawater Desalination Scenario
Table 5-7 shows estimates of various water sources' water production energy consumption for the "Surface 35 Seawater Desalination Scenario." This table is based on the water production energy consumption of different water sources (Chapter 4), and the water sources configuration protocols under Surface 35 scenarios (Section 5.2.1).

Compared to 2011, if the surface water exploitation rate remains at 35% in 2020 and seawater desalination is prioritized, then total water production energy consumption will increase 164% to 1.24 billion kWh because seawater desalination consumes so much energy. Even though seawater desalination accounts for only 10% of the total water demand under this scenario, it consumes 49% of the energy needed for water production (see Figure 5-9).

Table 5-7 | **Water Source Structure and Energy Consumption under "Surface 35 Seawater Desalination Scenario" (2020)**

WATER SOURCE	WATER SUPPLY (100 MILLION M^3)	ENERGY CONSUMPTION (100 MILLION KWH)
Local Surface	5.60	2.39
Local Groundwater	5.50	2.20
From Yellow River	1.10	0.77
From Yangtze River	0.70	0.80
Seawater Desalination	1.53	6.12
Low-Quality Reclaimed Water	0.37	0.13
Total	14.80	12.40

Figure 5-9 | **Comparison of the Expected Changes in Qingdao's Water Production Energy Consumption ("Surface 35 Seawater Desalination Scenario")**



Water from the Yangtze River and the Yellow River enters Qingdao's municipal water withdrawal system via the Jihongtan Reservoir. Then, it is mixed with local water from Yifu Reservoir and Chanzhi Reservoir. After treatment, it is delivered to users in each service district via the municipal water distribution system. The mixing means that it is impossible to trace the ratio of transferred water from the Yellow River or the Yangtze River in each administrative division. We calculated an average energy consumption for transferred water of 0.867 kWh/m^3 based on the proportion of water transferred from the Yellow River compared to the Yangtze River.

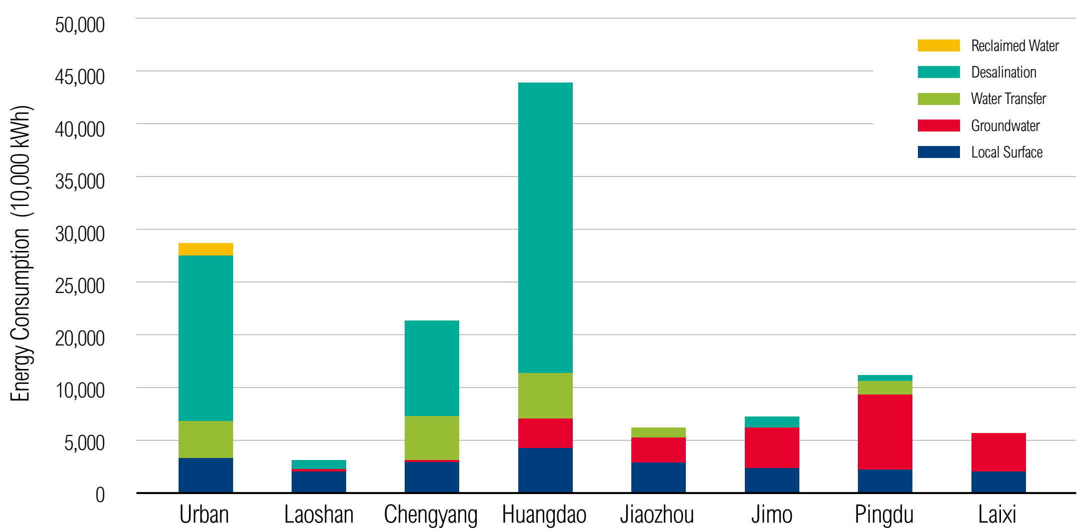
Table 5-8 below shows the water-related energy consumption of each administrative division.

By 2020, Huangdao District (previous Huangdao District combined with Jiaonan) will replace the downtown area as the area with highest water demand and highest energy consumption in Qingdao, followed by the downtown area and Chengyang District. This trend correlates with the seawater desalination capacity of each district. Seawater desalination is the main cause of Qingdao's increase in water production energy consumption (see Figure 5-10).

Table 5-8 | **Water Production Energy Consumption by District for "Surface 35 Seawater Desalination Scenario" (in 2020, in 10,000 kWh)**

ENERGY CONSUMPTION	URBAN	LAOSHAN	CHENG-YANG	HUANGDAO	JIAOZHOU	JIMO	PINGDU	LAIXI	SUBTOTAL
Local Surface	3,609	2,245	3,140	4,489	3,040	2,639	2,533	2,160	23,856
Groundwater	0	40	120	3,280	2,840	4,000	7,800	3,920	22,000
Water Transfer	3,913	0	4,771	4,771	786	0	1,388	0	15,627
Desalination	17,428	980	10,112	30,844	0	1,224	612	0	61,200
Reclaimed Water	1,314	0	0	0	0	0	0	0	1,314

Figure 5-10 | **Energy Consumption in 2020 for Water Production by District under the Surface 35 Scenario with Desalination Seawater Prioritized**



Chengyang and Huangdao will see the fastest growth in energy consumption between 2011 and 2020, mainly because of the energy required by seawater desalination facilities (Figure 5-11).

We estimate that under the desalination scenario Qingdao's water production energy consumption will reach 0.84 kWh/m³ in 2020, which is 80% higher than the 2011 baseline of 0.465 kWh/m³. The energy consumed by water production will reach 1.36 kWh/m³ in Huangdao, 1.25 kWh/m³ in the downtown area and 1.16 kWh/m³ in Chengyang District. However, water production energy consumption in Jiaozhou, Jimo, Pingdu and Laixi, where the water supply mainly depends on the local surface water and groundwater, will not change significantly from 2011 levels, and will stay between 0.41 and 0.48 kWh/m³ (Figure 5-12).

2. Energy Consumption under Surface 35 Reclaimed Water Scenario

Table 5-9 shows estimates of the water source structure and corresponding energy consumption under "Surface 35 Reclaimed Water Scenario." Under this scenario, the total energy consumed in 2020 by Qingdao's water supply will be 0.753 billion kWh, which is nearly 40% lower than the seawater desalination sub-scenario.

Between 2011 and 2020, Qingdao's total water supply will increase 47% and the total energy consumption for water production will increase 60% (Figure 5-13). The use of high-quality reclaimed water accounts for most of the growth in energy consumption. NEWater accounts for 12% of the high-quality water (and is mainly for industrial uses), while accounting for 20%

Figure 5-11 | **Trend of Change in the Water Production Energy Consumption in Each District for "Surface 35 Seawater Desalination Scenario"**

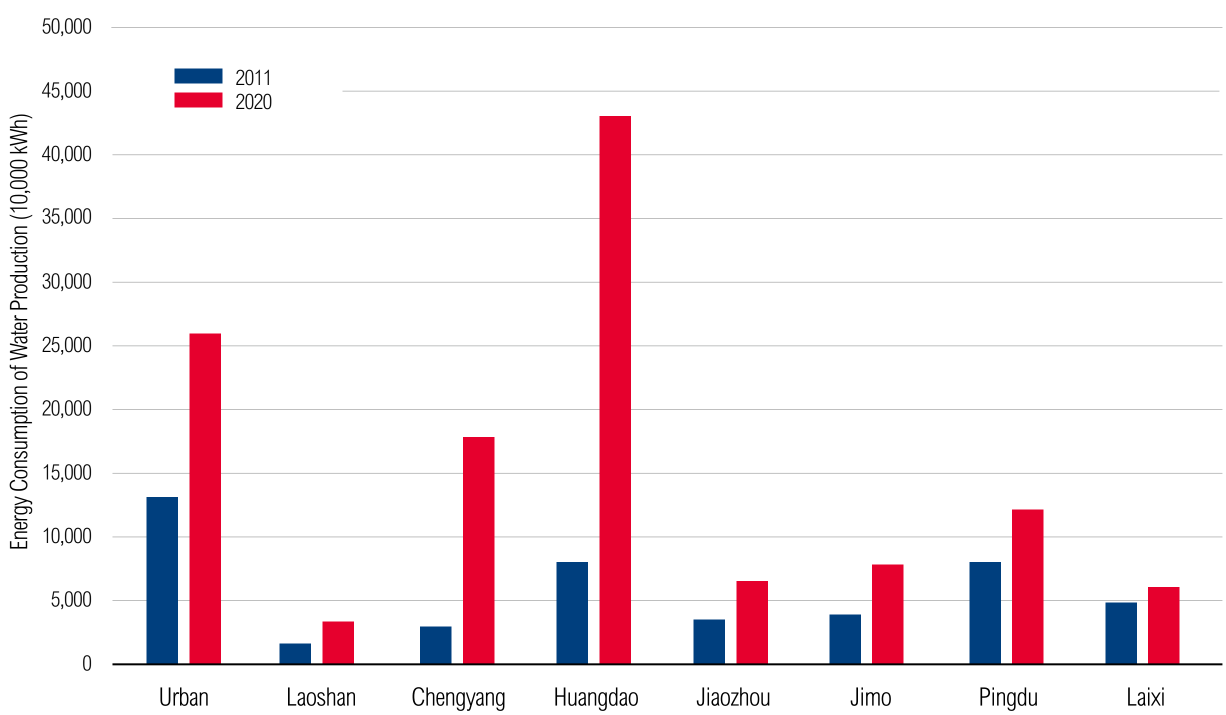


Figure 5-12 | **Water Production Energy Consumption in 2020 in Each District for "Surface 40 Seawater Desalination Scenario"**

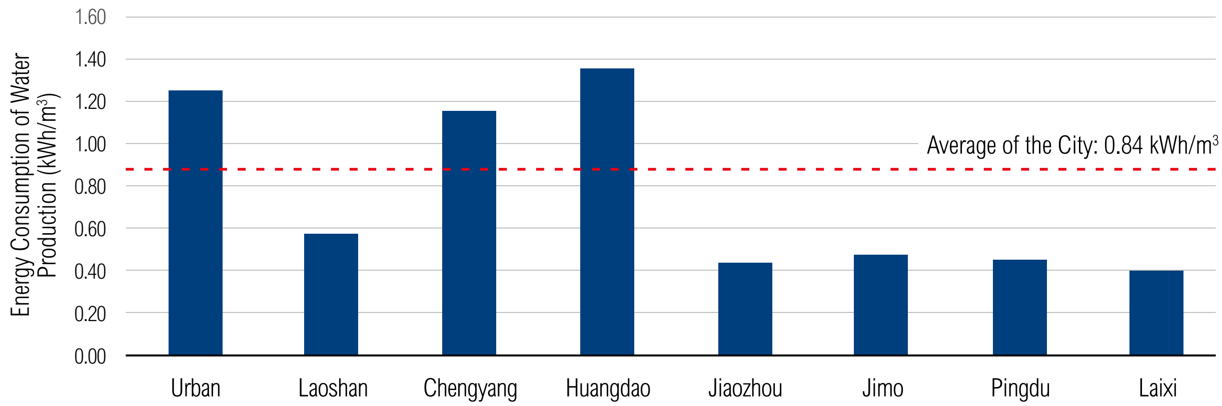
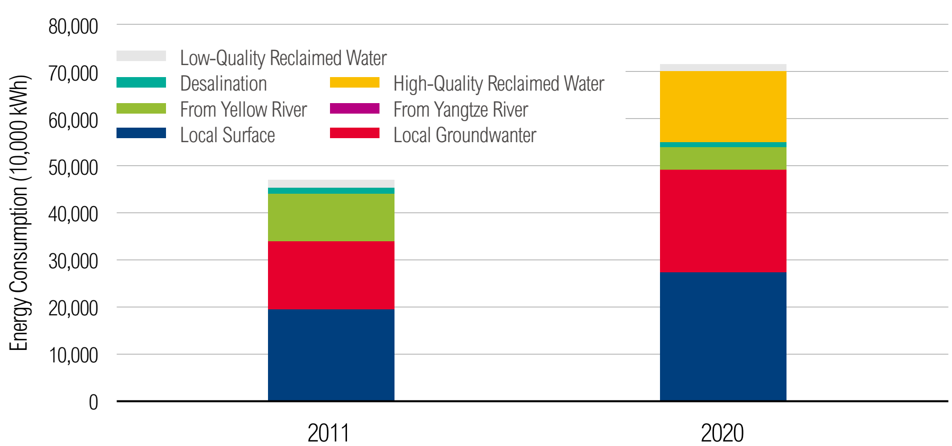


Table 5-9 | **Water Source Structure and Related Energy Consumption in 2020 for "Surface 35 Reclaimed Water Scenario"**

WATER SOURCE	WATER SUPPLY (100 MILLION M³)	ENERGY CONSUMPTION (100 MILLION KWH)
Local Surface Water	5.60	2.39
Local Groundwater	5.50	2.20
From Yellow River	1.10	0.77
From Yangtze River	0.33	0.37
Desalination	0.04	0.14
High-Quality Reclaimed Water (NEWater)	1.87	1.53
Low-Quality Reclaimed Water	0.37	0.13
Total	14.80	7.53

Figure 5-13 | **Comparison of Water Production Energy Consumption for the "Surface 35 Reclaimed Water Scenario"**



of the total energy consumption of Qingdao's water supply system.

Table 5-10 shows the water production energy consumption of each administrative division.

In this scenario, Huangdao has the largest energy consumption from water production, followed by the downtown area (Figure 5-14). This is because the new Huangdao District will have the highest water demand in Qingdao, and also because the energy consumed by producing water from unconventional sources is higher than from local sources.

Figure 5-15 shows that the water production energy consumption of all districts except for the downtown area, Chengyang and Huangdao are lower than the city's average, with only small variations between 0.44 and 0.48 kWh/m³. In the downtown area, the energy consumed by water production is 0.65 kWh/m³, which is higher than the city's average of 0.51 kWh/m³. That is because all the current seawater desalination facilities in Qingdao are concentrated in the downtown area.

Table 5-10 | **Water Production Energy Consumption by District under "Surface 35 Reclaimed Water Scenario" (in 2020, 10,000 kWh)**

WATER SOURCE	URBAN	LAO-SHAN	CHENG-YANG	HUANG-DAO	JIAO-ZHOU	JIMO	PING-DU	LAIXI	TOTAL
Local Surface Water	3,042	2,264	4,572	6,645	2,574	1,917	1,533	1,308	75,271
Groundwater	0	46	141	3,160	2,840	3,800	7,800	4,213	
Water Transfer	7,968	0	1,328	797	0	0	1,275	0	
Desalination	800	0	0	600	0	0	0	0	
Reclaimed Water	1,314	0	0	0	0	0	0	0	
High-Quality Reclaimed Water	0	164	2,460	5,740	1,640	1,640	2,050	1,640	

Figure 5-14 | **Water Production Energy Consumption in 2020 by District for "Surface 35 Reclaimed Water Scenario"**

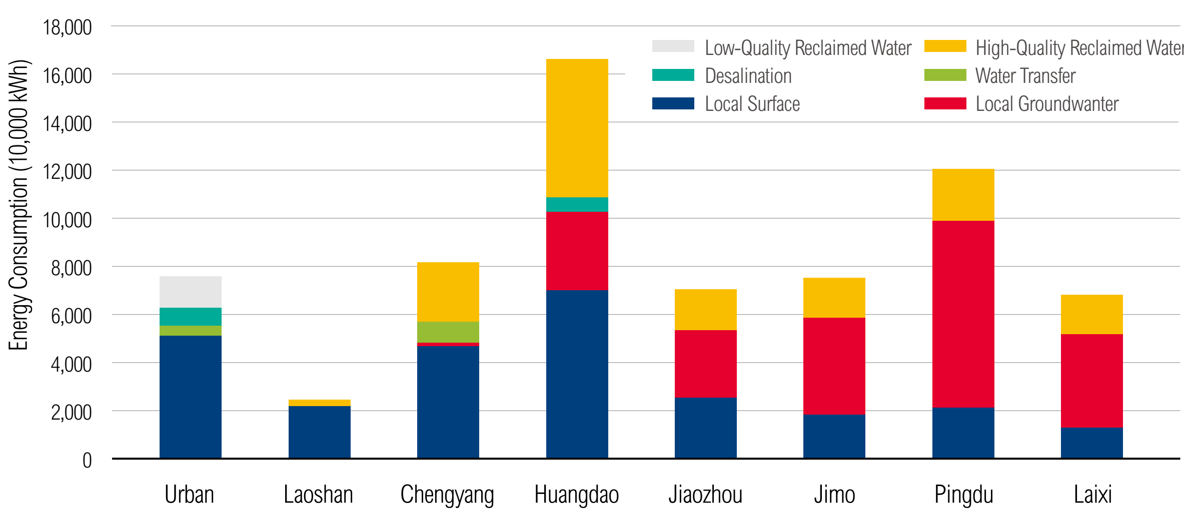


Figure 5-15 | **Water Production Energy Consumption by District in 2020 for "Surface 35 Reclaimed Water Scenario."**

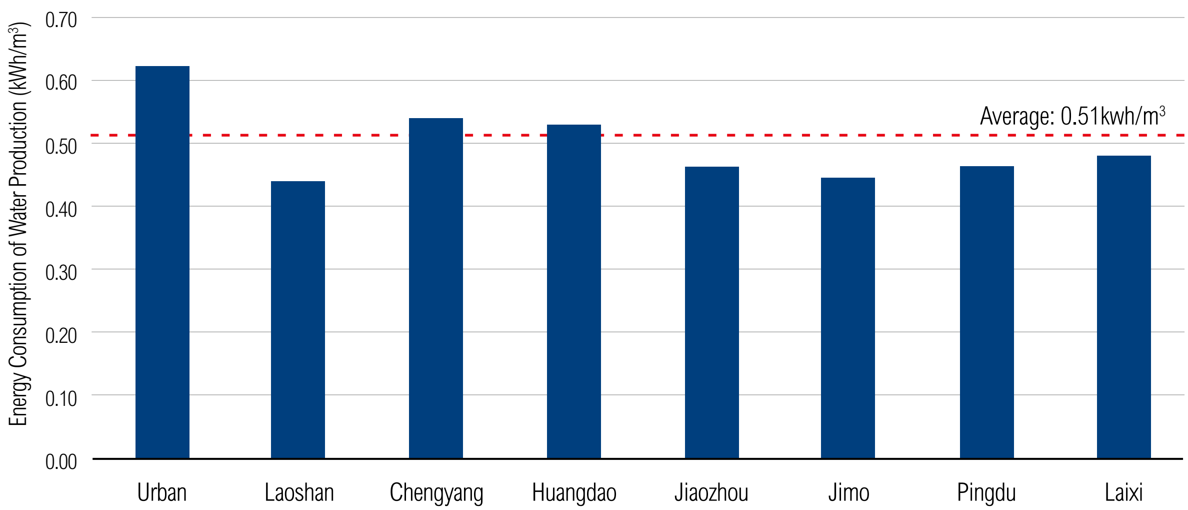


Table 5-11 | **Water Source Structure and Related Energy Consumption in 2020 for "Surface 35 Transferred Water Scenario."**

WATER SOURCE	WATER SUPPLY (100 MILLION M³)	ENERGY CONSUMPTION (100 MILLION KWH)
Local Surface Water	5.60	2.39
Local Groundwater	5.50	2.20
From Yellow River	1.10	0.77
From Yangtze River	2.20	2.50
Seawater Desalination	0.04	0.14
Low-Quality Reclaimed Water	0.37	0.13
Total	14.80	8.12

3. Energy Consumption under "Surface 35 Transferred Water Scenario"

Table 5-11 shows the water source structure and related energy consumption for this scenario.

In this scenario, Qingdao will receive nearly 0.33 billion m³/year of transferred water in 2020. Because of Yellow River supply pressures and lower guarantee rates, water transfers from there will be maintained at about 110 million m³ of water. Meanwhile 0.22 billion m³ will be transferred from the Yangtze River. The energy consumed by Qingdao's water supply system in 2020 will therefore be 0.812 billion kWh per year, 34.5% less than that for the seawater desalination sub-scenario, but still 8% higher than the reclaimed water sub-scenario.

Between 2011 and 2020, Qingdao's total water production energy consumption will increase 73% under the "Surface 35 Transferred Water Scenario." The growth mainly results from the water diversion from the Yangtze River, which will account for 15% of the water supply and 31% of the water production energy consumption (Figure 5-16).

Table 5-12 below shows the water production energy consumption by district.

The energy consumed by transferring water from the Yangtze River is relatively high at 1.136 kWh/m³. That is even higher than the energy needed to produce NEWater from wastewater (0.82 kWh/m³). Therefore, transferring significant amounts of water from the Yangtze River will increase water production energy consumption in some areas. The downtown area, Huangdao and Chengyang are the main users of transferred water from the Yangtze River, so the energy consumed by their water supplies will be the highest in the city (Figure 5-17, Figure 5-18).

Figure 5-16 | **Comparison of Water Production Energy Consumption in Qingdao ("Surface 35 Transferred Water Scenario")**

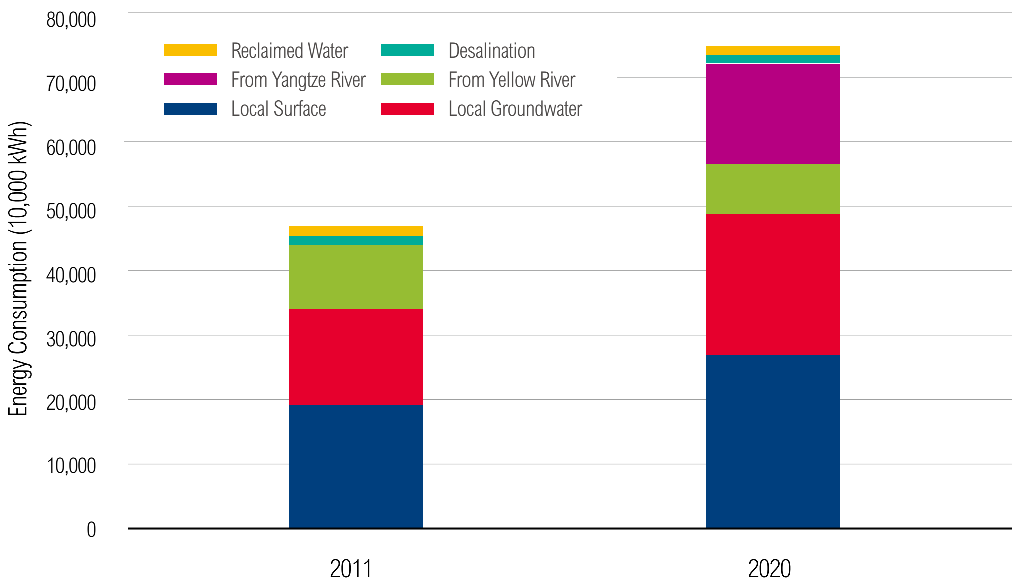


Table 5-12 | **Water Production Energy Consumption in 2020 by District for "Surface 35 Transferred Water Scenario" (in 10,000 kWh)**

WATER SOURCE	URBAN	LAO-SHAN	CHENG-YANG	HUANG-DAO	JIAO-ZHOU	JIMO	PING-DU	LAIXI	TOTAL
Local Surface Water	3,042	2,350	2,300	5,793	2,844	2,769	2,598	2,160	81,180
Groundwater	0	40	120	3,280	2,840	4,000	7,800	3,920	
Water Transfer	9,892	0	9,892	9,892	1,352	0	1,583	0	
Desalination	800	0	0	600	0	0	0	0	
Reclaimed Water	1,314	0	0	0	0	0	0	0	
Subtotal	15,047	2,390	12,312	19,565	7,036	6,769	11,981	6,080	

Figure 5-17 | **Water Production Energy Consumption by District in 2020 for "Surface 35 Transferred Water Scenario"**

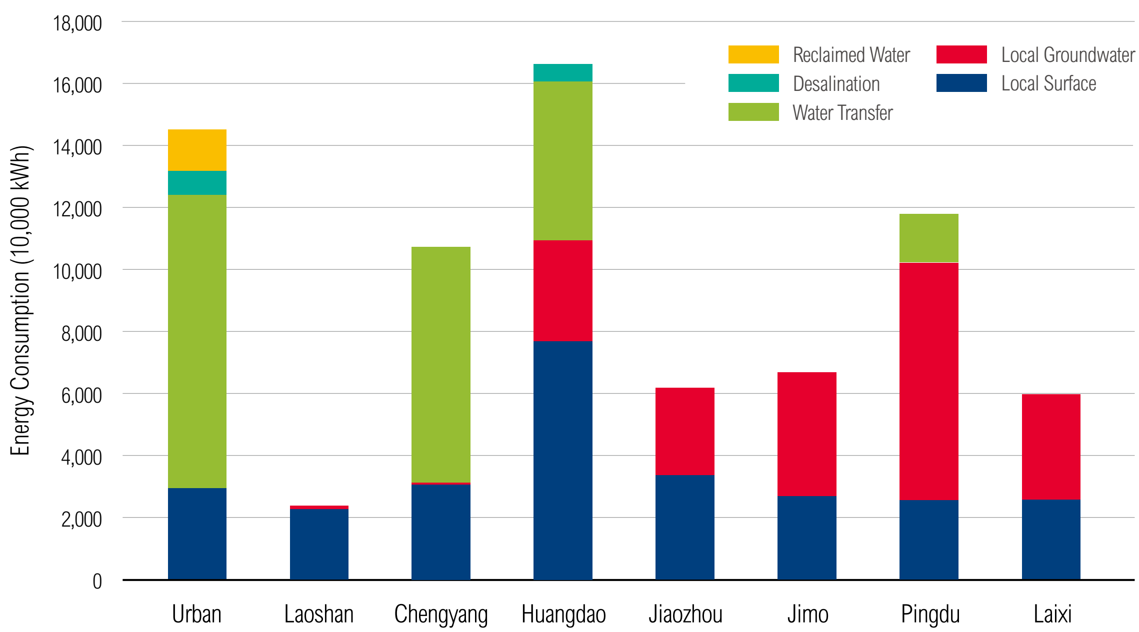
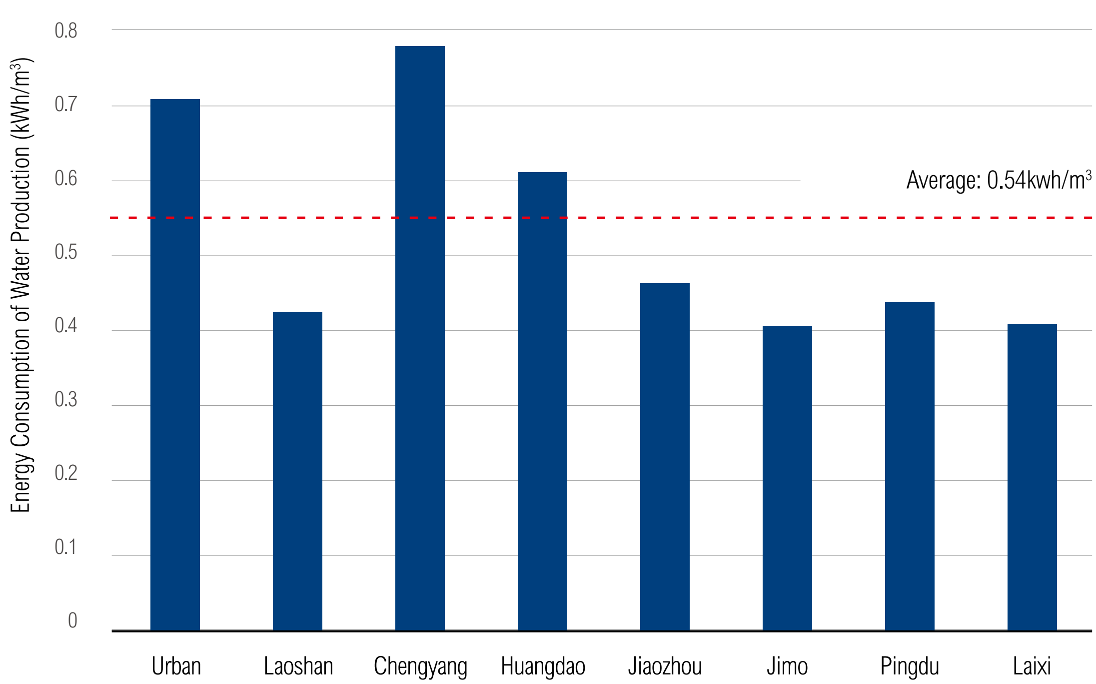


Figure 5-18 | **Water Production Energy Consumption by District in 2020 for "Surface 35 Transferred Water Scenario"**



5.3.2 Comparison of Water Production Energy Consumption under Various Surface 35 Scenarios

The total energy consumed by Qingdao's water supply in 2020 will increase significantly in all three sub-scenarios because of the growth of water supplies. The sub-scenario prioritizing reclaimed water will have the lowest increase in energy use, water diversion will have a middle amount, and seawater desalination will have the highest (Figure 5-19).

Figure 5-20 shows the water production energy consumption of each administrative district.

In all sub-scenarios, the areas with the highest water demand (namely, the downtown area, Chengyang and Huangdao, which together account for 46% of the city's total water demand), also consume the most energy for water production. Together, the three districts make up 51% of city's total water production energy consumption under the reclaimed water sub-scenario, 58% under the water diversion sub-scenario and 71% under the seawater desalination sub-scenario.

Local water resources are limited in the downtown area, Chengyang and Huangdao, so these areas will increasingly depend on transferred water or other unconventional water resources. They will also be more sensitive to changes in energy consumed by water production. Since other regions in Qingdao depend more on local surface water and groundwater, energy consumption will mainly be determined by water amount rather than different scenario settings.

Unit water production energy consumption has a similar trend to total energy consumption, with the reclaimed water sub-scenario consuming the least, the water diversion sub-scenario in the middle, and seawater desalination consuming the most. In 2011, Qingdao still relied mainly on local surface water and groundwater, so energy consumption was relatively low. But local water will not be able to meet the water demands of urban development in 2020, so Qingdao will have to use unconventional sources (reclaimed water and desalinated seawater), as well as transferred water. This will lead to an increase in energy consumed for water production.

However, as Figure 5-21 shows, development of reclaimed water will cause much less growth in the system's energy consumption.

5.3.3 Predictions of Carbon Emissions under Surface 35 Basic Scenarios

Figure 5-22 compares GHG emissions for each sub-scenario of Surface 35 (prioritizing seawater desalination, reclaimed water and water diversion).

Under the scenario prioritizing seawater desalination, water production will cause 1.0968 million tons of carbon dioxide emissions, which is 2.64

Figure 5-19 | **Comparison of the Energy Consumption in 2020 for Different Surface 35 Scenarios**

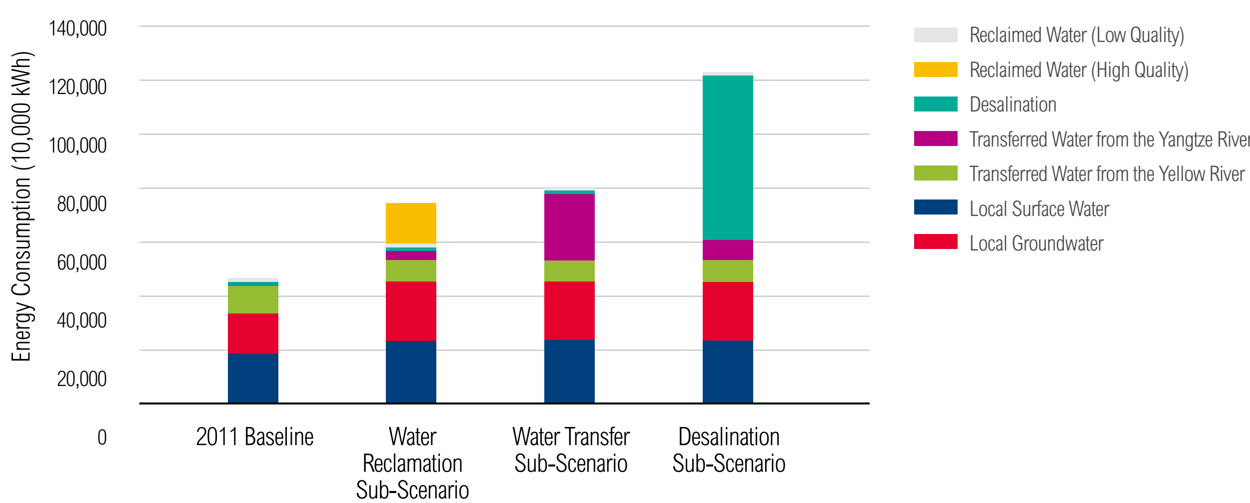


Figure 5-20 | **Water Production Energy Consumption by District in 2020 for Each Surface 35 Sub-Scenario**

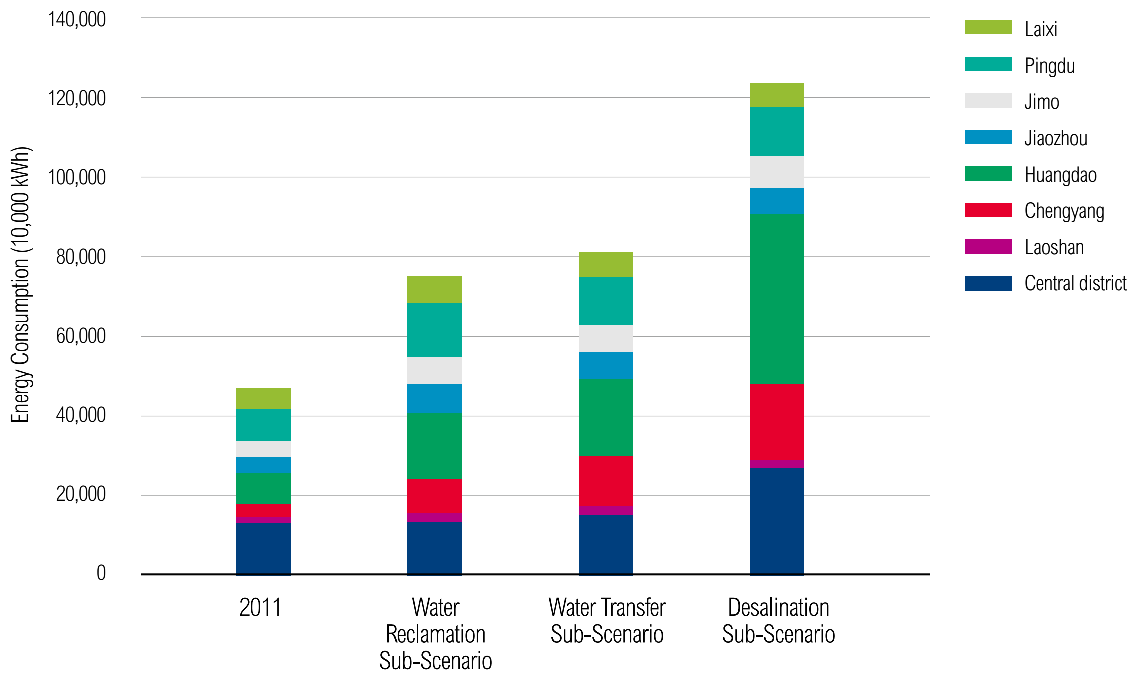


Figure 5-21 | **Comparison of Unit Water Production Energy Consumption in Each District in Each of the Surface 35 Sub-Scenarios**

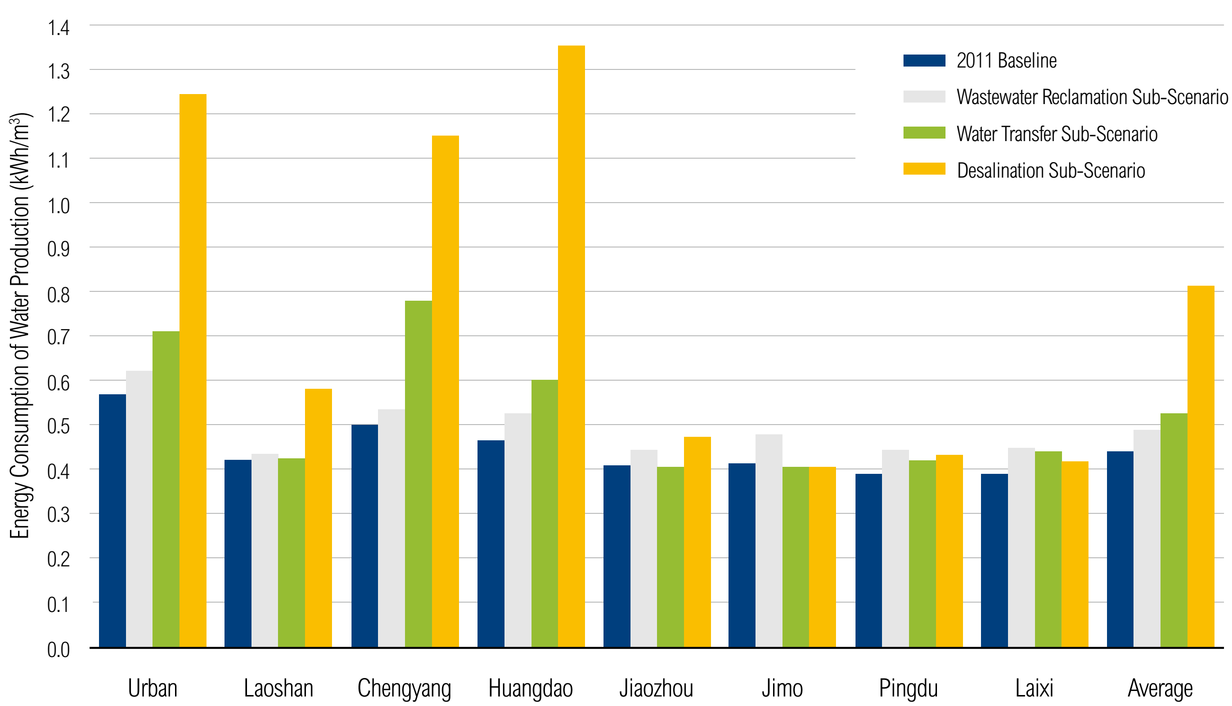
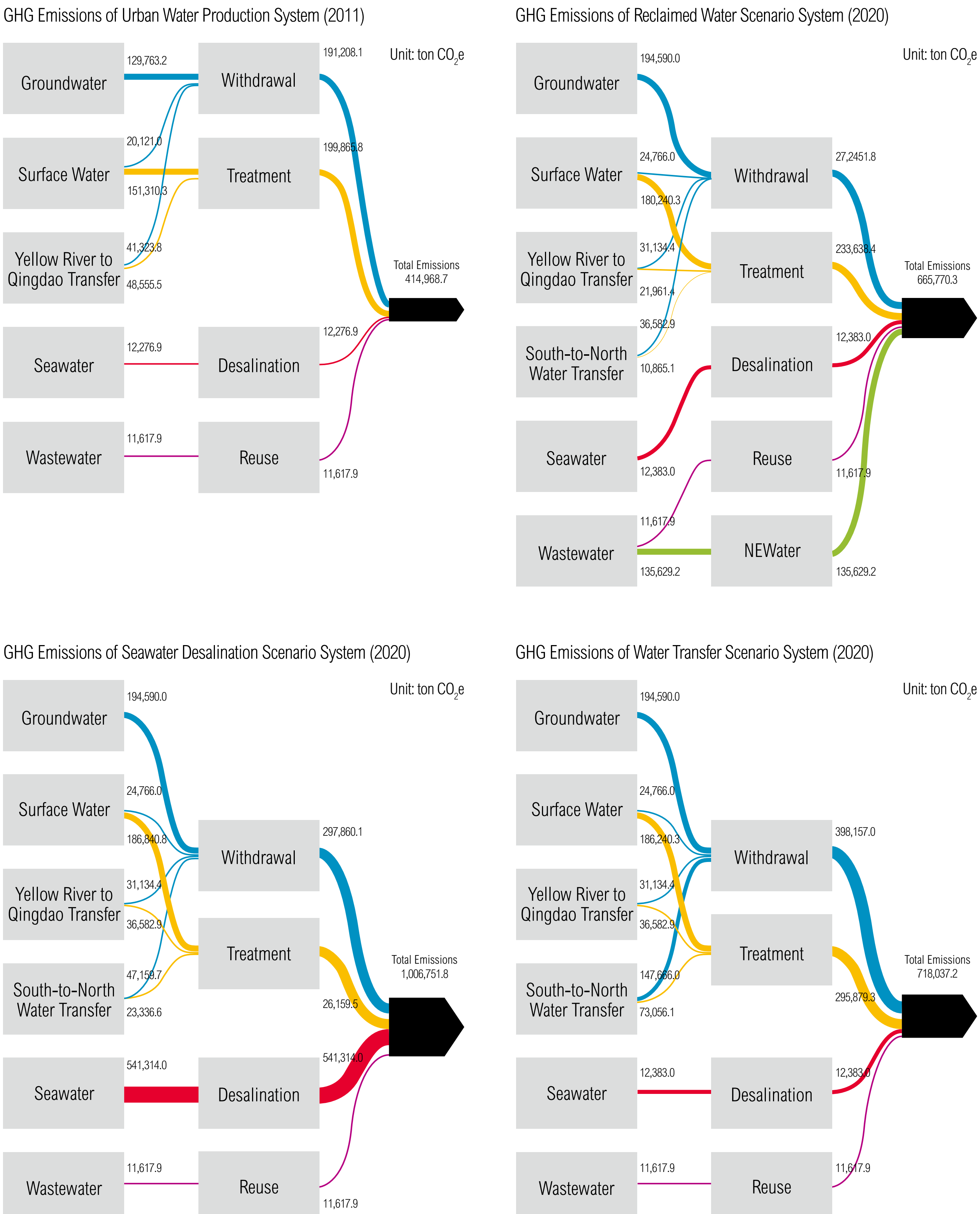


Figure 5-22 | **Comparison of GHG Emissions from Qingdao's Water Production for Surface 35 Scenarios in 2011 and 2020**



times of that in 2011. The water intake of conventional sources generates 297,700 tons of emissions (27% of the total), while the other production processes generate 226,200 tons (22% of the total). Seawater desalination generates 541,300 tons of carbon emissions (49% of the total).

Under the scenario prioritizing reclaimed water, carbon dioxide emissions from water production increase 60% between 2011 and 2020, reaching 665,800 tons. Carbon emissions from conventional water intake account for 41% of the total (272,500 tons), while conventional water production accounts for 35% (233,700 tons) and high-quality reclaimed water (NEWater) production accounts for 20% (135,600 tons).

Under the scenario prioritizing water diversion, carbon dioxide emissions from Qingdao's water production in 2020 will be 718,000 tons, which is 73% higher than 2011. Conventional water intake will account for 55% of that (398,200 tons), while other related production processes will account for 41% (295,900 tons).

Compared to 2011, GHG emissions in all three sub-scenarios will increase, mainly because of the growth of water supply. The sub-scenario prioritizing seawater desalination will have the largest growth, followed by the sub-scenario prioritizing water diversion. GHG emissions under the sub-scenario prioritizing use of reclaimed water are the lowest.

GHG emissions from Qingdao's water system for the sub-scenario prioritizing reclaimed water are 8% lower than the sub-scenario prioritizing water diversion, and 40% lower than the sub-scenario prioritizing seawater desalination.

Meanwhile, the analysis on carbon emissions of unit water production shows that Qingdao's water system has the lowest carbon footprint under the scenario prioritizing reclaimed water (high-quality), at 0.45 kg $CO2\ /m^3$ per ton of water produced. Therefore, using more reclaimed water can reduce the carbon emissions of the water system (Figure 5-23).

5.4 Analysis of Qingdao's Water Production Energy Consumption under Surface 40 Scenarios in 2020

5.4.1 Water Production Energy Consumption under Surface 40 Basic Scenarios

We conducted similar analyses on Surface 40 scenarios, calculating the water production energy consumption of each administrative division under sub-scenarios prioritizing seawater desalination, wastewater reclamation and water diversion (Figure 5-24). Differences in water endowment and available water resources resulted in different levels of water

Figure 5-23 | **Unit Water Production Carbon Emissions for Surface 35 Scenarios (in 2020)**

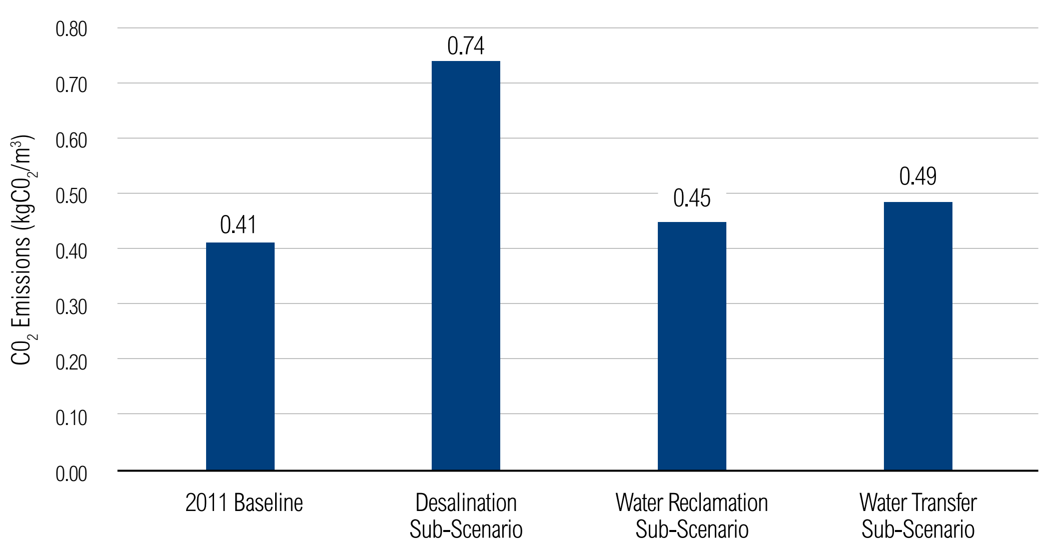
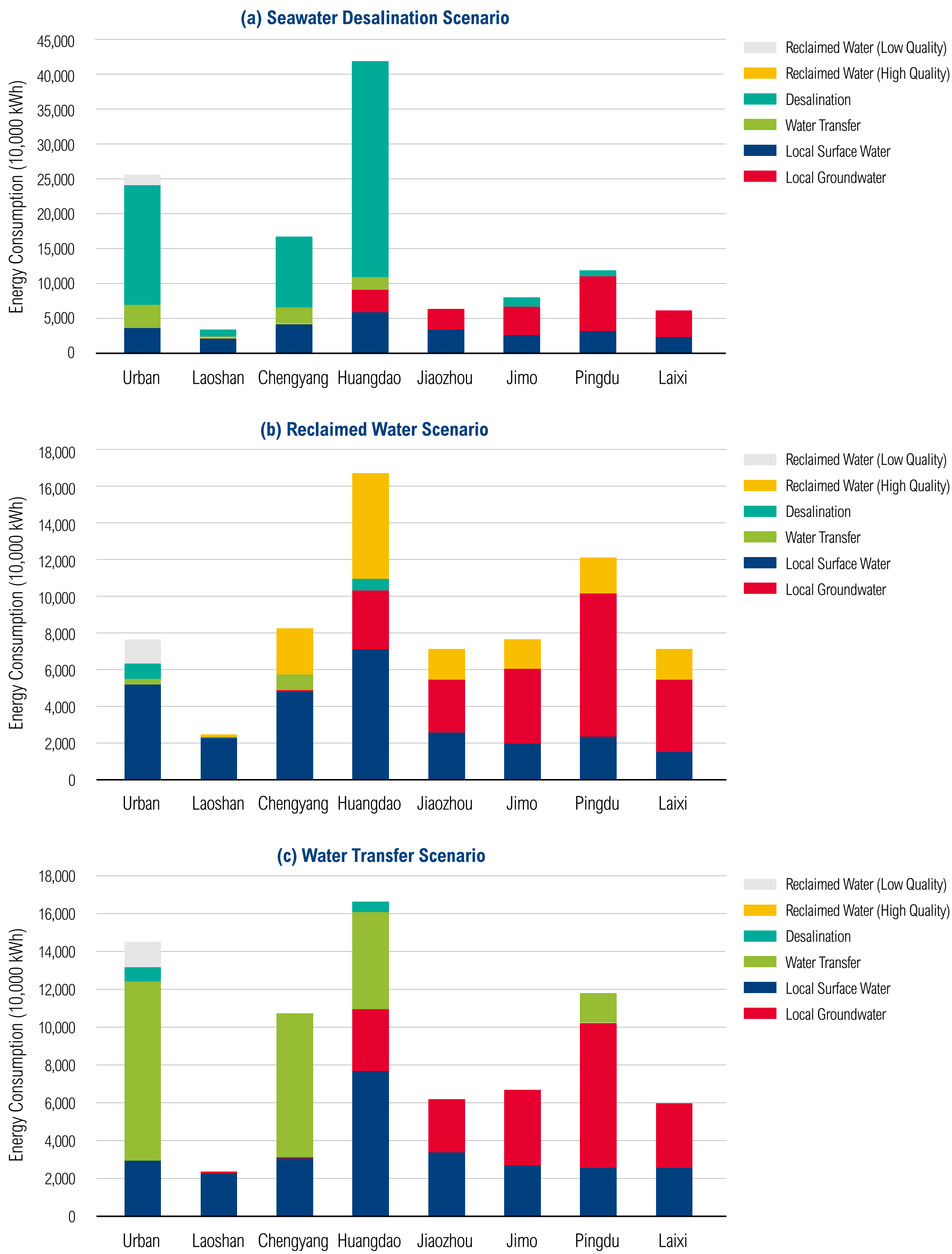


Figure 5-24 | **Analysis of Water Production Energy Consumption in 2020 by District under Different Surface 40 Scenarios**



production energy consumption for different scenarios. In general, the downtown area, Chengyang and Huangdao benefit the most from water diversions and other high energy consuming unconventional water sources, resulting in significant differences in energy consumption between sub-scenarios. Meanwhile, the other four districts rely largely on local water sources, and thus have relatively low and stable energy consumption.

Under all three sub-scenarios, the water production energy consumption in the new Huangdao District is the highest, especially under the scenario prioritizing seawater desalination, since the area is home to nearly 60% of the city's new seawater desalination capacity. In the end, the area contributes the most to the city's growth in energy consumed by water production.

Figure 5-25 shows unit water production energy consumption by district in all sub-scenarios. For all three, the downtown area, Huangdao and Chengyang have higher unit water production energy consumption than the city's average. Unit water production

Figure 5-25 | **Analysis of Unit Water Production Energy Consumption by District in 2020 under Different Surface 40 Scenarios**

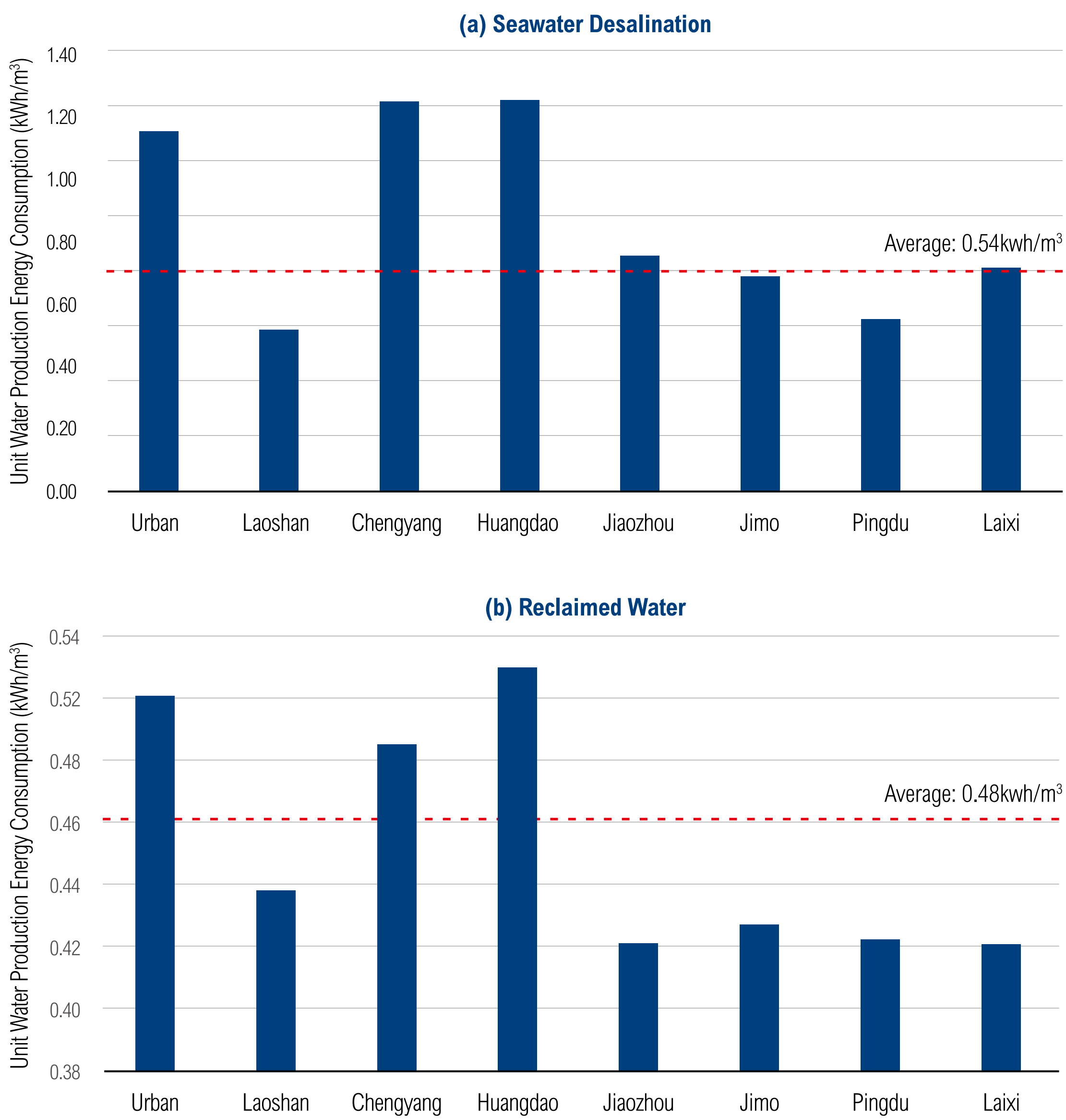
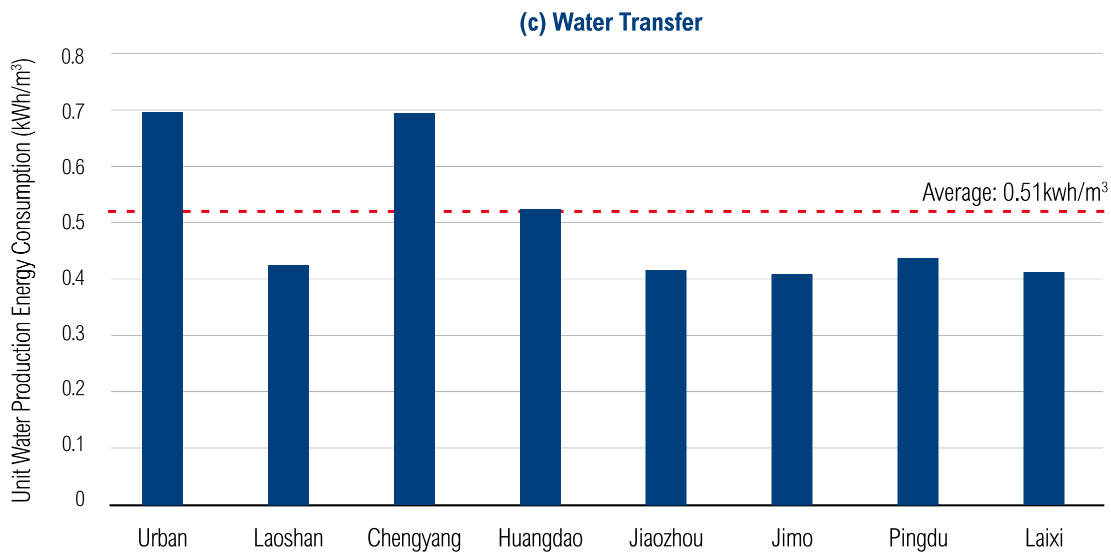


Figure 5-25 | **Analysis of Water Production Energy Consumption by District in 2020 under Different Surface 40 Scenarios (continued)**



energy consumption is directly proportional to the amount of transferred water and other unconventional water resources used. Huangdao District has the highest unit water production energy consumption under the sub-scenario prioritizing seawater desalination, while Huangdao and Chengyang have the highest under the sub-scenario prioritizing reclaimed water. The downtown area has the highest unit water production energy consumption under the scenario prioritizing transferred water, because it depends the most on transferred water.

Overall, unit water production energy consumption in Qingdao is the highest under the scenario prioritizing seawater desalination and the lowest (40% lower) under the scenario prioritizing reclaimed water.

5.4.2 Comparison of the Water Production Energy Consumption for Surface 40 Scenarios

Assuming that water demand rises to 1.48 billion m^3 by 2020 (47% higher than in 2011), energy consumption will rise the least under the sub-scenario prioritizing reclaimed water, with an increase of 53%. The other two sub-scenarios see greater increases in energy consumption: the sub-scenario prioritizing transferred water rises 61% and the sub-scenario prioritizing seawater desalination rises 153% (Figure 5-26).

Figure 5-27 shows that regardless of whether Qingdao prioritizes transferred water or other unconventional water resources, water production energy consumption will increase by 2020. Seawater desalination has the biggest impact on water production energy consumption. Under the sub-scenario prioritizing seawater desalination, the city's average water production energy consumption will increase 72.5% between 2011 and 2020. Energy consumption is less impacted under the sub-scenarios prioritizing reclaimed water utilization (4.1% increase) and transferred water (9.7% increase).

Figure 5-27 also shows that unit water production energy consumption in some areas will rise significantly if seawater desalination is used. If Huangdao and Chengyang, for example, develop the planned seawater desalination capacity by 2020, they will consume 2 to 2.5 times the amount of energy they would consume if they had pursued reclaimed or transferred water instead.

Using diverted water and reclaimed water has a smaller impact on the system's energy consumption. High-quality reclaimed water is the same quality as desalinated seawater, and it has cost advantages. Exploring local water sources and utilizing reclaimed water would be the two best ways to secure Qingdao's water supply.

Figure 5-26 | **Comparison of Water Production Energy Consumption for Different Surface 40 Scenarios**

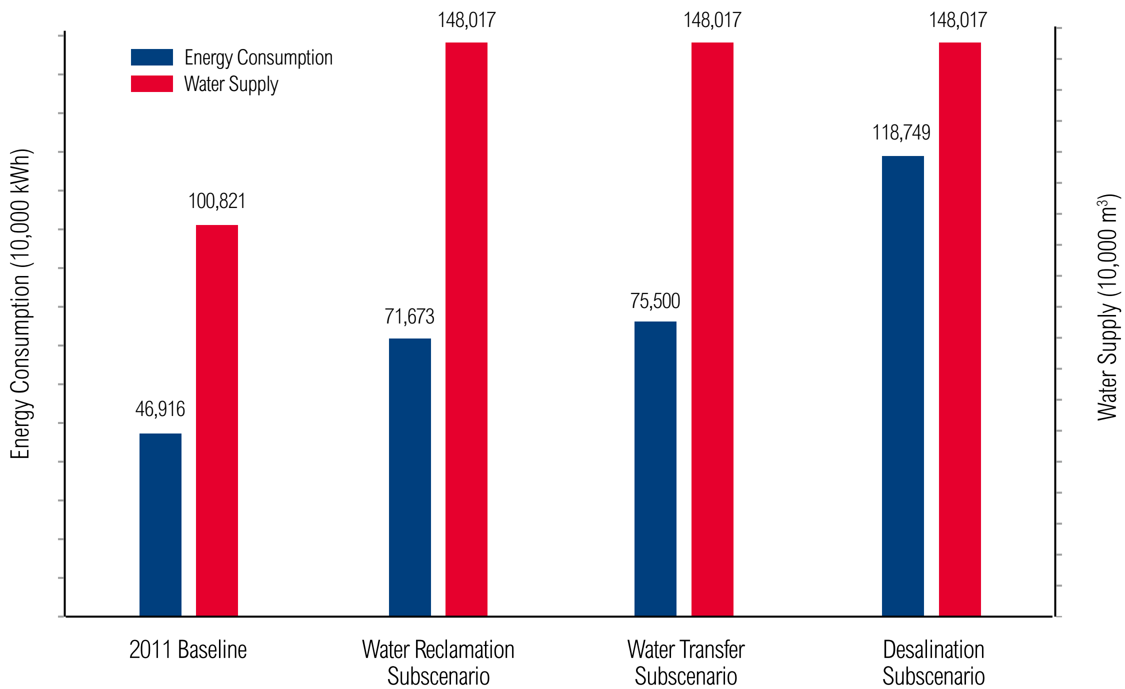


Figure 5-27 | **Comparison of Unit Water Supply Energy Consumption under Different Surface 40 Scenarios**

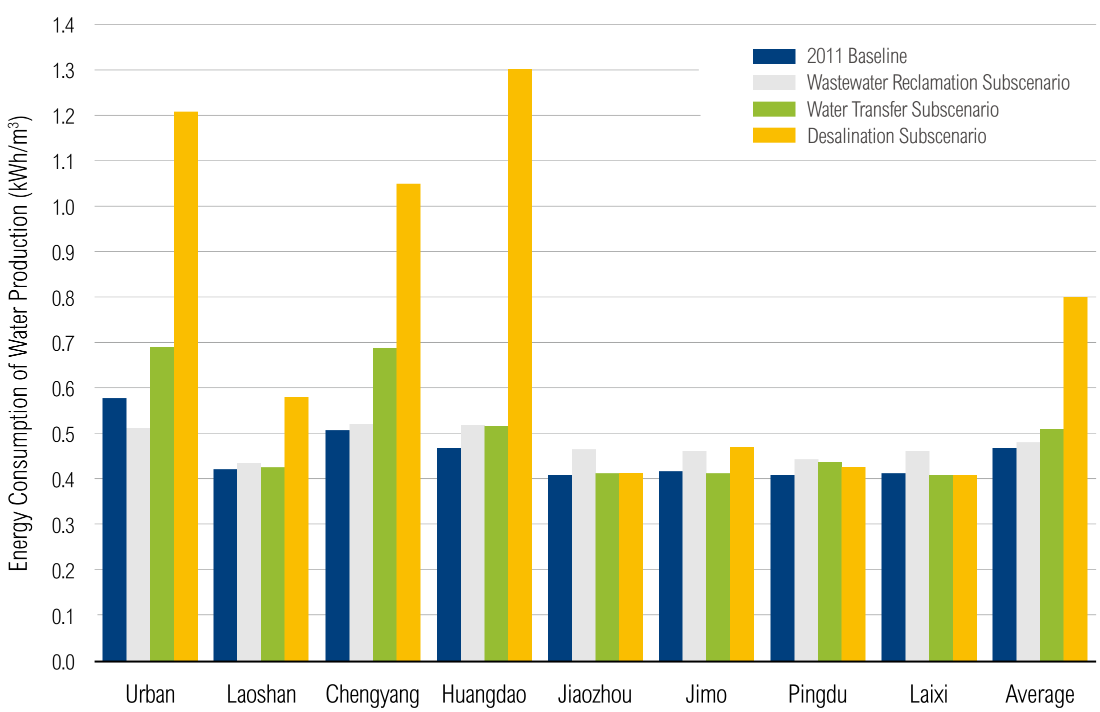
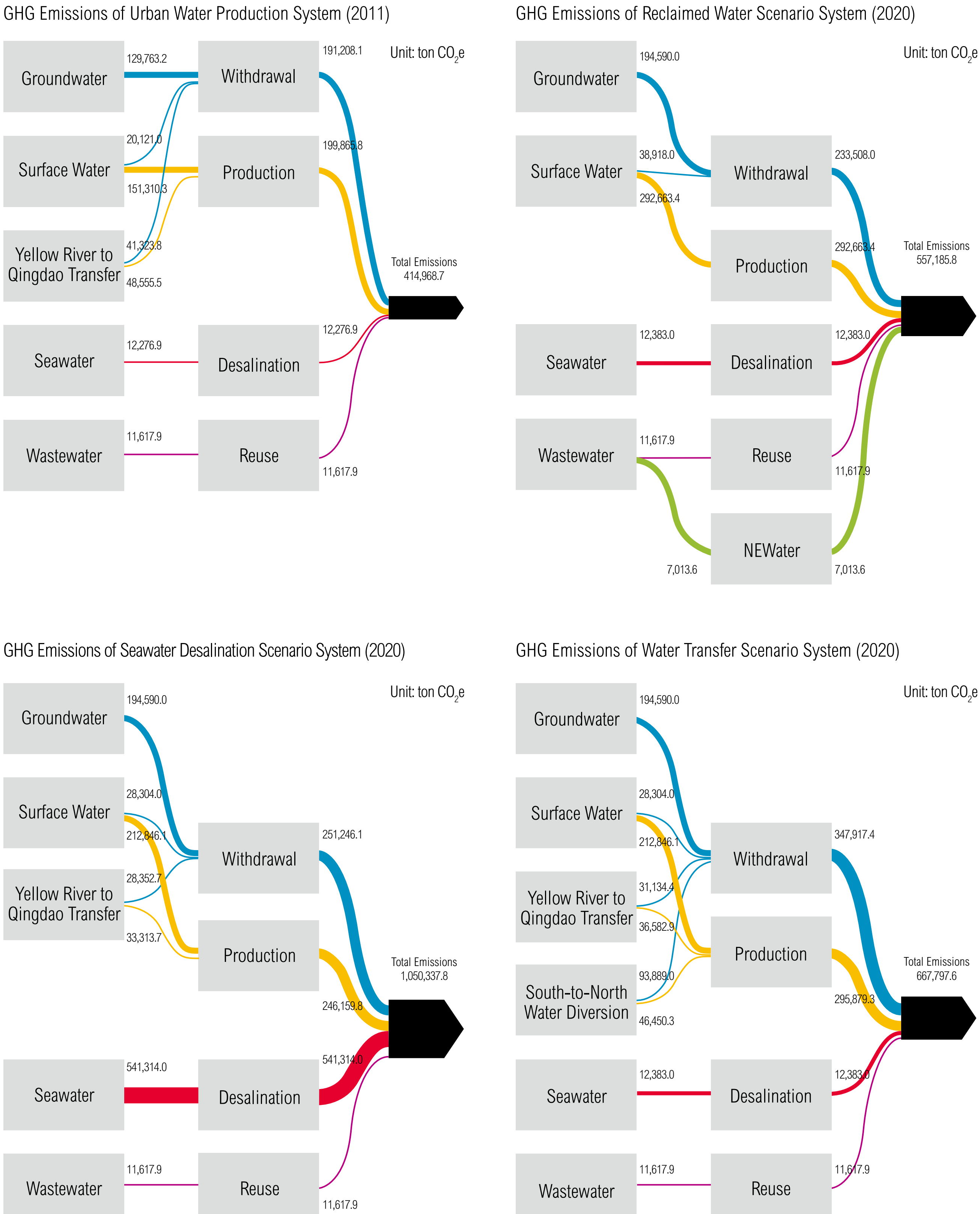


Figure 5-28 | **Comparison of 2011 and 2020 GHG Emissions from Water Production Processes for Surface 40 Scenarios**



5.4.3 Carbon Emissions for Surface 40 Basic Scenarios

Figure 5-28 shows a comparison of GHG emissions in three sub-scenarios of Surface 40 (seawater desalination, reclaimed water utilization and water diversion) from 2011 to 2020.

Water production processes for the Surface 40 sub-scenario prioritizing seawater desalination will result in 1.05 million tons of CO2 emissions, which is 2.53 times higher than in 2011. Of that, water intake will account for 24% (251,200 tons) and related water production processes from conventional sources will account for 23% (246,200 tons). Seawater desalination will account for 52% (541,300 tons).

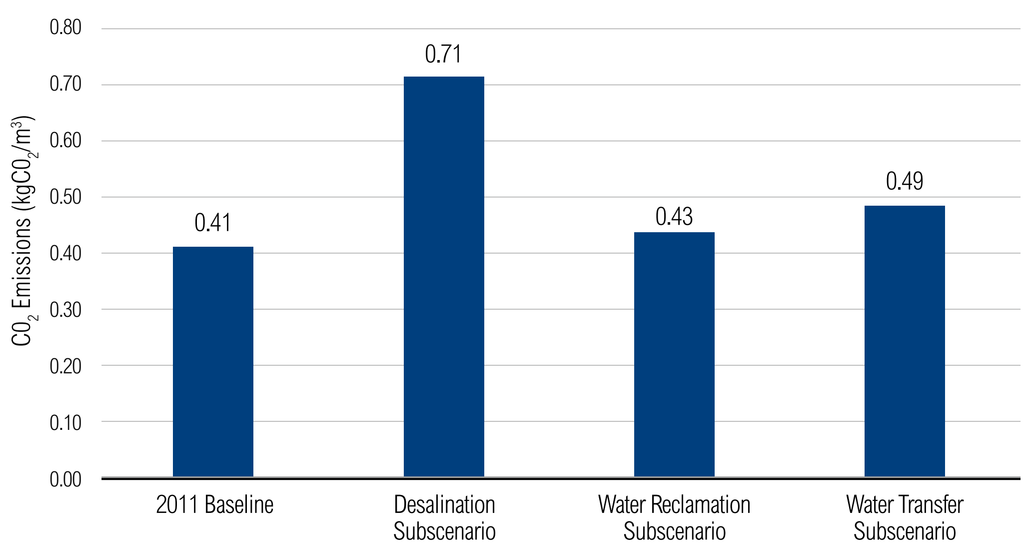
The Surface 40 sub-scenario prioritizing reclaimed water will result in 634,000 tons of CO2 emissions in 2020, 53% more than in 2011. Conventional water intake will account for 38% of that (240,600 tons), production of reclaimed water (NEWater) will account for 37% (233,700 tons) and use of reclaimed water (NEWater) will account for 21% (135,600 tons).

In the Surface 40 sub-scenario prioritizing transferred water, Qingdao's water production energy consumption will increase 61% between 2011 and 2020, to 667,800 tons. Water intake accounts for 52% (348,000 tons) of total carbon emissions and related production processes from conventional water sources account for 44% (295,900 tons) of total emissions.

In conclusion, when Qingdao's 2020 surface water utilization rate reaches 40%, then prioritizing reclaimed water will result in the lowest levels of carbon emissions. Those emissions are 40% lower than if seawater desalination is prioritized, and 5% lower than if water diversion is prioritized. Additionally, prioritizing seawater desalination results in the highest growth of carbon emissions.

We found similar results on unit water production carbon emissions in the Surface 35 scenarios: the sub-scenario prioritizing seawater desalination resulted in the most carbon emissions, while sub-scenarios prioritizing reclaimed water and transferred water resulted in lower emissions (Figure 5-29).

Figure 5-29 | **Unit Water Production Carbon Emissions in 2020 for Surface 40 Scenarios**



5.5 Analysis of Qingdao's Water Production Energy Consumption for Surface 55 Basic Scenarios in 2020

5.5.1 Water Production Energy Consumption for Surface 55 Scenarios

If Qingdao raises the local surface water utilization rate to 55% by 2020, then, based on demand projections, local surface and groundwater will supply 1.43 billion m^3, which is only 50 million m^3 short of the total water demand of 1.48 billion m^3. That means Qingdao will have no need to transfer water from other regions if the city prioritizes using seawater desalination or reclaimed water. If the city prioritizes water diversion, it will still only need to divert 9.7 million m^3 of water from the Yellow River. Since local surface water has the lowest water production energy consumption among all Qingdao's available sources, all three surface 55 sub-scenarios will result in lower water production energy consumption than the aforementioned scenarios in all districts.

Figure 5-30 shows water production energy consumption for each administrative division for Surface 55 sub-scenarios. Since nearly 96% of the city's water is supplied by local surface water or groundwater in the sub-scenarios, water diversion and use of unconventional water resources have little impact on the whole system. The energy consumed by water production is directly proportional to the amount of water supplied. Under all three sub-scenarios, Huangdao has the highest energy consumption. Under the scenario prioritizing seawater desalination, the downtown area follows Huangdao and has the second largest water production energy consumption. The downtown area uses a large amount of desalinated seawater, while other areas, such Pingdu, mainly depend on local water resources. In contrast, Pingdu has the second highest water production energy consumption under the two sub-scenarios prioritizing reclaimed water and diverted water (higher than the downtown area).

Figure 5-31 shows unit water production energy consumption by district under all three sub-scenarios. Using local surface water will actually help Qingdao lower the average unit water production energy consumption, though different sub-scenarios will make it decrease by different amounts. The sub-scenario prioritizing seawater desalination will make it drop 4%, the sub-scenario prioritizing reclaimed water 8% and transferred

Figure 5-30 | **Analysis of Water Production Energy Consumption by District in Different Surface 55 Scenarios**

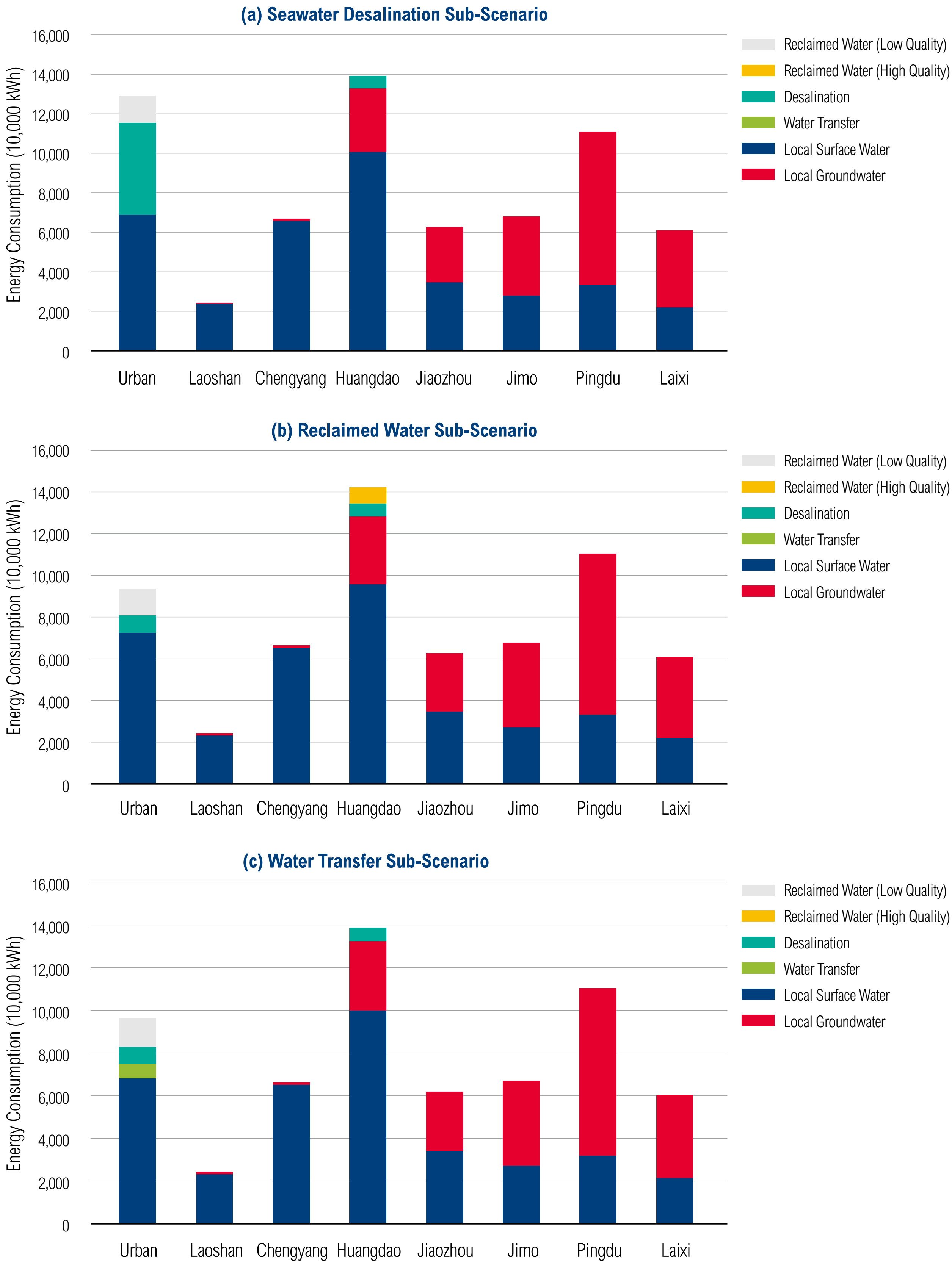
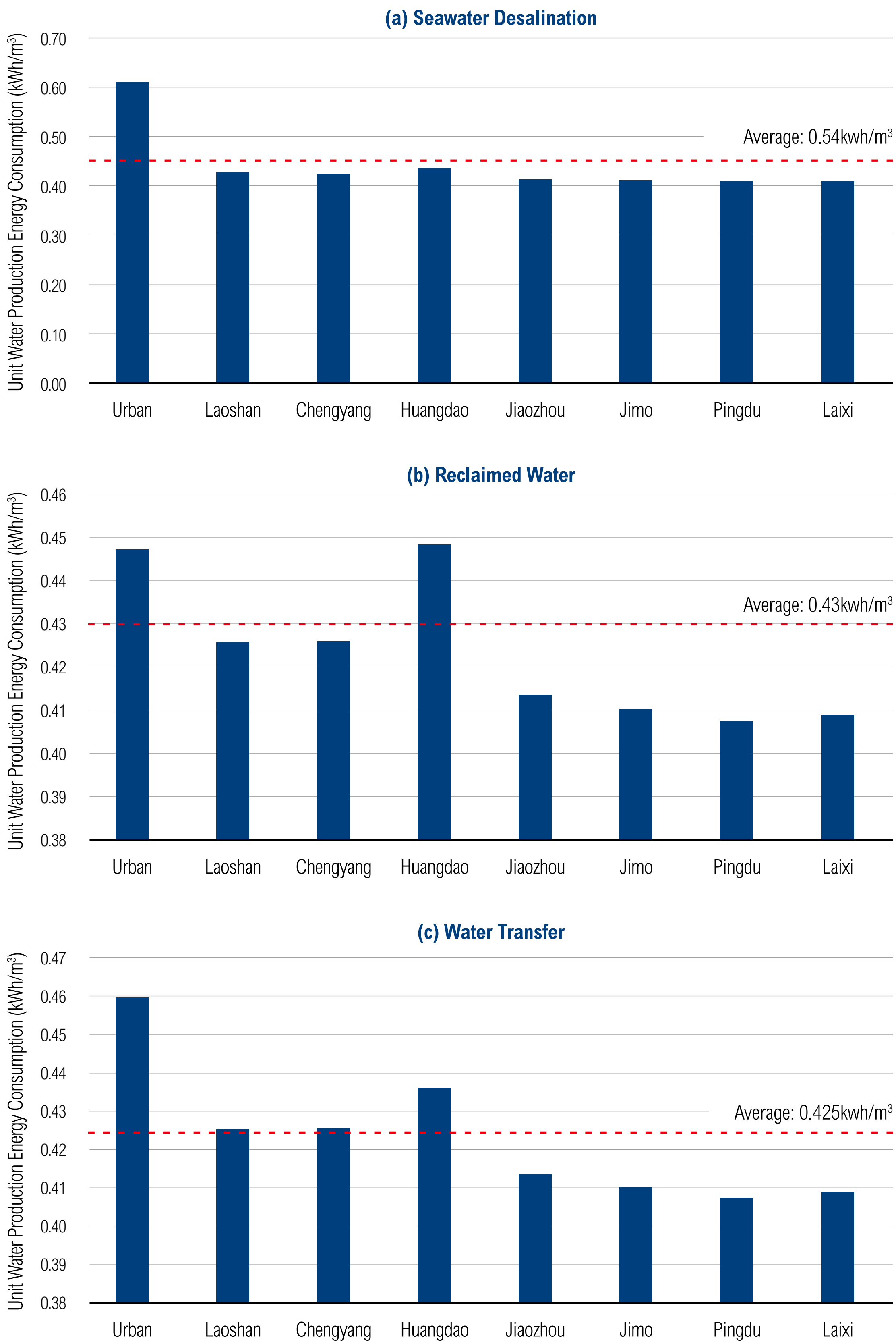


Figure 5-31 | **Analysis of Unit Water Production Energy Consumption by District in Different Surface 55 Scenarios**



water 9%, compared to 2011.

Unit water production energy consumption in both the downtown area and Huangdao is higher than the city's average for all three sub-scenarios because the use of unconventional water sources (seawater desalination and reclaimed water) is concentrated in those two areas.

5.5.2 Comparison of the Water Production Energy Consumption for Surface 55 Scenarios

The differences between sub-scenarios fade when local surface water potential is more developed; the sub-scenario prioritizing transferred water has the lowest energy consumption, rising 34% between 2011 and 2020. It is followed by the scenario prioritizing reclaimed water, which causes energy consumption to rise 34.3% compared to 2011. The scenario prioritizing seawater desalination has the highest energy consumption, and is 41% higher than 2011 (Figure 5-32).

Only the downtown area sees significant differences in unit water production energy consumption, and it is the highest under the sub-scenario prioritizing seawater desalination, followed by the sub-scenarios prioritizing transferred water, then reclaimed water. For the rest of the districts, unit water production energy consumption differences are marginal (Figure 5-33).

Figure 5-32 | **Comparative Analysis of the Water Production Energy Consumption in 2020 for Different Surface 55 Scenarios**

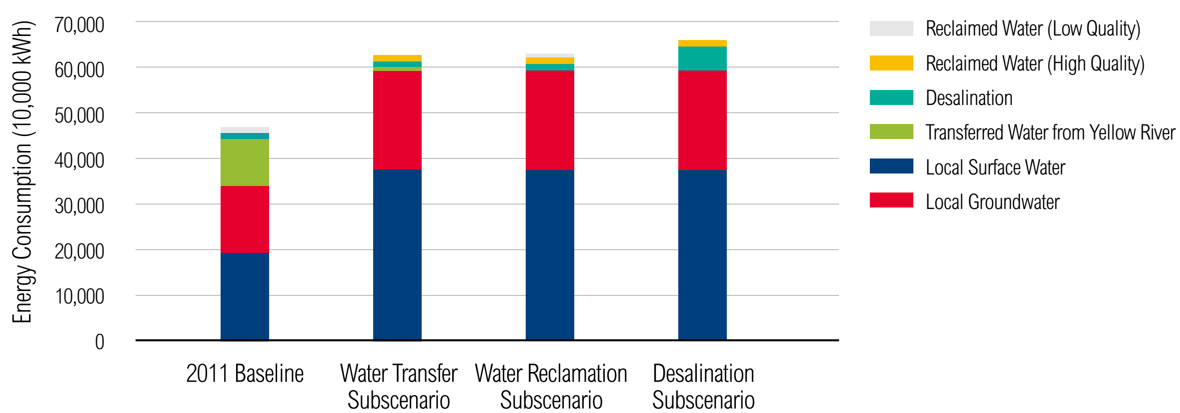
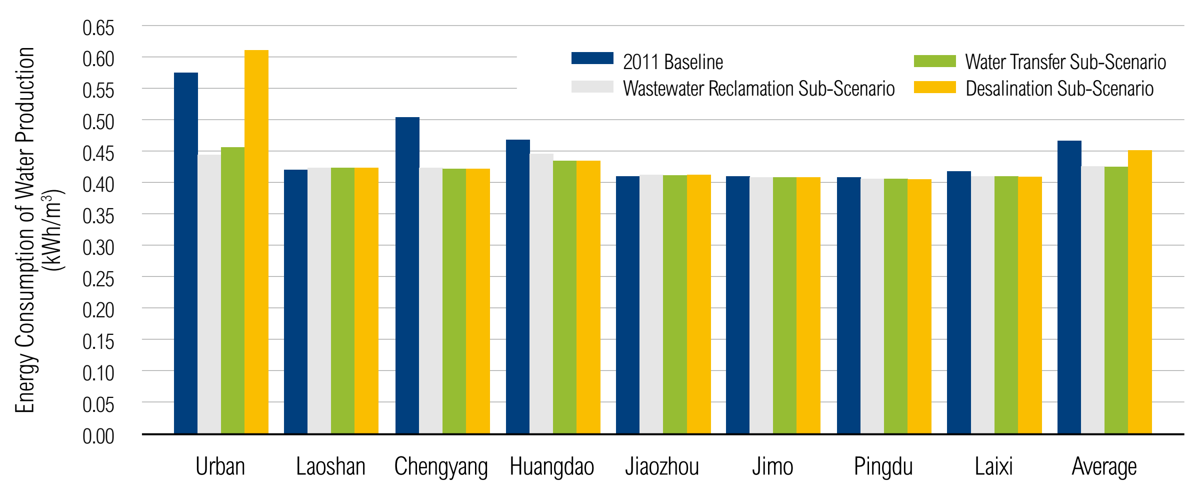


Figure 5-33 | **Comparative Analysis of Unit Water Supply Energy Consumption by District for Different Surface 55 Scenarios**



Overall, exploiting local water sources reduces the energy consumed by water production. However, Qingdao cannot sustain a 55% utilization rate of local water sources in dry years. Therefore, transferred water, desalinated seawater and reclaimed water are required as backup water sources and must be available during dry years.

5.5.3 Carbon Emissions under Surface 55 Scenarios

Figures 5-34 and 5-35 compare GHG emissions in 2020 for Surface 55 sub-scenarios (seawater desalination, reclaimed water utilization and water diversion) to baseline emission levels in 2011.

The sub-scenario prioritizing seawater desalination will result in 584,400 tons of water production-related carbon dioxide emissions, which is 41% more than in 2011. Water intake will account for 40% (233,500 tons) of the total, while related water production processes will account for 50% (292,700 tons). Seawater desalination will account for 8% (46,600 tons).

The sub-scenario prioritizing reclaimed water will result in 556,100 tons of water production-related carbon dioxide emissions in 2020, which is 34% more than in 2011. Conventional water intake will account for 42% (236,200 tons) of the total, production of reclaimed water (NEWater) will account for 53% (295,700 tons) and utilization of NEWater will account for 2% (12,400 tons).

Similar to the sub-scenario prioritizing reclaimed water, the transferred water sub-scenario will cause Qingdao's water production energy consumption to increase 34% between 2011 and 2020, to 556,100 tons. Water intake for conventional sources accounts for 42% (236,200 tons) of the total emissions, while related production processes for conventional water sources accounts for 53% (295,900 tons).

The sub-scenario prioritizing seawater desalination still results in the most carbon emissions, which are 5% higher than in sub-scenarios prioritizing transferred and reclaimed water.

Prioritizing seawater desalination also results in the highest unit water production energy consumption, while the sub-scenarios prioritizing transferred and reclaimed water are slightly lower. However, all three options are lower than the baseline value in 2011 (Figure 5-34). Exploring the local water potential and reducing the dependence on transferred water will help to reduce the energy consumed by Qingdao's water supply system.

Figure 5-34 | **Unit Water Production Carbon Emissions for Surface 55 Scenarios**

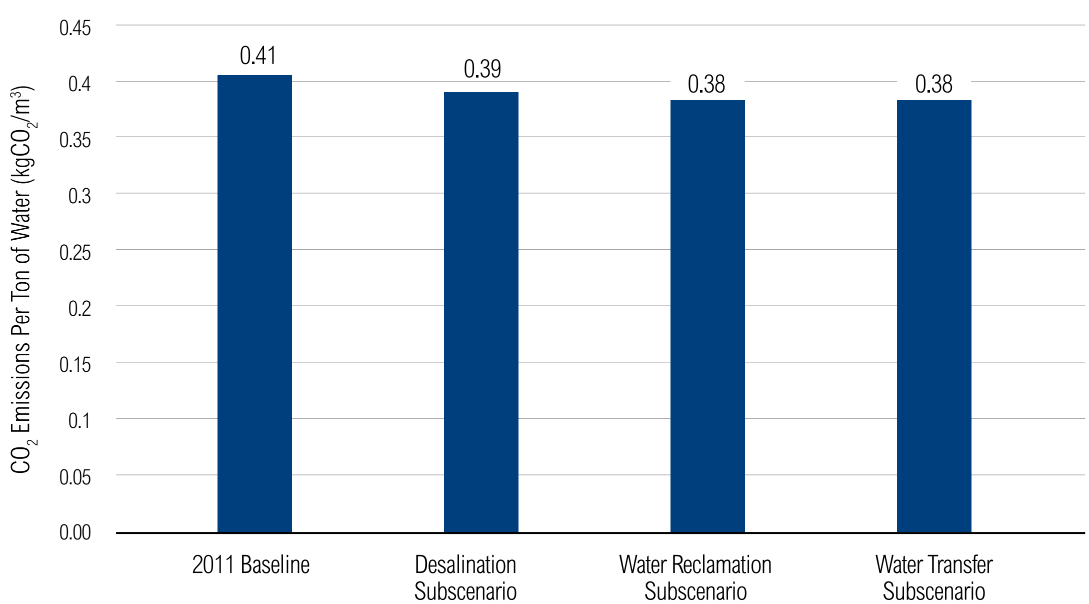
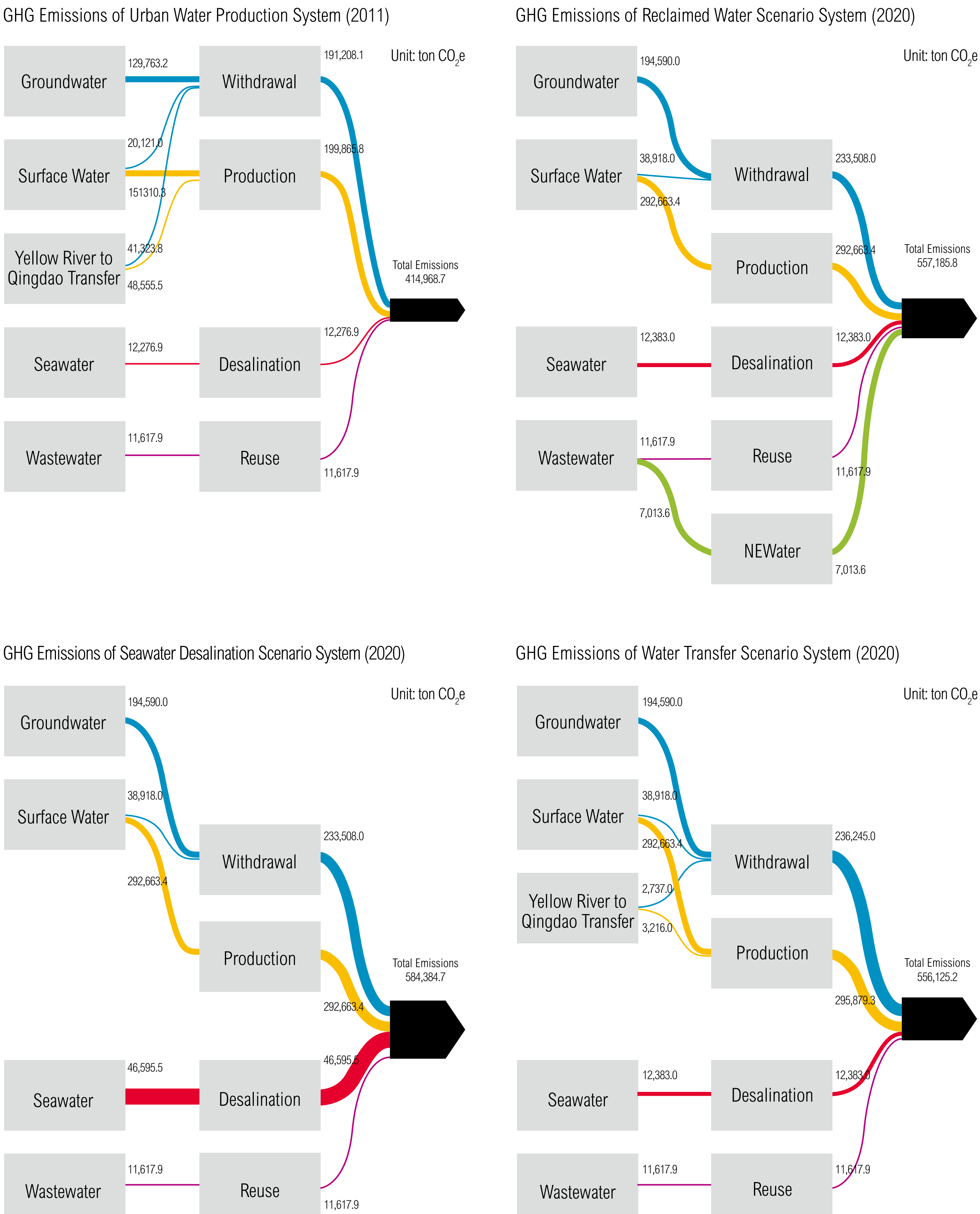


Figure 5-35 | **GHG Emissions of Qingdao's Water Production in 2011 and for Surface 55 Scenarios in 2020**



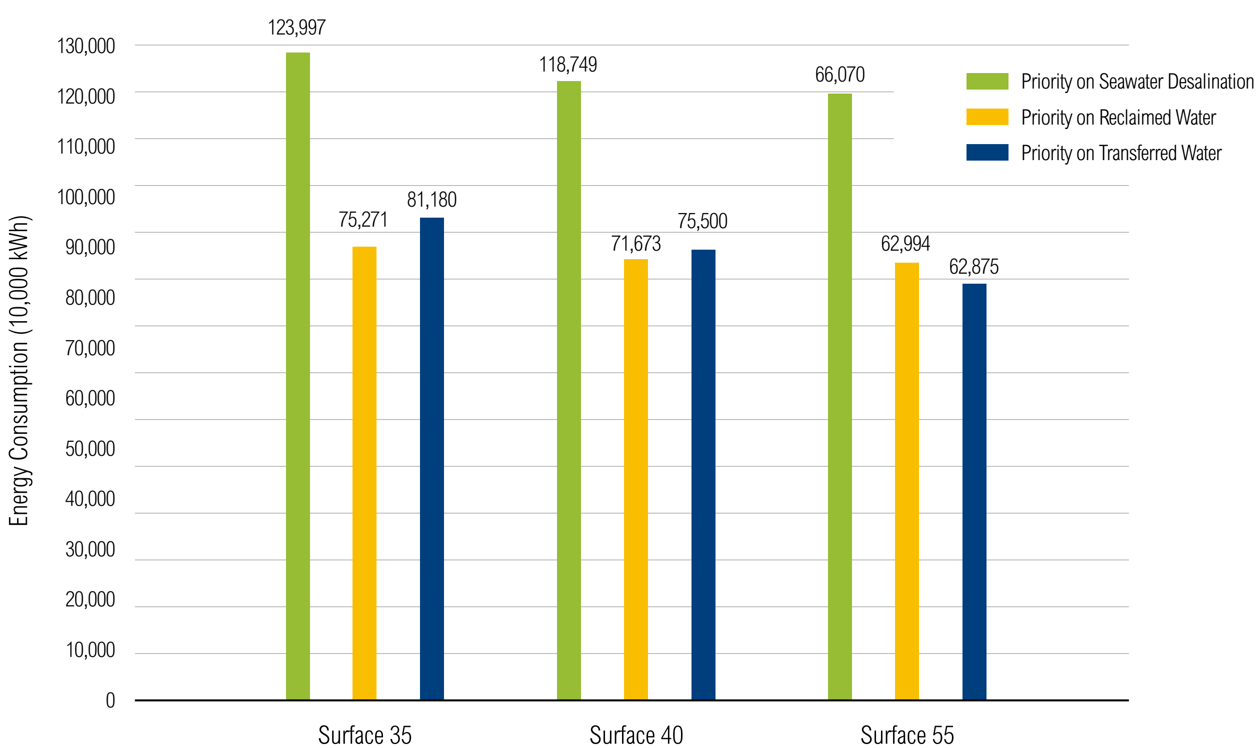
5.6 Comparison of the Water Production Energy Consumption under Different Basic Scenarios

Figure 5-36 shows the differences in the water system's energy consumption when different sources (desalinated seawater, reclaimed water and transferred water) are prioritized, for the Surface 35, 40 and 55 scenarios. Between 2011 and 2020, the energy consumed by water production could rise as little as 34% or as much as 164%, depending on which sources Qingdao develops. When just sub-scenarios that prioritize the same water source are considered, energy consumption for the whole system is higher when less surface water is exploited. So, energy consumption is highest for Surface 35, then Surface 40, then Surface 55. Additionally, the energy consumption under the scenarios prioritizing reclaimed water are generally lower than those under the scenarios prioritizing transferred water and desalinated seawater.

Under both Surface 35 and 40 scenarios, the sub-scenarios prioritizing reclaimed water result in the least energy consumed. However, under Surface 55 scenarios, there is little difference in the energy consumed under the two sub-scenarios prioritizing transferred water and reclaimed water. That is mainly because Surface 55 scenarios rely on local water resources (to meet 96% of total water demand). Meanwhile, there's little difference in the energy consumed by reclaimed water and transferred water (from the Yellow River), thus resulting in little obvious impact on the system's energy consumption.

Surface 55 scenarios assume the limit on developing surface water is reached. Maintaining a local surface water utilization rate of 55% perennially is difficult because of significant variations in the amount of Qingdao's water resources from year to year. Therefore, regardless of the utilization rate of local surface water, it is still the best option to supplement local water by developing reclaimed water and unconventional water resources, so Qingdao can secure its water supply and develop as a low-carbon city.

Figure 5-36 | **Comparison of the System's Energy Consumption in Three Basic Scenarios**



5.7 Analysis of Water Production Costs from Different Water Sources

In addition to calculating energy consumption performance, we also analyzed the water production costs of different water sources. Table 5-13 lists the costs of producing water that meets the drinking water standard from different water sources.

The aforementioned data only include the operational costs of water production, not initial infrastructure investment. For example, the cost of building reservoirs and water transportation pipe networks is not included in the cost of producing local surface water. Meanwhile, the use of local surface water in Qingdao mainly depends on water storage infrastructure. According to an estimate by the city of Qingdao, the water production cost from the new Guanlu Reservoir will reach 3.8 RMB/m^3 .

We did not use the estimate of the cost of seawater desalination given by the *Development Planning of Seawater Desalination Industry in Qingdao* (6.7 RMB/m^3). Instead, we adjusted the number based on the cost of the desalination units in the Huangdao Power Plant. The electricity consumed for water production by the desalination units (13,000 m^3/day) in the Huangdao Power Plant is 5 kWh/m^3, and the water production cost is 8 RMB/m^3. However, we calculate that the cost of water production will reach 10 RMB/m^3 if the commercial electricity price is used. Without subsidies from the government, the water production cost is 8 RMB/m^3 in commercial seawater desalination plants in Qingdao.

Since RO is the primary process and main energy consumer in seawater desalination, brackish water desalination and NEWater production, and since energy consumption contributes the most to the operational cost of RO units, we estimated the cost of brackish water desalination and NEWater production based on how much energy they consume. According to international studies, the energy

Table 5-13 | **Costs of Water Production from Different Water Sources in Qingdao**

WATER SOURCE	COSTS OF WATER PRODUCTION (RMB/M^3)	DATA SOURCE
Local Surface Water	0.94	Water Resource Fees of surface water are 0.35 RMB/m^3. (The Measure on Administrative of Collection of Water Resource Fees in Qingdao); cost of water production is 0.59 RMB/m^3 (the Xianjiazhai water supply company)
Local Groundwater	1.39	Water Resource Fees of groundwater are 0.8 RMB/m^3 (The Measure on Administrative of Collection of Water Resource Fees in Qingdao); cost of water production is 0.59 RMB/m^3 (the Xianjiazhai water supply company)
From Yellow River	1.5	Development Planning of Seawater Desalination Industry in Qingdao
NEWater	2	Estimate it's one-quarter of the cost of seawater desalination (interview with PUB, Singapore)
Brackish Water Desalination	2.8	Estimate it's 35% of the cost of seawater desalination
South-to-North Water Diversion	5.5	Development Planning of Seawater Desalination Industry in Qingdao
Seawater Desalination	8	Development Planning of Seawater Desalination Industry in Qingdao; interview with Huangdao power plant and water desalination company in Qingdao

consumption of brackish water desalination is about 35% that of seawater desalination, or between 0.3 and 1.4 kWh/m^3 [31]. Meanwhile NEWater production consumes about a quarter of the energy of seawater desalination, according to data from Singaporean NEWater plants. Therefore, we estimate the costs of brackish water desalination to be 2.8 RMB/m^3 and of NEWater production to be 2.0 RMB/m^3.

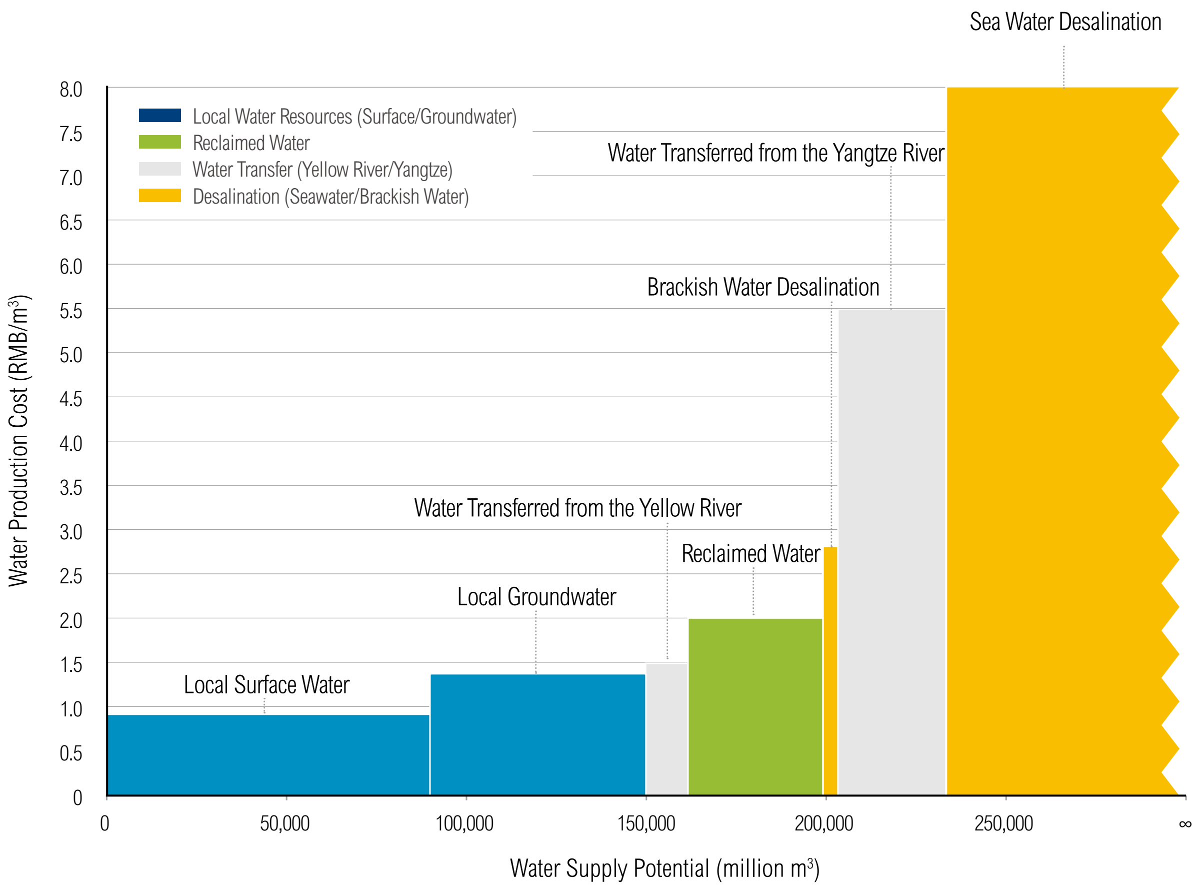
Figure 5-37 shows the water supply potential and unit water production costs of different water resources in Qingdao. At current levels of technology, local surface water has the lowest water production costs, followed by local groundwater, then transferred water from Yellow River, NEWater, desalinated brackish water, transferred water from the South-to-North water diversion and lastly desalinated seawater. Among unconventional water resources, NEWater has a cost advantage, since it costs only a quarter of what seawater desalination costs, and is, in fact, cheaper than transferring water from the South-to-North water diversion.

Because of their low water production cost, local water resources should be prioritized, followed by transferred water from the Yellow River and NEWater from urban wastewater. Transferred water from the South-to-North water diversion and seawater desalination both have relatively high costs, so using those sources will both cost more and raise carbon emissions. Seawater desalination facilities with a capacity of 133,000 m^3/day have already been installed in Qingdao. But due to its cost, desalinated seawater should to be used mainly for industrial use. Although current desalination technology makes it more expensive than other water sources, desalination is not impacted by spatial-temporal and climate factors. It thus always provides a stable, high-quality water supply. The quality of desalinated water makes it suitable for industrial enterprises that require pure water, such as power generation; chemical, iron and steel production; and computer chip manufacturing.

At the Huangdao power plant, for example, the cost of softening tap water is 14 RMB/m^3, while the cost of desalinating seawater (using RO technology) is 8 RMB/m^3. The overall cost of producing seawater for the power plant is 13 RMB/m^3, once the expense of water softening (5 RMB/m^3) is factored in. [32] There is a certain cost advantage to using seawater desalination for industrial purposes, in addition to environmental benefits.

NEWater has an even more significant cost advantage when used for industrial purposes, since it costs half as much as producing pure water from tap water.

Figure 5-37 | **Water Production Costs of Different Water Sources in Qingdao**



CHAPTER 6

CONCLUSIONS AND SUGGESTIONS

1. The gap between water demand and supply will grow larger as Qingdao's society and economy continue to develop. While urban domestic water use will grow the fastest and make up the biggest share, the exact rate and driving forces differ by district.

We estimate that Qingdao's water demand in 2020 will reach 1.48 billion m^3, which is 47% more than in 2011. Demand growth in the industrial sector will make up 58%, agriculture will make up 7% and urban domestic uses (including municipal use) will make up 89%. Urban domestic water use will still be the largest user, at 40% of total demand. The share of water for industrial use will stay stable, while the share of agricultural use is estimated to drop from 45% in 2011 to 33%.

Meanwhile, the forces driving the changes differ by district. Water demand will drop 8% in the east bank area (Shinan, Shibei and Licang) because there is little room for population growth, and the local economy is shifting to the service industry. In other districts, water demand will increase in different levels. The development of the north bank area will inevitably lead to rapid urban population growth and a significant increase in water demand in Chengyang District. It is estimated that by 2020 water demand in Chengyang will be 154% higher than in 2011. Growth in Huangdao District (previous Huangdao District and Jiaonan County-Level City) is slightly lower than in Chengyang District, so its growth in water demand is mainly due to the industrial shift in the east bank area. It is estimated that water demand in Huangdao District will increase 85% between 2011 and 2020. Of that, 152% will be in the previous Huangdao District, and 48% will be in the previous Jiaonan County-Level City. The other districts' water demand growth is relatively heavily impacted by industrial and agricultural water uses, and ranges from 25% to 70%.

2. Exploiting unconventional water resources (including transferred water, reclaimed wastewater and desalinated seawater) is inevitable because of the need to resolve the disparity between Qingdao's water supply and its demand. The configuration of water sources will have a direct impact on the

water system's energy consumption and carbon emissions.

Qingdao's water demand amounts to 67% of the city's long-term average annual total water amount, which is far beyond the limit of safe utilization of water resources (40%), according to estimates. Additionally, Qingdao's fresh water mainly comes from natural precipitation, which can be inconsistent. Therefore, using unconventional water resources (including transferred water, reclaimed water and desalinated seawater) is inevitable because of the need to meet the water demand shortfall in Qingdao.

Different water sources have vastly different levels of water production energy consumption. Depending on the water source, water production (including water intake) consumes as little as 0.426 kWh/m^3 and as much as 4 kWh/m^3 to meet the standard for drinking water. Production of local surface water consumes the least energy, followed by transferred water from the Yellow River to Qingdao project, then groundwater, reclaimed water, water from the South-to-North diversion, desalinated brackish water and lastly desalinated seawater. The energy consumed by seawater desalination (the highest) is 10 times higher than local surface water (the lowest). Therefore, Qingdao's future water source selection and configuration will directly impact the energy consumption and carbon emissions of the city's urban water system, and could potentially put pressure on carbon emissions.

3. Both the energy intensity and carbon emissions of Qingdao's water system will inevitably grow. To achieve low-carbon sustainable development and lower the carbon footprint of the city's water system, Qingdao must factor carbon accounting and energy management into water source planning.

This study estimated both the energy consumption and carbon emissions resulting from Qingdao's water production (including water intake) based on three levels of local surface water development: 35% (the Surface 35 scenario), 40% (the Surface 40 scenario) and 55% (the Surface 55 scenario). Then, we estimated energy consumption and carbon emissions for the three rates of surface water utilization under three sub-scenarios, which prioritized desalinated seawater, reclaimed water and transferred water. We found that both the energy intensity and carbon emissions resulting from Qingdao's water production will grow. The city's water production energy consumption will grow between 34% and 164%, depending on how much surface water is used and what other sources are prioritized. Sub-scenarios prioritizing seawater desalination have the largest growth in energy intensity: growing to 0.84 kWh per ton for Surface 35, to 0.8 kWh per ton for Surface 40 and to 0.45 kWh per ton for Surface 55. Sub-scenarios prioritizing reclaimed water have the lowest increases in energy intensity, growing to 0.51 kWh per ton for Surface 35, to 0.48 kWh per ton for Surface 40 and to 0.43 kWh per ton for Surface 55. Meanwhile, the energy intensity for sub-scenarios prioritizing transferred water grow to 0.55 kWh per ton for Surface 35, to 0.51 kWh per ton for Surface 40 and to 0.42 kWh per ton for Surface 55.

In 2011, the water production energy consumption (including water intake, and calculated based on electricity consumption) accounted for 1% of the total electricity consumed by the city. Under the "Surface 35 seawater desalination scenario," the water production energy consumption in 2020 will be 2.6 times that of 2011, reaching 1.240 billion kWh. When the energy consumed by water distribution is also included, the share of energy consumed by the city's water system is projected to increase.

Western countries have recognized that adjustments to cities' water sources and improvements in water quality requirements result in urban water systems that consume more energy and emit more carbon. Therefore, a carbon calculation mechanism has been developed by the UK and it is required to select water source configuration protocols with lower carbon emissions. With the development of Qingdao's economy, the energy consumed and carbon emitted by the city's water system will become new challenges, especially as low-carbon development requirements increase and pressures multiply to reduce carbon emissions. To develop a low-carbon and sustainable water system, we recommend that Qingdao incorporate carbon calculation and energy management mechanisms into water source planning processes as soon as possible.

4. Reclaimed water costs less and results in fewer carbon emissions than other unconventional water resources.

High-quality reclaimed water (NEWater) not only has a high guaranteed rate, but also consumes less energy and costs less than other unconventional water sources. According to estimates, unit water production energy consumption of high-quality reclaimed water is 0.82 kWh, which is lower than that of transferring water from the South-to-North diversion or desalinating seawater. And its water production cost is also lower than the South-to-North diversion, and only a quarter that of seawater desalination.

Because of its lower levels of energy consumption, brackish water desalination should be prioritized where suitable, such as in Pingdu. The energy consumed by brackish water desalination is under 1.4 kWh/m^3, which is a quarter of that of seawater desalination. It is an appealing low-carbon solution in Pingdu, an area short of fresh water but rich in brackish water. When developing transferred water capacity, the Yellow River should be prioritized because diverting water from that river uses only 60% of the energy needed to transfer water from the Yangtze River.

Given current technology and capacity, local surface water costs the least to produce, followed by groundwater, then transferred water from the Yellow River to Qingdao, NEWater, desalinated brackish water, transferred water from the South-to-North diversion and, lastly, desalinated seawater. Qingdao should prioritize local water resources, and then transferred water from the Yellow River and NEWater created from urban wastewater. Water from the South-to-North diversion and desalinated seawater both have relatively high costs, so using those sources will raise both the cost of supplying water and the carbon emissions resulting from water production.

We suggest Qingdao upgrade its current water reclamation plants and make plans to develop high quality reclaimed water. Meanwhile, the city should use water price incentives to increase the proportion of reclaimed water used in urban areas. According to this study, by 2020, the water supply potential of high quality reclaimed water in Qingdao will reach 0.374 billion m^3, which is about 24% of the total water demand.

5. When considering water source configurations, Qingdao should examine not only cost and guaranteed rate, but also water usage, water production energy consumption, carbon emissions and environment-ecological health risks.

Qingdao should consider various factors when selecting the city's water sources. Qingdao should examine different water sources' quality, guaranteed rate, economic cost, energy consumption, impacts on the ecology and environment, and their ability to deal with climate change, especially as environmental protection requirements ramp up and climate change intensifies.

Reservoirs supply most of Qingdao's local surface water, which is of good quality and consumes little energy, but takes up large amounts of land, requires resident resettlement and significant financial investment, and has a weak ability to deal with climate change. Groundwater is mainly used for agriculture, takes up little land and requires little capital investment. However, groundwater is hard to restore after overexploitation, and is difficult to protect. It also has weak ability to deal with climate change. We suggest using local water for urban domestic purposes first.

Qingdao can develop large amounts of reclaimed water, not only for municipal miscellaneous uses, but also for industrial uses (NEWater). Reclaimed water has a high guaranteed rate and robust ability to deal with climate change, but it also has a relatively high energy consumption and cost.

We suggest using desalinated seawater only as a strategic backup water source for the city because of its high cost, high energy consumption and uncertain health risks, and it should be mainly used for industrial purposes. Seawater desalination can also be combined with renewable energy utilization. Water power coproduction with power plants can be developed to reduce GHG emissions as much as possible. To reduce the potential environmental impact of strong brine discharges, desalination plants can use the brine through methods like seawater desalination-salt chemical.

We recommend that Qingdao, as a coastal city, further reduce the demand for fresh water resources by encouraging the direct use of seawater, for uses such as industrial cooling.

Transferred water (from both the Yellow River and the Yangtze River) can help conserve local water resources, but it takes up large amounts of land, requires significant investment, costs more and consumes higher amounts of energy. It also risks being contaminated along the diversion route. Additionally, since transferred water involves negotiations with other administrative regions as well as higher-ranking departments, over-dependency on transferred water will lower the guaranteed rate. Therefore, we suggest that Qingdao should evaluate the risks of using transferred water systematically and avoid over-dependency on that source.

6. Establish dedicated city water management by user and by water source.

Qingdao should configure its water sources based on both the endowments and demands of different districts (see Table 6-1). In the east bank area, future water resources will mainly be consumed by domestic and service industry because many water-consuming enterprises are relocating outward.

Table 6-1 | **Suggestions on the Water Source Selection Priority by District in Qingdao**

	INDUSTRY		DOMESTIC USE AND MUNICIPAL USE			AGRICULTURE
			POTABLE WATER		NONPOTABLE WATER	
	PRIMARY	SECONDARY	PRIMARY	SECONDARY		
Urban	(High Quality) Reclaimed Water		Transferred Water	Local Surface Water	(Low Quality) Reclaimed Water	
Laoshan	(High Quality) Reclaimed Water		Local Surface Water		(Low Quality) Reclaimed Water	Local Ground Water
Chengyang	(High Quality) Reclaimed Water		Transferred Water	Local Surface Water	(Low Quality) Reclaimed Water	Local Ground Water
Huangdao	(High Quality) Reclaimed Water	Seawater Desalination	Transferred Water	Local Surface Water	(Low Quality) Reclaimed Water	Local Ground Water
Jiaonan	(High Quality) Reclaimed Water	Seawater Desalination	Local Surface Water	Transferred Water	(Low Quality) Reclaimed Water	Local Ground Water
Jiaozhou	(High Quality) Reclaimed Water		Local Surface Water		(Low Quality) Reclaimed Water	Local Ground Water
Jimo	(High Quality) Reclaimed Water		Local Surface Water		(Low Quality) Reclaimed Water	Local Ground Water
Pingdu	(High Quality) Reclaimed Water	Brackish Water Desalination	Local Surface Water	Transferred Water	(Low Quality) Reclaimed Water	Local Ground Water
Laixi	(High Quality) Reclaimed Water		Local Surface Water		(Low Quality) Reclaimed Water	Local Ground Water

We suggest using local surface water (including the Dagu River, Yifu Reservoir and Chanzhi Reservoir) and transferred water for domestic drinking water, while using low quality reclaimed water for non-contact and non-drinking uses such as municipal landscaping and toilet flushing. Because of rapid urban population growth and industrial development in the west bank area, we suggest using high quality reclaimed water as the main supply for industrial water needs and using externally transferred water and local water for domestic uses. In Pingdu, we suggest desalinating abundant supplies of brackish water to meet industrial needs at the Pingdu Industrial Park, and leaving valuable local fresh water resources for domestic uses.

During the municipal planning process (especially when designing satellite cities), we recommend choosing water sources based on quality as much as possible. Designated pipeline systems should separately carry high quality drinking water, industrial water and water for domestic miscellaneous uses, so that high quality water is better priced and better matched with the proper applications. Separate pipeline systems will help improve the water use efficiency and facilitate the city's sustainable use of water resources and development.

7. Reform water pricing and reinforce the management on water saving

The price of water in Qingdao is still low and depends on large financial subsidies from the government. Since Qingdao's residents have relatively high incomes, we recommend appropriately raising the price of water to cover the cost. Additionally, tiered pricing for water could be implemented to enhance social fairness and allow low-income families to affordably meet their basic needs.

With multiple water sources, it is important to coordinate the pricing and management of those different sources. Proper pricing could encourage reclaimed water and desalinated water and promote sustainable development. We recommend appropriately increasing financial subsidies for water recycling and reuse to make those sources preferable.

The government needs to increase investment in water conservation and raise public awareness through public education campaigns and other means. While Qingdao is a leader in China when it comes to industrial water conservation, the city has a relatively high domestic water consumption rate of 180 L per capita per day, which is higher than most other cities in China (such as Jinan, the provincial capital city). We suggest Qingdao revise water conservation standards and enhance demand management to meet the national requirement of a water-saving city. Appropriate incentives and allowances could be applied to promote better water-saving appliances and facilities.

APPENDIX I

ESTIMATE OF QINGDAO'S WATER DEMAND IN 2020

According to the *Outline of Qingdao's 12th Five-Year Plan of the Social and Economic Development* and *Qingdao's Overall City Planning (2006-2020)*, we estimated the water consumed by industrial, agricultural and municipal domestic uses based on analyses of population and industry structures, using the year 2011 as a baseline. Due to data limitations, the amount of water for ecological use is taken from *Qingdao's Planning on Modernization of the Water Conservancy (2012)*.

I. ESTIMATE OF INDUSTRIAL WATER DEMAND

Up until 2011, industrial water uses accounted for 18.9% of the total water consumed in Qingdao, which was 3.4% less than in 2005 [68]. The water consumption per 10,000 RMB of industrial value added will decline further with improved industrial water use efficiency and adjustments in the industrial structure. However, total industrial water demand will continue to gradually increase because of rapid economic growth.

I.1 Comparison of the Methods to Estimate Industrial Water Demand

Currently, several main methods are used to to estimate industrial water consumption: the water consumption quota method, growth rate method, annual declining rate model estimating method, exponent model estimating method and the regression analysis method. Table I-1 shows the pros and cons of each method. The water consumption quota method and regression analysis method are more suitable for medium- to long-term predications, and their data requirements are relatively low. We used the water consumption quota method for this study because of data availability and other advantages.

I.2 Estimate of Industrial Value Added and Industrial Structure in 2020

Qingdao's industrial value added reached 279.456 billion RMB in 2011. Of that, the previous Huangdao District contributed the most (22.6%), followed by Chengyang District (14.8%), while the five county-level cities (Jimo, Laixi, Pingdu, Jiaozhou and previous Jiaonan) accounted for 48.7% (QDSB, 2012).

Qingdao's total industrial water consumption in 2011 was 0.191 billion m^3. The downtown area, which is where the most old enterprises are located, instead of the areas with the highest industrial value added, consumed the largest amount of water. The downtown area generated 8% of the city's total industrial value added, but consumed 28% of the city's industrial water. Table I-2 shows Qingdao's industrial water use efficiency by administrative district.

Statistical data from 2005 to 2011 indicates that the percentages of industrial value added in the downtown area, Huangdao, Laoshan and Chengyang decreased each year, while industrialization in Jiaozhou, Jimo, Pingdu, Jiaonan and Laixi grew. Six key industrial functional zones will be established in five county-level cities in Qingdao: Dongjiakou heavy chemical industry zone in

Table I-1 | **Comparison of Various Estimating Methods for Industrial Water Use**

METHOD	QUOTA METHOD[a]	GROWTH RATE METHOD[a]	EXPONENT MODEL ESTIMATING METHOD[b]	ANNUAL DECLINING RATE MODEL ESTIMATING METHOD[c]	REGRESSION ANALYSIS METHOD[a,c]
Advantage	Intuitive, easy to apply, easy to include changes to the factors and policy adjustments	Suitable for medium-term planning, results are relatively reliable. Can be used as reference for transformation of urban water plants	Takes into consideration multiple impacting factors of industrial water use. Suitable for long-term planning, can be used to determine the capacity of new water plants	Simplicity	Mature principles, simple processes and easy to understand; Suitable for short-term planning, can be used as reference for the reform of the city's pipe network
Disadvantage	Deviations can be caused by predictions of future economic and social situations	High subjectivity in determing parameters	High subjectivity in determing parameters and selecting permissible errors	Low reliability; the annual declining rate normally not constant	Only the impact of time is considered, not any other factors.

Source: a. Huang, Zhang, and Jia, 2009
b. Dong, Shi, and Li, 2011
c. Lu, and Li, 2012

Table I-2 | **Water Consumption Per 10,000 RMB Industrial Value Added by District in Qingdao (2011)**

INDICATOR	URBAN	LAO-SHAN	CHENG-YANG	HUANG-DAO	JIAONAN	JIAO-ZHOU	JIMO	PINGDU	LAIXI
Industrial Value Added (100 million RMB)	249.84	180.59	460.07	700.13	344.32	336.96	335	289.14	205.95
Industrial Water Consumption (10,000 m^3)	5,423	1,086	2,859	3,270	1,278	1,576	1,716	1,357	533
Water Consumption Per 10,000 RMB Industrial Value Added (m^3)	21.71	6.01	6.21	4.67	3.71	4.68	5.12	4.69	2.59

Data Sources: Qingdao Statistical Yearbook, 2012; Qingdao Water Resource Bulletin, 2011; WRI estimation

Jiaonan, Xinhe ecological chemical industry zone in Pingdu, Yanghe equipment manufacturing industry zone in Jiaozhou, Jiangshan light industry zone in Laixi, Longquan automobile and components industry zone and Nv'dao shipping industry zone in Jimo. These regions will be the key areas for future industrial distribution and adjustments. Because the chemical industry is water intensive, industrial water demands in the previous Jiaonan and Pingdu may increase significantly.

According to the *12th Five-Year Development Plan for Manufacturing Industry in Qingdao*, Qingdao's industrial value added will reach 700 billion RMB by 2020. The output share of high

Table I-3 | **Table of Estimates of Qingdao's Industrial Value Added by District**

DISTRICT	RATIO OF INDUSTRIAL VALUE ADDED BY DISTRICT (%)				INDUSTRIAL VALUE ADDED IN 2020 (100 MILLION RMB)
	2005	2010	2011	2020	
Shinan	1.79	1.29	1.13	0.64	45
Shibei	3.32	1.13	1.02	0.56	39
Sifang	3.14	2.32	2.13	1.16	81
Licang	6.53	3.88	3.78	1.94	136
Laoshan	8.03	5.97	5.82	2.99	209
Huangadao	16.52	22.8	22.57	17.1	1197
Chengyang	13.21	15.05	14.83	10.69	748
Jiaozhou	10.93	10.7	10.86	13.9	973
Jimo	10.2	10.5	10.8	13.65	956
Pingdu	9.31	9	9.32	12.6	882
Jiaonan	11.38	10.9	11.1	16.35	1145
Laixi	5.64	6.46	6.64	8.4	588
Total	100	100	100	100	7000

and new technology industry will increase from 45% to to 65% between 2010 and 2020. The share of the total output of the manufacturing industry of the five county-level cities will grow to 65%. Table I-3 shows the growth rate of Qingdao's industrial value added by district and the estimated industrial value added in 2020.

I.3 Method for Determining the Quota for Industrial Water Use

According to the *Technical Outline of National Water Resource Overall Planning*, the water consumption quota per 10,000 RMB value added is estimated using the industrial water reuse rate method. The equations are as below (He and et al., 2005; MWR, 2002):

$M_n = M_0 \times (1-a)^{n-0} \times (1-\mu_n)/(1-\mu_0)$

Where

M = water consumption per 10,000 RMB industrial value added (m^3)

a = improving factor of industry technologies

μ = industrial water reuse rate

0 = baseline year

n = year of estimation

The improving factor of industry technologies refers to the improvement level and water use efficiency of the industries in a certain area. In general, it is between 0.02 and 0.05. In areas with a developed economy and high water use efficiency, a lower value is normally adopted since there is a little room for improvement, while in areas with relatively undeveloped economy and low water use efficiency, the value can be adjusted within the range according to water-saving policies and plans (Dong and et al., 2011). Since Qingdao's industrial water use efficiency is a leader in China, 0.02, the lower limit, is adopted in the calculation. According to *Qingdao's Planning on Modernization of the Water Conservancy*, the current industrial water reuse rate is 84% and is estimated to reach 88% in 2020.

I.4 Estimate of the Industrial Water Demand

The city's total industrial water demand in 2020 is calculated based on the annual average of statistics (water consumption per industrial value added of 10,000 RMB, and industrial water reuse rate) from 2004 to 2011. Then, the city's total industrial water demand is differentiated by district according to each district's share of industrial value added. Due to differences in water use efficiency, errors might be induced.

(1) Determine the industrial water consumption quota for the whole city in 2020.

First, the water consumption quota per 10,000 RMB value added is caliberated according to historical data (Table I-4).

Table I-4 | **Table of Model Testing Values**

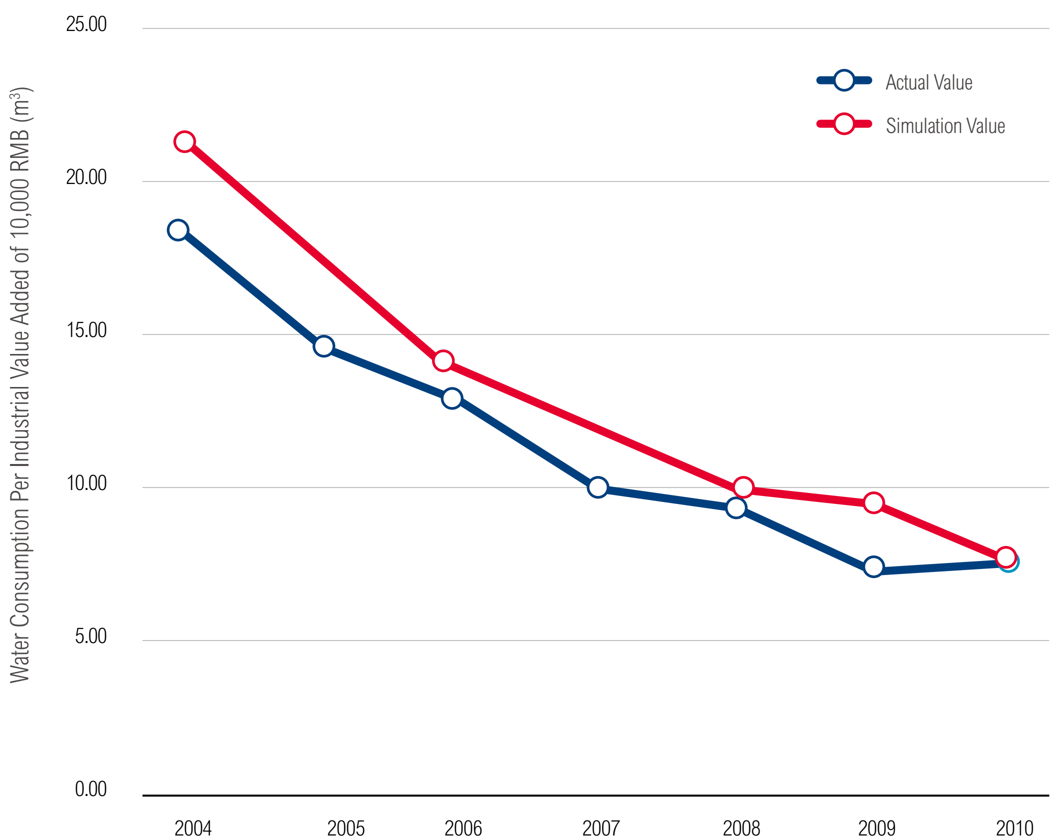
YEAR	INDUSTRIAL WATER CONSUMPTION (100 MILLION M³)	INDUSTRIAL VALUE ADDED (100 MILLION RMB)	WATER CONSUMPTION PER INDUSTRIAL VALUE ADDED (M³)	SIMULATION VALUE (M³)	RELATIVE DISCREPANCY (%)
2005	2.31	1,259.06	18.35	20.96	14
2006	2.17	1,517.28	14.30	17.43	22
2007	2.22	1,766.28	12.57	13.59	8
2008	2.05	2,034.25	10.08	11.94	18
2009	2.05	2,174.43	9.43	9.88	5
2010	1.73	2,454.19	7.05	8.96	27
2011	1.91	2,794.56	6.83	6.98	2

It is indicated that the relative discrepancies between the simulation values and actual values in 2006, 2008 and 2010 are large (>15%), while the results in other years are well fitted. It can be seen that the water consumption per 10,000 RMB industrial value added decreased year on year, and the trend of simulation value is basically the same. Therefore, the model can be used to estimate the quota in 2020. The calibration results are demonstrated in Figure I-1.

Based on the model results, Qingdao's water consumption per 10,000 RMB of industrial value added will reach 4.3 m^3 in 2020, which is 37% lower than in 2011 (6.83 m^3). The rate of decline is lower than in the 11th Five-Year period, 62%. This is because industrial water saving projects with the most potential already have been implemented, and future water saving will depend more on industrial structure adjustments.

However, Qingdao's industrial water use efficiency is already a leader in China, and is even at an advanced level compared to the rest of the world (Figure I-2).

Figure I-1 | **Comparison of the Simulation Values and Actual Values of Industrial Water Use Efficiency**



Data Sources: Qingdao Water Resource Bulletin, 2004 to 2011; Qingdao Statistical Yearbook 2005-2012

Figure I-2 | **Comparison of the Water Consumption Per 10,000 RMB Industrial Value Added of Qingdao and Foreign Countries (2011)**

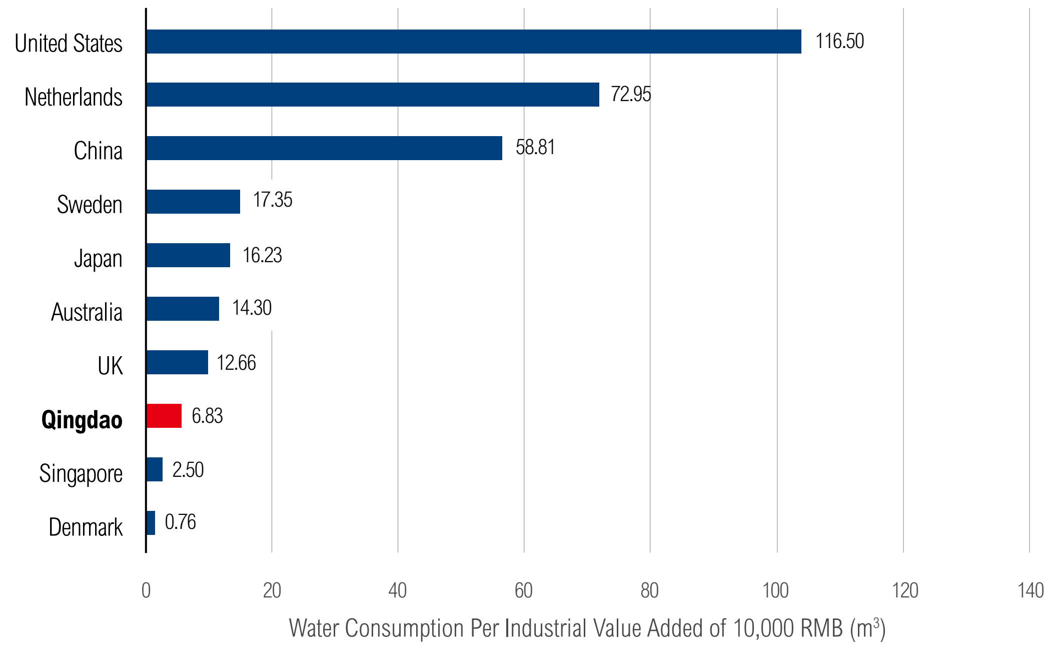


Table I-5 | **Industrial Water Demand by District in 2020 in Qingdao (in 10,000 m^3)**

FORMAL ADMINISTRATIVE DIVISION	URBAN	LAOSHAN	CHENG-YANG	HUANG-DAO	JIAONAN	JIAO-ZHOU	JIMO	PINGDU	LAIXI	TOTAL
Industrial Water Demand	1,297	899	3,217	5,146	4,922	4,185	4,109	3,793	2,532	30,100
NEW ADMINISTRATIVE DIVISION	**URBAN**	**LAOSHAN**	**CHENG-YANG**	**HUANGDAO**		**JIAO-ZHOU**	**JIMO**	**PINGDU**	**LAIXI**	
Industrial Water Use	1,297	899	3,217	10,068		4,185	4,109	3,793	2,532	

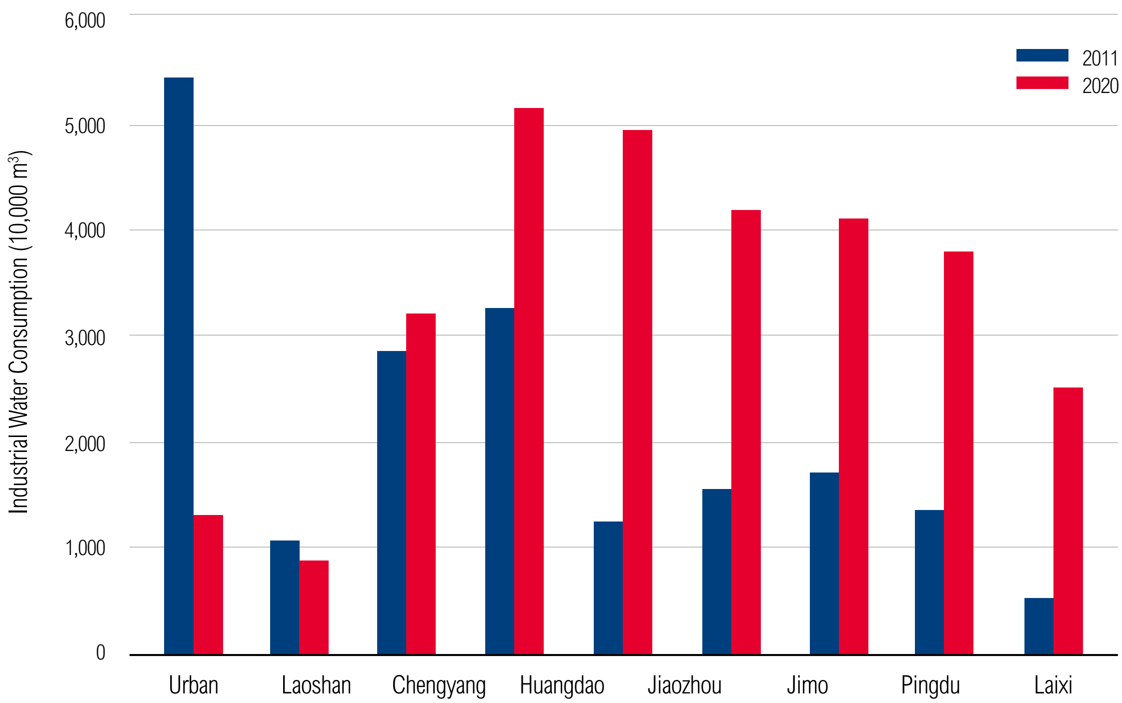
The data shows that in 2011, Qingdao's water consumption per 10,000 RMB of industrial value added is only a tenth of the national average, which is lower than in some developed countries, such as Japan and some European countries. Room for improvement on water use efficiency is limited. According to the Three Red-Lines defined by Shandong Province for Qingdao, the city's water consumption per 10,000 RMB of industrial value added in 2020 must be lower than 10.1 m^3 (in constant prices in 2000, the same hereafter). As the planned value is relatively conservative, it is determined to be 4.3 m^3 based on Qingdao's current status and development trends.

(2) Estimate of industrial water demand of the whole city and each district in 2020.

Industrial water demand in 2020 is estimated to be 301 million m^3, according to the estimated water use efficiency and industrial value added target of 700 billion RMB.

The industrial water demand by district is calculated based on the estimated industrial value added of each district (Table I-5)[33].

Figure I-3 | **Comparison of Qingdao's Industrial Water Consumption by District in 2020 and the Baseline Value in 2011**



SOURCE	INDUSTRIAL WATER DEMAND IN 2020 (100 MILLION M^3)	Note
The 11th 5-year construction plan for the comprehensive utilization and development of Water Resources in Qingdao (2007)	3.23	Water consumption quota method
Qingdao's planning on modernization of the water conservancy (2012)	2.67	
Prediction of Qingdao's industrial water demand (ZB Lu, South-to-North water diversion and Water conservancy Sci& Tech., 2012)	3.87	Regression analysis method
WRI estimate (estimate for the whole city)	3.01	Water consumption quota method

Figure I-3 shows that future industrial water demand mainly comes from the new Huangdao District (previous Huangdao and Jiaonan), Jiaozhou, Jimo, Pingdu and Laixi. Of that, industrial water demand in the new Huangdao District will account for one-third of the total, since heavy chemical industries are centralized in that area. The industrial water demands in Chengyang and Laoshan will remain almost the same, while there will be large reduction in the downtown area.

I.5 Comparison among the Estimated Values, Planned Values and Values from Related Studies

Based on the estimated results, Qingdao's industrial water demand in 2020 will be 301 million m^3.

II. ESTIMATE OF WATER DEMAND FOR URBAN RESIDENTIAL AND MUNICIPAL USES

As Qingdao rapidly urbanizes, urban residential and municipal water use will grow quickly and its percentage of the city's total water consumption will increase. Between 2004 and 2011, urban domestic water use increased 80%. Since it is at the center of the

Jiaodong Peninsula's economic development, Qingdao's living standards will keep improving and absolute urban population will keep growing. Therefore, the city's urban water demand is projected to increase significantly by 2020.

According to the *City Construction Statistical Yearbook*, domestic water use includes household water use and public service water use. And, according to the *Qingdao Water Resources Bulletin*, public service water use includes water use in the construction and service industries. Therefore, domestic water use estimated in this study includes water use for households, public services, the construction and building industry, and tertiary industries.

II.1 Comparison of Methods for Estimating Urban Domestic Water Uses

Currently, the main methods for estimating domestic water uses are the water consumption quota method, growth rate method, annual declining rate model estimating method, exponent model estimating method and the regression analysis method. Table I-6 shows the pros and cons of some selected water demand projection methods.

The water consumption quota method is adopted in this study to estimate Qingdao's urban domestic and municipal water demands in 2020.

Table I-6 | **Comparison of Various Estimating Methods for Urban Domestic Water Use**

		ADVANTAGES	DISADVANTAGES
Overall water consumption quota per capita method[a,b]		Intuitive, easy to apply, high accuracy on estimating water consumption, suitable for short-, medium- and long-term planning.	Applicable time period (i.e., different planning horizon) needs to be differentiated and consistent with the statistical caliber of urban water-consuming population.
Target by category method[a]		Clear identification on the water usages and sources.	Low data availability, and water for firefighting is neglected due to the small amount.
Average annual growth rate method[a]		Suitable for long-term estimation.	Deviations in selecting the growth rate can be created by errors of predicting the future social economic situations.
Grey forecast method[a]		Raw data can be used directly and less data is required; can be used effectively in regions with little data. Suitable for medium- to long-term estimation.	Modeling, result calculation and accuracy testing are complicated.
Time series analysis[a]	Autoregression method	Simple calculation and easy to understand.	Potential significant predicting errors due to few factors considered.
	Exponential smoothing method	Single exponential smoothing method is suitable for short-term prediction.	Predicted values cannot react to abnormal changes in actual values; errors may happen during abnormities.
	Growth curve method	Upper limit of water consumption is introduced; therefore, artificial factors, e.g. policy formulation and changes, are considered. Suitable for long-term prediction.	Using this method, the changing trend of estimated values is not obvious when the upper limit of water consumption is the same.
Explanatory predicting method[b]		Including Multiple Linear Regression method, Multiple non-Linear Regression method and Artificial Neural Network method. Parameters modification can be applied for system changes. Suitable for long-term prediction.	Hard to identify the causality.
Water consumption quota predicting method[a]		Water quota is assigned according to actual demand from the city's development, water use characteristics of each department and decision makers' intention. Results are reasonable and fit the actual changing trend of water use.	Predicting function and parameters of different water uses are hard to decide.

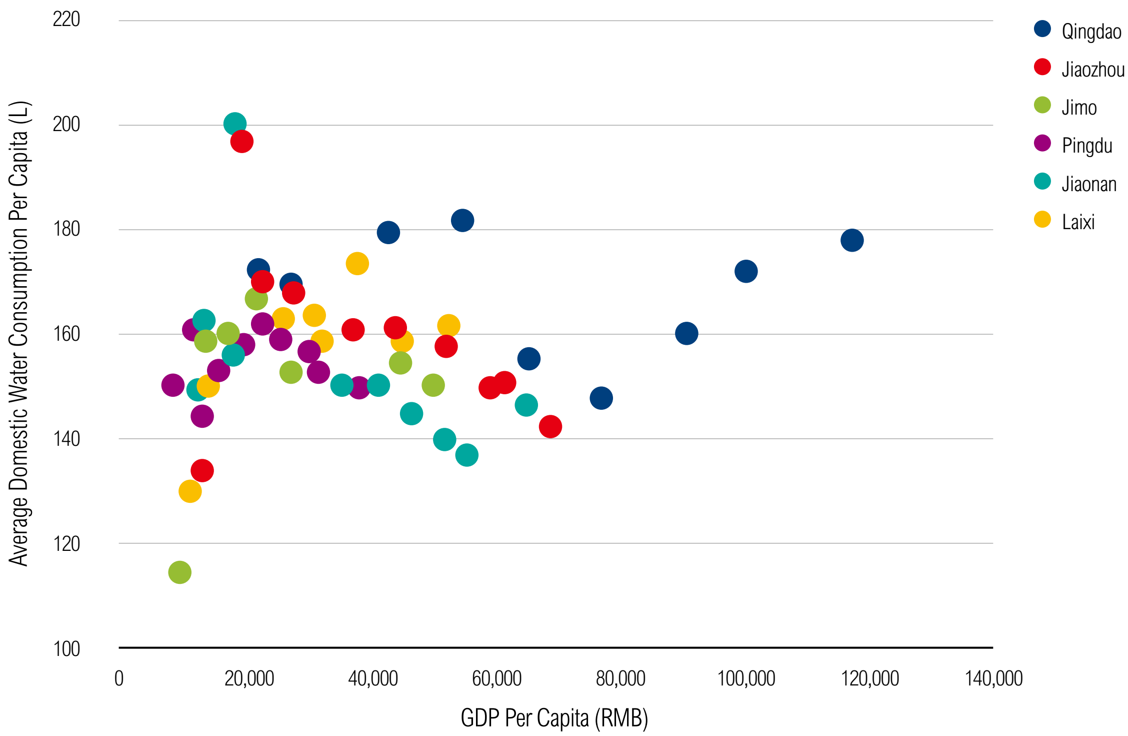
Data Sources: a. Sun, Kong, and Jiang, 2011
b. Li, and Zuo, 2005

Table I-7 | **Table of Predictions of Urban Population in Each Administrative District in Qingdao in 2020 (10,000 People)**

SHINAN	SHIBEI	SI-FANG	LI-CANG	LAO-SHAN	HUANG-DAO	CHENG-YANG	JIMO	LAIXI	PING-DU	JIAO-NAO	JIAO-ZHOU	TOTAL
58	59	49	54	40	130	160	90*	50	50	65	64	869

*Including 600,000 people in Jimo city and 300,000 people in Blue Silicone Valley.

Figure I-4 | **Relationship of Average Domestic Water Consumption Per Capita and GDP Per Capita by District in Qingdao**



Data Source: China City Construction Statistical Yearbook 2010 (MOHURD, 2011)

Table I-8 | **Domestic Water Consumption Quota in Each District in Qingdao**

ADMINISTRATIVE DIVISION	QINGDAO	JIMO	PINGDU	JIAONAN	JIAOZHOU	LAIXI
Domestic Water Consumption Per Captia in 2010 (L)	178	151	151	147	142	162
Domestic Water Consumption Per Captia in 2020 (L)	197	167	166	162	157	153

Data Source: China City Construction Statistical Yearbook 2010 (MOHURD, 2011)

W=Pn×Q (in which W is water demand, P is the population, Q is the water consumption quota, and n is the year for estimation).

II.2 Urban Population Prediction

According to the 12^{th} *Five-Year Planning for the Social and Economic Development in Qingdao* and *Qingdao's Overall City Planning*, it is estimated that the city will hold 11 million people in total in 2020 with 8.69 million of them living in urban areas, or 79% (Table I-7).

The downtown area is almost saturated now (with a population density of 1,884 person/km^2 in 2011) and the population appears to be decreasing. The urban population growth will mainly happen in Huangdao, Chengyang and the remote suburban districts.

II.3 Water Consumption Quota

According to the *Code for Urban Water Supply Engineering Planning (GB50282-98)* by the Ministry of Construction, the downtown area in Qingdao is a Class II Supercity (in Shandong Province, with an urban population of more than 1 million), and the quota of average overall domestic water consumption is 230 to 400 L per capita per day; the remote suburb areas belong to Class II Medium City, with a quota of 190 to 360 L per capita per day.

The city of Qingdao faces severe water shortages. In recent years, however, urban domestic water use has been kept under control with the promotion of water conservation. In 2010, the average daily overall domestic water consumption per capita was 178 L, and the number in all five county-level cities was between 140 and 160 L. All of them were lower than the water consumption quota allocated by the state.

The analysis of the average daily overall domestic water consumption per capita in Qingdao and the regions under its jurisdiction in the last 10 years shows that there is a relationship between domestic water consumption per capita and GDP per capita. When GDP per capita is less than 80,000 RMB, there is a declining trend in water consumption. Once GDP per capita exceeds 80,000 RMB, the water consumption will increase gradually, with an annual growth rate of about 1% (Figure I-4).

Table I-8 shows the estimate of the water consumption quota per capita for urban residents in each administrative district in 2020 in Qingdao.

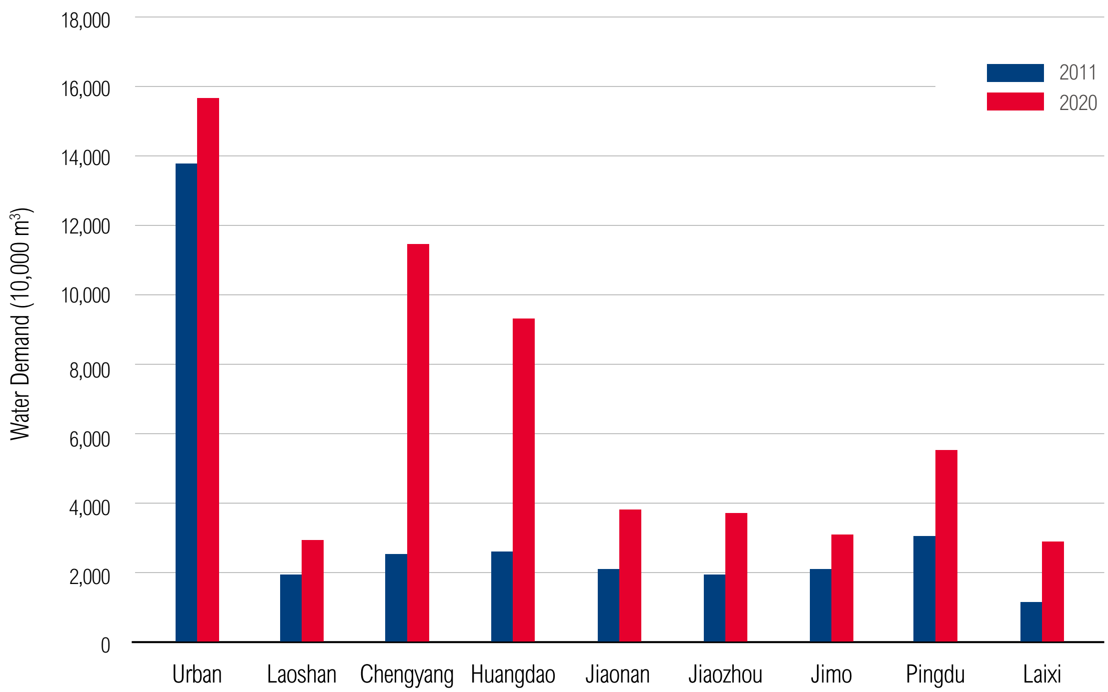
II.4 Estimate of Urban Domestic Water Demand

According to the city's population and water consumption quota, the water demand of Qingdao's urban domestic and municipal public water is 583.14 million m^3. The water demand by districts is shown in Table I-9.

Table I-9 | **Qingdao's Urban Domestic and Municipal Water Demand in 2020 (in 10,000 m^3)**

FORMAL ADMINISTRATIVE DIVISION	WATER DEMAND	NEW ADMINISTRATIVE DIVISION	WATER DEMAND
Urban	15,782	Urban	15,782
Laoshan	2,882	Laoshan	2,882
Chengyang	11,486	Chengyang	11,486
Huangdao	9,332	Huangdao	13,185
Jiaonan	3,852		
Jiaozhou	3,677	Jiaozhou	3,677
Pingdu	3,035	Pingdu	3,035
Jimo	5,483	Jimo	5,483
Laixi	2,785	Laixi	2,785
Total		58,314	

Figure I-5 | **Comparison of Qingdao's Domestic and Municipal Water Consumption in 2020 and 2011**



SOURCE	URBAN HOUSEHOLD AND MUNICIPAL WATER USE IN 2020 (100 MILLION M³)	Comment
The 11th 5-year construction planning for the comprehensive utilization and development of Water Resources in Qingdao (2007)	4.43	Water consumption quota method
Qingdao's planning on modernization of the water conservancy (2012)	6.1	
WRI estimate	5.83	Water consumption quota method

The downtown area and Laoshan will see only small growth in domestic water use in the years after 2011, since the urban population in these two areas is already almost saturated, and growth in water demand is mainly caused by economic development and rising living standards. The water demand for domestic and municipal uses in Chengyang and the new Huangdao District, however, will greatly increase because of the cities' expansion and the construction of new districts (see Figure I-5).

II.5 Comparison among the Estimated Values, Planned Values and Values from Related Studies

Compared to the current relevant water resource plans in Qingdao, our estimated value is between the value in the *11th 5-Year Plan for the Comprehensive Utilization and Development of Water Resources* issued in 2007 and the value in the *Water Conservancy Modernization Plan in 2012*.

III. ESTIMATE OF RURAL DOMESTIC WATER DEMAND

In recent years, according to the development concept of "Urbanization of Rural Water Supply and Integration of Urban and Rural Water Supplies," Qingdao has extended the distribution of the urban water supply network into rural areas to promote centralized water supply in villages and towns, as well as to guarantee the water supply in rural areas. Meanwhile, an increasing number of migrant workers are moving to cities as urbanization accelerates. Rural domestic water use dropped significantly in the 11th Five-Year period. In 2011, total rural domestic water consumption was 71.62 million m^3, which was 14% lower than in 2005 (83.02 million m^3). This declining trend is projected to continue in the next decade.

Like urban domestic water consumption, the water consumption quota method is used to estimate the rural domestic water consumption.

III.1 Rural Population Prediction

According to the *12th Five-Year Planning for the Social and Economic Development in Qingdao* and *Qingdao's Overall City Planning*, it is estimated there will be 11 million people in total in 2020, with 79% of them living in urban areas, while 2.31 million people live in rural areas (see Table I-10).

III.2 Water Consumption Quota

According to the estimate by the *Qingdao Water Resource Bulletin*, the rural residential domestic water consumption is 66 L per person per day in Qingdao.

According to the *Technical Code for Rural Water Supply Engineering (SL310-2004)* issued by the Ministry of Water Resources and Qingdao's scale rural water supply planning, it is estimated that the standard of all-day water supply can be met in three districts in 2020 in Qingdao (Shandong Province, all-day water supply). The quota for average daily domestic overall water consumption per capita is 70 to 90 L. Due to the enhanced utilization of water conservation projects (such as water-saving appliances) the quota of rural water consumption is set to be 80 L per capita per day, considering that Qingdao lacks water.

III.3 Estimate of Rural Domestic Water Consumption

The rural domestic water demand in 2020 in Qingdao is determined to be 67.45 million m^3, based on the estimated rural population and the water consumption quota. Table I-11 shows the water consumption by district.

Attached Figure I-6 shows that rural domestic water demand in most areas is going to decline, while demands will increase significantly in the new Huangdao District. This is because, the adjustment of administrative divisions resulted in the new Huangdao District including the rural population of the previous Jiaonan County-Level City, as well as its corresponding water demands.

Table I-10 | **Prediction of Qingdao's Rural Population in 2020 (in 10,000 People)**

URBAN	LAOSHAN	FORMER HUANGDAO	CHENG-YANG	JIMO	LAIXI	PINGDU	FORMAL JIAONAN	JIAOZHOU	TOTAL
0	0	0	2	50	39	47	51	42	231

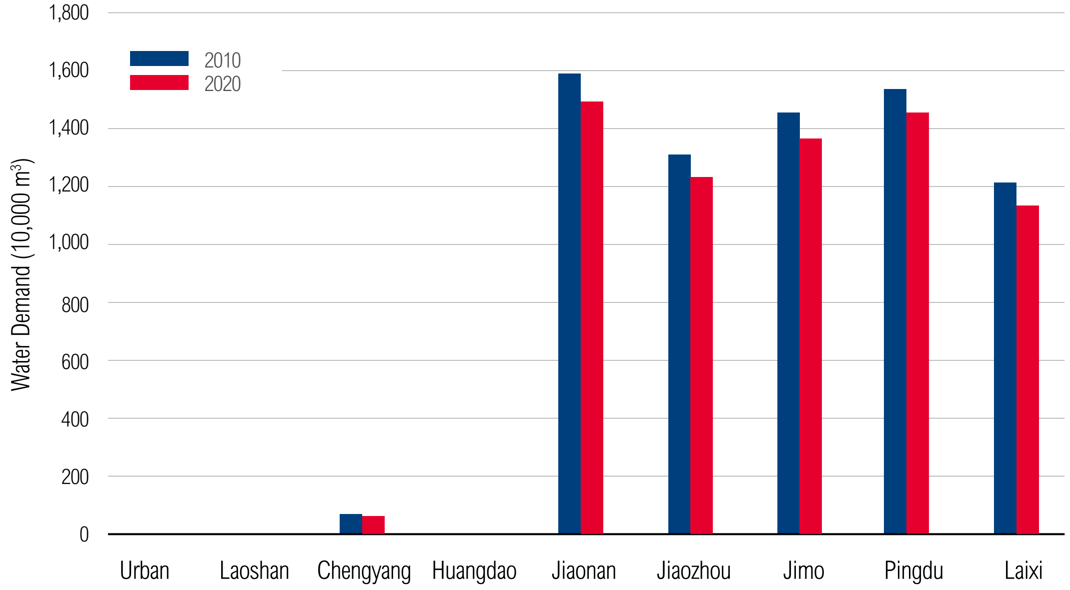
Note: Rural domestic water use in Laoshan, previous Huangdao and Chengyang district, is included in the integrated rural and urban water supply system.

Table I-11 | **Qingdao's Rural Domestic Water Demand in 2020 (in 10,000 m^3)**

FORMER ADMINISTRATIVE DIVISION	URBAN	LAO-SHAN	CHENG-YANG	HUANG-DAO	JIAONAN	JIAO-ZHOU	PINGDU	JIMO	LAIXI	TOTAL
Water demand	0	0	59	0	1,498	1,233	1,366	1,454	1,135	
NEW ADMINISTRATIVE DIVISION	URBAN	LAO-SHAN	CHENG-YANG	HUANG-DAO	JIAO-ZHOU	PINGDU	JIMO	LAIXI		6,745
Water demand	0	0	59	1,498	1,233	1,366	1,454	1,135		

Note: Rural domestic water use in Laoshan, previous Huangdao and Chengyang district, is included in the integrated rural and urban water supply system.

Figure I-6 | **Comparison of Qingdao's Rural Domestic Water Consumption in 2020 and 2010**



III.4 Comparison among the Estimated Values, Planned Values and Values from Related Studies

Based on the estimate by WRI, the rural domestic water consumption will be 67 million m³ in 2020 in Qingdao.

SOURCE	RURAL DOMESTIC WATER DEMAND IN 2020 (100 MILLION M³)	Note
The 11th 5-year construction planning for the comprehensive utilization and development of Water Resources in Qingdao (2007)	0.56	Water consumption quota method
Qingdao's planning on modernization of the water conservancy (2012)	0.75	
WRI estimate	0.67	Water consumption quota method

IV. ESTIMATE OF WATER DEMAND FOR LIVESTOCK BREEDING

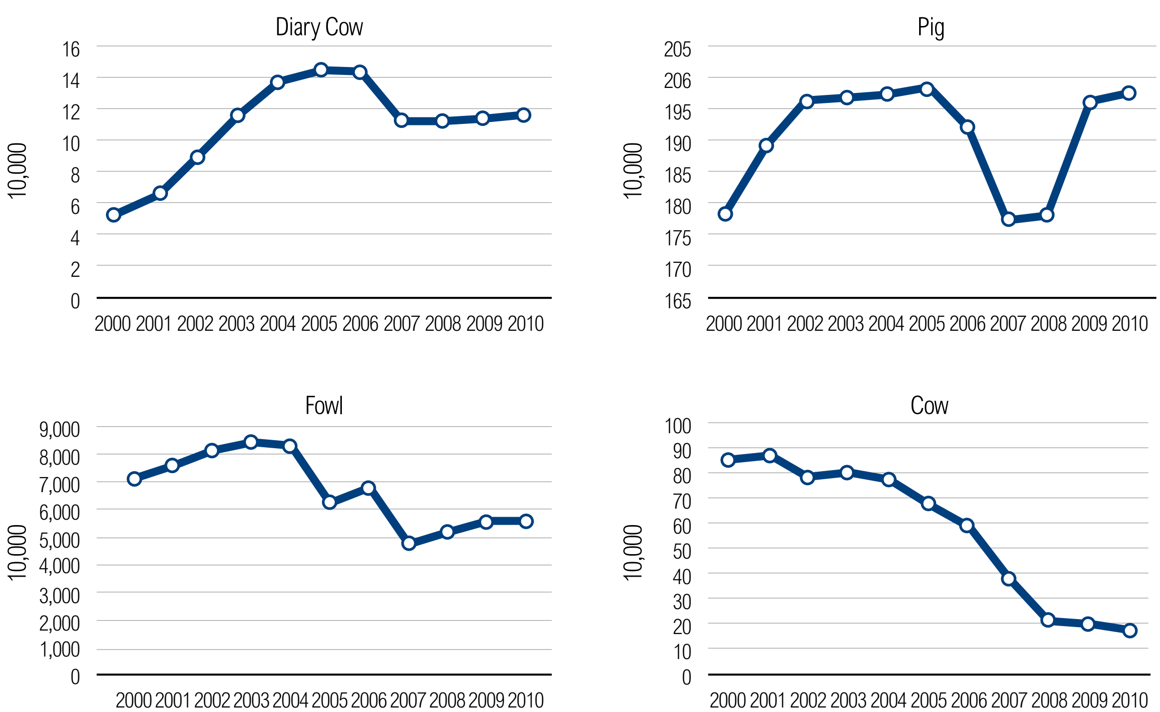
As industrialization and urbanization accelerate in Qingdao, demand for animal products by new urban residents will grow quickly and inelastically. Meanwhile, agricultural administrations will further adjust the types of livestock and industrial layout to facilitate the construction of a standardized breeding base in scale. This will promote the transformation of animal husbandry from quantity oriented to quality and benefit oriented, from extensive to intensive and from a resource-intensive style to a circulation style[34]. The water use efficiency of livestock breeding will improve further.

IV.1 Estimate of the Output of Major Livestock Products

Since 2000, the year-to-year fluctuations of major livestock in Qingdao have been relatively large. The number of dairy cows and pigs has grown, while the number of beef cattle and poultry has decreased gradually (Figure I-7).

According to the *12th Five-Year Plan for the Development of Animal Husbandry in Qingdao*, future development will focus on

Figure I-7 | **Changes in Major Livestock Numbers in Qingdao**



Data Source: Qingdao Statistical Yearbook 2001-2011 (QDSB, 2002-2012) seven major livestock products: pigs, dairy cows, broiler chickens, laying hens, beef cattle, meat rabbits and meat ducks. Table I-12 and Table I-13 show the number of livestock and the main production areas.

IV.2 Water Consumption Quotas for Animal Husbandry

According to the *Technical Code for Rural Water Supply Engineering (SL310-2004)* and the projected livestock products in Qingdao, the quotas of water consumption for major livestock products are determined as shown in Table I-14.

IV.3 Estimate of the Water Consumption of Livestock Farming

The water consumption of livestock breeding in 2020 in Qingdao is estimated to be 28.42 million m^3, based on the estimates of livestock numbers and the water consumption quota. Pig breeding and poultry feeding consume the most water, and together make up about 84% of the total livestock breeding water consumption. Laixi has the highest water consumption for livestock breeding, which accounts for nearly one-third of the total livestock water consumption. See Table I-15 for the water consumption by district and by livestock species.

Table I-12 | **Estimate of the Number of Major Livestock Products in 2020 in Qingdao**

YEAR	PIGS (MILLION)	DAIRY COWS (MILLION)	BEEF CATTLE (MILLION)	BROILER CHICKENS (MILLION)	LAYING HENS (MILLION)	MEAT DUCKS (MILLION)	MEAT RABBITS (MILLION)
2010	3.3	0.115	0.077	160	20	13	4
2020	4	0.143	0.1	250	20	15	13

Table I-13 | **Major Livestock Producing Areas in Qingdao**

LIVESTOCK	MAIN PRODUCTION REGIONS AT PRESENT	MAIN PRODUCTION REGIONS IN THE FUTURE
Pigs	Five Counties	Five Counties
Dairy Cows	Laixi, 60%	Laixi, Jiaozhou, Jimo
Beef Cattle	Pingdu, Laixi	Pingdu, Laixi
Broiler Chickens	Laixi, Jimo, Pingdu	Laixi, Jimo, Pingdu, Jiaonan
Laying Hens	Jiaozhou, Jimo, Pingdu	Jiaozhou, Jimo, Pingdu
Meat Ducks	Pingdu, 93%	Pingdu, Jiaozhou
Meat Rabbits	Jiaonan, 90%	Jiaonan, Jiaozhou

Data Source: The 12th Five-Year Plan for the Development of Animal Husbandry in Qingdao (QDAHB, 2011)

Table I-14 | **Quotas of Water Consumption for Major Livestock Products in 2020 in Qingdao (L/Day)**

PIGS	DAIRY COWS	BEEF CATTLE	BROILER CHICKENS	LAYING HENS	MEAT DUCKS	MEAT RABBITS
20	50	50	0.5	0.5	0.5	0.3

Table I-15 | **Water Demand by Livestock Breeding in 2020 in Qingdao (in 10,000 m^3)**

LIVESTOCK	DAIRY COWS	BEEF CATTLE	POULTRY	PIGS	RABBITS
Laoshan	0.45	0	9.89	7.6	0
Chengyang	13.57	0	45.17	29.67	0
Huangdao	0.23	0.1	1.92	6.26	0
Jiaonan	2.94	24.84	74.81	214.98	35.1
Jiaozhou	11.08	33.47	95.3	192.48	3.9
Jimo	33.02	13.1	203.41	144.88	0
Pingdu	11.76	65.58	310.14	352.32	0
Laixi	187.93	45.42	419.37	251.82	0
Total			2,842.48		

IV.4 Comparison of the Estimated Values, Planned Values and Values from Related Studies

Based on the estimate by WRI, the water consumption for livestock breeding will be 28 million m^3 in 2020 in Qingdao.

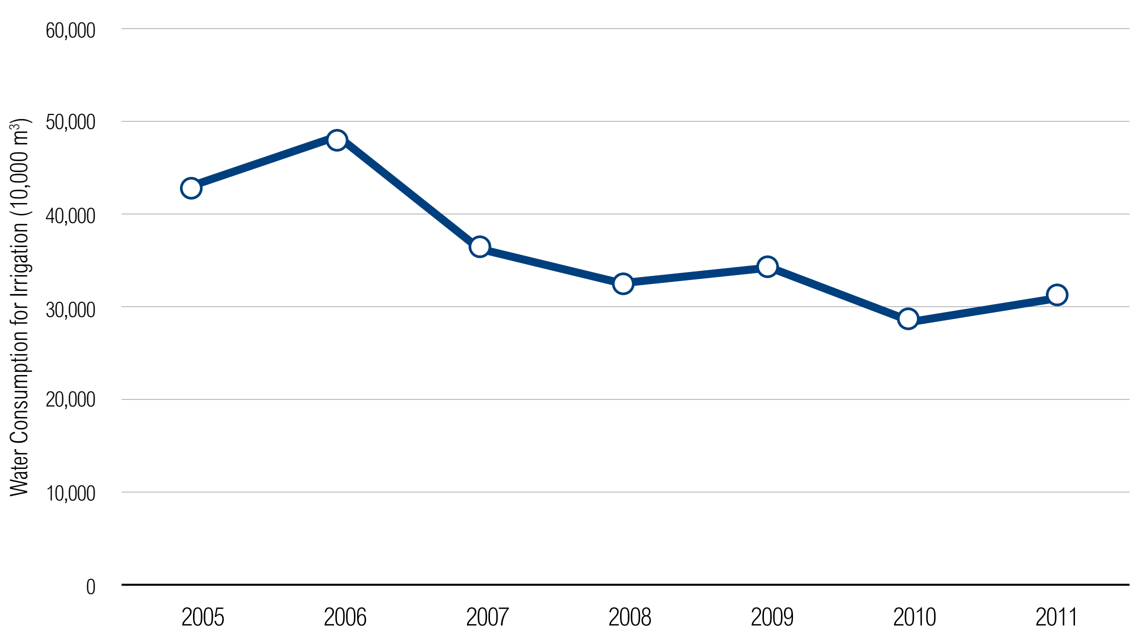
SOURCE	LIVESTOCK BREEDING WATER CONSUMPTION IN 2020 (100 MILLION M^3)	Note
The 11th 5-year construction planning for the comprehensive utilization and development of Water Resources in Qingdao (2007)	0.26	Water consump-tion quota method
Qingdao's planning on modernization of the water conservancy (2012)	0.25	
WRI estimate	0.28	Water consump-tion quota method

V. ESTIMATE OF THE WATER USED FOR IRRIGATION

Because of the promotion of water-saving irrigation and improvements in water use efficiency, the water consumed in Qingdao for irrigation has declined. The city's total irrigation water consumption dropped 28% between 2005 and 2011 (Figure I-8). The declining trend is especially apparent in 2006 and 2008, though it has reversed somewhat since 2010. That is because irrigation water consumption is impacted by factors such as precipitation, evaporation, temperature, relative humid-ity, irrigation management level, crop species and planting area, irrigation mechanism, water source and irrigation cost. The uncertainties result in siginificant fluctuations from season to season and year to year.

Currently, the main methods for estimating irrigation water include the penman method, auto regression moving aver-age (ARMA) method, water consumption quota method, grey predicting method and artificial neural network method. Table I-16 shows the advantages and disadvantages of each method. The water consumption quota method requires less data and is more suitable for long-term prediction, compared to the other methods. Therefore, the water consumption quota method is adopted by this study to predict the irrigation water consumption in Qingdao.

Figure I-8 | **Variations in Water Consumption for Irrigation from 2005 to 2011 in Qingdao**



Data Source: Qingdao Water Resource Bulletin 2004-2011

Table I-16 | Comparison of Various Estimating Methods for Irrigation Water Consumption

	ADVANTAGES	DISADVANTAGES
Penman Method[a]	Factors like crops, evaporation, precipitation and field leakage are considered in calculating the irrigation water consumption	High data demand, such as meteorology data, planting structure and soil physical data.
Auto Regression Moving Average (ARMA)[a]	Prediction with time hyphen series data, low data demand and suitable for short-term predictions.	Singularity of model data type, significantly impacted by abnormal values and large errors in long-term predictions
Regression Analysis Method[a]	Suitable for long-term predictions	The accuracy is impacted by too many variablees, not suitable for short-term predictions
Water Consumption Quota Method[a]	Water consumption quota is determined according to the actual demand of the crops; the prediction is relatively accurate and requires less data	Heavily impacted by actual irrigation area and irrigation performance
Grey Predicting Method[a,b]	Low data demand, suitable for cases with raw data that has no clear pattern	Dynamic changes in time series are simulated by Exponential model, while the water consumption volume is not a simple exponential relationship.
Artificial Neural Network Method[a,b]	Black-box model, suitable for short-term predictions	Not suitable for long-term predictions

Source: a. Huang, Kang, and Wang, 2004;
b. Liu, Hu, and Wu, 2008

Table I-17 | Irrigation Quota for the Planting Industry in 2020 in Qingdao

	EFFECTIVE UTILIZATION FACTOR OF IRRIGATION WATER	Irrigation Water Consumption Quota (m^3/Mu)
2015	0.66	105
2020	0.68	102

V.1 Determine the Water Consumption Quota

The irrigation water consumption quota refers to the total irrigation water supplied from the water source per unit of irrigation area within the crop-growing period. It is determined according to the region, crop species, water source type, irrigation method and efficiency. For example, the water demand of corn is less than that of wheat, while the water consumption of wheat is far less than that of cotton (Mekonnen and Hoekstra, 2010). The transmission loss of well irrigation, which is widely used in Qingdao, is less than that of transferring water from the Yellow River.[35] The higher the effective utilization factor of irrigation is, the lower the quota will be [36].

According to the 12[th] *Five-Year Water-Saving Irrigation Plan in Qingdao*, the overall water consumption quota for planting in 2015 was 105 m^3/mu, if the effective utilization factor of irrigation is 0.66.

Since the irrigation water quota is closely related to the irrigation efficiency, we adjusted the water consumption quota for 2020 based on the planned effective utilization factor of irrigation water. The overall water consumption quota for planting is estimated to be 102 m^3/mu in 2020 in Qingdao.

V.2 Area of Irrigation

The 12[th] *Five-Year Plan for the Development of Agriculture in Qingdao* projected that the effective irrigation area in the whole city would rise slightly from the current 4.98 million mu to 5.10 million mu by the year 2015. However, even as Qingdao urbanizes, the arable land in the city will be kept stable under the policy of "dynamic balance of the total amount." According to the analysis in Qingdao's 12th Five-Year plan for water-saving irrigation, transferred water can only be used for urban water demands, not irrigation, because of the high cost. Therefore, we estimate that the potential to further expand the irrigation area in Qingdao is limited, and the effective irrigation area in 2020 will be kept the same as that in 2015.

V.3 Quota Calibration

The traditional quota method is based on the estimated value of just irrigation. The supplementary water that comes from natural precipitation is not considered, which results in an obvious over-estimation. Based on the analysis of local precipitation levels, precipitation in Qingdao can be used to supplement irrigation and it is impossible to completely depend on artificial rainfall. To compensate, we adjusted the estimated results.

According to the statistical data of recent years in the *Qingdao Water Resource Bulletin*, agriculture irrigation water use is impacted by climate and actual irrigation area. It fluctuated, but declined overall. Compared to the theoretical values given by the water consumption quota method, the actual irrigation water consumption was always lower than the estimated quota, except for the year 2006, which was heavily impacted by drought. Between 2005 and 2011, the difference between Qingdao's actual irrigation water and quota was between 0.55 and 1, with an average difference of 0.75 (i.e. 75%).

Assuming the precipitation in 2020 in Qingdao remains the same as between 2005 and 2011, then the adjustment factor for actual irrigation water consumption is 0.75, which means the actual irrigation water consumption will be only 75% of the estimated quota.

Table I-18 | **Estimate of Effective Irrigation Area in Each Administrative District in Qingdao (in 10,000 Mu)**

	2010	2020
Laoshan	1.08	1.08
Huangdao	2.15	2.15
Chengyang	2.97	2.97
Jiaozhou	58.5	62.08
Jimo	83.45	87.32
Pingdu	193.37	197.04
Jiaonan	64.79	67.16
Laixi	86.82	90.2
Total	493.11	510

Figure I-9 | **Difference between Actual Irrigation Water Consumption and Estimated Quota Value in Qingdao**

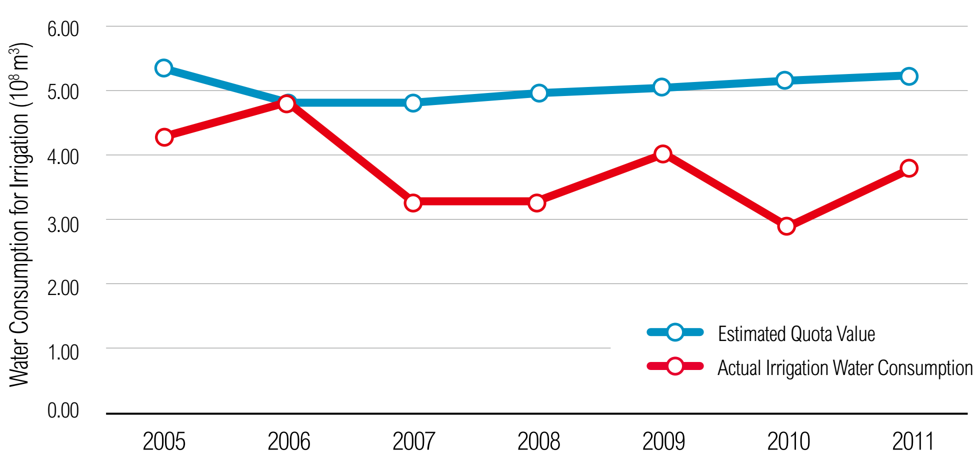


Table I-19 | **Irrigation Water Demand in Each Administrative District in 2020 in Qingdao**

	CULTIVATED FARMLAND AREA (104 MU)	Water Consumption Quota (104 m^3)	Adjusted Irrigation Water Demand (104 m^3)
Laoshan	1.08	110	83
Huangdao	2.15	219	164
Chengyang	2.97	303	227
Jiaozhou	62.08	6,332	4,749
Jimo	87.32	8,907	6,680
Pingdu	197.04	20,098	15,074
Jiaonan	67.16	6,850	5,138
Laixi	90.2	9,200	6,900
Total	510	52,020	39,015

V.4 Estimated Results Using the Water Consumption Quota Method

Given that the 2020 water consumption quota for the planting industry is 102 m^3/mu, the city's irrigation water demand is estimated to be 0.52 billion m^3 (using the water consumption quota method). When supplementary water from precipitaton is taken into consideration, the irrigation water consumption of the whole city will be 0.39 billion m^3 (after adjustment) (Table I-19).

V.5 Comparison of the Estimated Values, Planned Values and Values from Related Studies

Based on expert consultations, the proportion of society's total water consumption devoted to agricultural use will decline, since the total water supply is limited, population is growing and urbanization and industrialization are increasing. Any added water supply is mainly for the demands by the industrial and urban development, as well as living standard improvements. Qingdao's agriculture water shortage is projected to continue for a long time. Therefore, irrigation water consumption in Qingdao will not increase tremendously. The best estimate comes from the adjusted value by the water consumption quota method, which estimates irrigation water demand at 0.39 billion m^3 in 2020.

SOURCE	IRRIGATION WATER DEMAND IN 2020 (100 MILLION M^3)	Note
The 11th 5-year construction planning for the comprehensive utilization and development of Water Resources in Qingdao (2007)	4.68	Water consumption quota method (guarantee rate at 50%, water conservancy effective coefficient at 80%)
Qingdao's planning on modernization of the water conservancy (2012)	5.50	
WRI estimate: water consumption quota method	5.2	Water consumption quota method (guaranteed rate at 50%, water conservancy effective coefficient at 0.66)
WRI estimate: adjusted value based on water consumption quota method	3.9	Water consumption quota method (guaranteed rate at 50%, water conservancy effective coefficient at 0.66 and adjustment factor at 0.75)

VI. SUMMARY OF QINGDAO'S WATER DEMANDS IN 2020

In summary, Qingdao's total water demands in 2020 will be 1.48 billion m^3. Table I-20 shows the estimates of the demands of each administrative district.

Table I-20 | **Qingdao's Total Water Demand in 2020 (in 10,000 m^3)**

	INDUSTRY	DOMESTIC AND MUNICIPAL URBAN DEMAND	RURAL RESIDENTS	LIVESTOCK	IRRIGATION	ECOLOGICAL AND ENVIRONMENT	TOTAL
Urban	1,297	15,782	0			3,961	148,017
Laoshan	899	2,882	0	18	83	1,733	
Chengyang	3,217	11,486	59	88	227	621	
Huangdao	5,146	9,332	0	9	164	808	
Jiaonan	4,922	3,852	1498	353	5,138	727	
Jiaozhou	4,185	3,677	1,233	336	4,749	963	
Jimo	4,109	3,035	1,366	394	6,680	916	
Pingdu	3,793	5,483	1,454	740	15,074	655	
Laixi	2,532	2,785	1,135	905	6,900	615	

Note: The estimated water amount for ecological and environmental uses is from "Qingdao's Planning on Modernization of the Water Conservancy" (2012).

APPENDIX II

COMPARISON OF THE CHARACTERISTICS AND RISKS OF DIFFERENT WATER SOURCES

	LOCAL SURFACE WATER (RESERVOIR)	LOCAL GROUND WATER	TRANSFERRED WATER	SEAWATER DESALINATION	RECLAIMED WATER	RAINWATER
Water Source Guaranteed Rate	Storage can be adjusted, guaranteed to a certain degree, but the reservoir may be reduced or dried during long-term drought or high temperature.	Relatively stable amount, high guaranteed rate. However, depletion could happen due to ground water overexploitation, and the guaranteed rate will decrease gradually in the future.	Continuous water supply is limited by freezes and cut off in wintertime; the longer the distance of the diversion route, the higher the uncertainty will be.	Long-term secured supply, but the discharge of high-salinity effluent in enclosed bay areas may increase the salinity of those waters.	Can be assured as long as municipal water use is supplied.	Almost all comes from precipitation; storage is limited and highly impacted by weather and climate.
Seasonal Change Rate	Impacted by seasonal changing precipitation with long-term fluctuations.	Compared to surface water, the storage is relatively stable, but still impacted by seasonal and total precipitation.	Impacted by seasonal precipitation changes in broad areas, and many factors involved.	Sufficient resources, stable filtration treatment, not easily impacted by other climate or seasonal factors.	Is assured since urban water resource is essentially steady; the challenge is how to utilize it efficiently.	Large season-to-season variations and total amount that can be utilized is limited.
Land Occupation	Large area in the upstream watershed is submerged due to water storage reservoirs.	Low land occupation by the ground water extracting wells and low demand for supporting facilities.	Large land areas required to develop the channel for long-distance diversion.	Low land occupation by the seawater desalination facilities.	Only a small area of land in cities is occupied by reclaimed water facilities.	Households can be modified to collect rainwater using the undeveloped parts of the roof.
Capital Investment	Capital-intensive and huge difficulty in construction, repeated surveys and studies are required.	Relatively low capital investment, large scale projects are not needed, facilities can be scattered according to the distribution of ground water.	Large investment for buiding water transmission canal, large areas involved.	Complicated technologies and relatively high investment cost. However, due to location in coastal areas, supporting infrastructure is complete. Seawater desalination is not expensive due to increases in price of water. The price is only half that of long-distance water diversion. Significant advantage in areas with water shortage.	Large one-off investment. The reusing system requires professional management staff and the operational cost must be secured.	Low investment and low technical requirements. Cost and investment are limited, but it is hard to recover the investment at current water prices.

	LOCAL SURFACE WATER (RESERVOIR)	LOCAL GROUND WATER	TRANSFERRED WATER	SEAWATER DESALINATION	RECLAIMED WATER	RAINWATER
Energy Consumption	Low energy consumption due to the height difference that can be utilized.	Due to possible depletion caused by ground water over-exploitation, water resources may not be accessable using existing wells. Therefore, digging new wells or extending existing ones will increase the cost.	Some long-distance water diversion projects need to overcome height differences with energy-intensive pumps.	Relatively high energy consumption using current technology.	Low energy consumption due to biological or natural treatments.	Nearly no energy consumption, water stored by gravity, no energy-consuming facilities needed.
Ecological Impact	Hinders fish migration, changes the downstream water composition, quality and temperature, reduces the downstream flow, threatens the living environment of downstream species. Meanwhile, upstream species could be easily threatened by invasive species. Rapid growth of evaporative area due to the lake formed by blocking rivers with dams and reservoirs leads to significant changes in the climate at the shallower parts of reservoirs. The increased rainfall may cause debris flows and landslides.	Surface subsidence after ground water is withdrawn, lower flows in the rivers around ground water basin and loss of lakes. It takes an extremely long time to restore an independent water source after over-exploitation; pipeline corrosion by seawater leakage leads to further damage to the equipment that separates seawater and fresh water.	Impact on the receiving area: reduces flood risk in the supplying area, improvements to the climate/environment, ground water and water quality in the water passing area, mitigates ecological risks in the receiving area. Impact on the supplying area: reduces diversion river flow and leads to saline water flowing back, causes water shortage in supplying area; worsens the flow conditions of the watercourse and the water quality; largely damages the landscape; water leaking in transmission channels leads to soil salinization; invasion of invasive plants.	To prevent the oxidation of equipment and pipelines, oxygen is removed during the treating processes. The discharge has high salinity but lacks oxygen; high content of Cl ion in the effluent due to the chlorine used in the sterilization process before the treatment; high temperature due to heating during the processes can kill marine animals. Additionally, since the concentration of boron in the discharged water is higher than in the seawater, it settles to the seabed and causes ecological and environmental damage.	Facilitates the efficient use of ecological environment; studies indicate that the effects to growing and harvesting crops irrigated with reclaimed water are similar to wastewater. It is suggested the water be used only after treatment due to the potential soil structure change.	Normally suitable for urban areas without pollution; has almost no direct impact on natural environment due to being separated.

	LOCAL SURFACE WATER (RESERVOIR)	LOCAL GROUND WATER	TRANSFERRED WATER	SEAWATER DESALINATION	RECLAIMED WATER	RAINWATER
Environmental Pollution	Original plants are submerged by reservoirs and original forests decay and decompose, therefore a large amount of sequestered carbon dioxide is emitted into the air and causes slight environmental pollution.	The extraction processes cause relatively little pollution; does not cause cross-regional contamination or polluting discharge problems.	Higher risk on the whole basin, ecological disaster can be caused due to cross-basin pollution once pollution occurs upstream.	Water discharged to the sea from seawater filtration facilities may have high concentration of boron, residual heavy metals due to water purification equipment corrosion, pollution caused by acid and alkali used for sterilization of membrane cleaning.	Nearly no environmental pollution; improves the urban ecological environment and reduces the resource pressure on the environment.	The treatment approach is clean and has no pollution.
Project Relocation	Residents from the area being inundated by water storage at the upstream site must be relocated.	Little negotiation needed due to limited construction area and small land occupation.	Residents in the area with watercourse flowing through require relocation, farmers occupying the land need to be compensated by other methods.	Issue does not exist because projects are mostly built in coastal areas.	Fits well in the urban environment and offers new jobs.	In harmony within resident districts, can be retrofitted at various buildings.
Public Acceptance	Aggressive measures by governments during the relocation processes may cause various group events.	High public acceptance due to the long history.	The needs of local residents must be satisfied in the negotiation of water storage land procurement; some relocated residents' lives may experience huge changes.	Most residents in the Middle East and California support the construction of seawater desalination facilities.	Public doubt towards the direct use of reclaimed water. Acceptance is growing with increased proliferation.	Normally high public acceptance.

Sources:

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GLOSSARY

Fresh Water Resources: the water found in rivers and lakes, accumulated snow on mountains, glaciers, and in the ground. The water resources that humans use mainly consist of lakes, rivers, soil moisture, and shallow groundwater basins, which constitute about 1% of the earth's total fresh water volume. In a narrow sense, fresh water resources refer to the fresh water that can be used directly by humans.

Low Temperature/Multiple Effect Seawater Desalination: the distillation desalination technique in which the maximum evaporation temperature of saltwater is lower than 70°C. The technique involves connecting a series of horizontal tubes in a falling film evaporator. A certain amount of steam is inputted into the tubes in the first vessel (called an "effect"). The heat of the steam evaporates some of the seawater in the effect. That steam is routed in a tube to the next effect, where the heat evaporates more seawater. The evaporation temperature in each effect is lower than in the previous effect. The evaporation and condensation process is completed multiple times, resulting in an output of distilled water.

Surface Water: the water on the surface of the earth's crust that is exposed to the air. It's a generic term for four water bodies (rivers, glaciers, lakes and swamps), also called "land water." It is one of the important water sources for human life.

Groundwater: the water hidden and moving in the soil layer and rock voids at various depths under the surface of the earth. In a narrow sense, it refers to the water at a depth of less than 1,000 m. It can be classified as aeration zone water, diving water and confined water, based on the hidden conditions. It can also be classified as pore water, fissure water and karst water.

Multi-Stage Flash (MSF) Seawater Desalination: a desalination technique in which heated seawater is evaporated in multiple flash chambers with declining pressure, extracting fresh water through steam condensation. The technique is mainly co-constructed with a thermal power station. It works well for large and extra-large desalination facilities, and is mainly used in Gulf countries.

Reverse Osmosis (RO) Seawater Desalination: a desalination technique in which a semipermeable membrane allows only solvent to pass through and not solute, thereby separating seawater and fresh water. External pressure greater than the solution's osmotic pressure is applied to the water feed-in side of the membrane. Only fresh water can pass the semipermeable membrane; other substances cannot pass through and are kept at the surface of the membrane.

Unconventional Water Resources: the water resources other than regularly-used surface water and groundwater. They mainly consist of rainwater, reclaimed water (wastewater and contaminated water after regeneration treatment), seawater, water in the air, pit water and brackish water. The commonality between these water sources is that they can be reclaimed and reused after treatment. The main methods of using and developing unconventional water sources include reclaimed water treatment, rainwater, seawater desalination, direct application of seawater, artificial precipitation, pit water utilization and brackish water desalination.

Industrial Water: the volume of water used directly and indirectly in the industrial production process.

Seawater Desalination: the process of removing the salt from seawater to obtain fresh water. Seawater desalination techniques are sorted into two major categories: distillation methods (thermal methods) and membrane methods. Currently, the most widely used methods are multi-stage flash, low temperature/multiple effect and reverse osmosis.

External Water: the water that comes from outside a given area. This includes water in an inbound river and water in a diversion project, as well as rolling slope water caused by rainfall that comes from high-elevation areas. External water can be used in case of a shortage of local water sources.

Agricultural Water: the water for irrigation and rural livestock. Agricultural irrigation water consumption is influenced by factors such as water consumption efficiency, climate, soil, crops, planting method, irrigation technique, and canal system efficiency. There are obvious differences between regions, and the volume of water consumed will vary due to the differences in water sources, crop species and planting area.

Three Red Lines: targets set in a strict water resource management program that was set up by the central government in 2011. The program established the "three red lines" for the total volume of water consumption, the efficiency of water consumption and the limitation of waste in water functional area. The corresponding targets (i.e., three red lines) were developed for these three programs.

Domestic Water: urban water consumption and rural water consumption for daily life. Urban water consumption is composed of residential water consumption and water for public services (including water for the service industry, catering services, goods transportation, postal and telecommunication, and the construction industry).

Water-Electricity Co-production: the co-production and co-supply of desalinated seawater and power generation. Since the cost of seawater desalination largely derives from the cost of electricity and steam, water-electricity co-production can lower costs by providing the power and steam for the seawater desalination facility from the power plant. Combining desalination and power generation results in highly efficient energy use and lower desalination costs. Currently, most large seawater desalination plants are built this way.

External Diversion Water: the diversion of large volumes of water from a region with extra water to a region with a water shortage; also called cross-basin diversion water. The water is diverted via an artificial method in large volumes to facilitate the economic development in the water-poor area, and to relieve the pressure on water consumption for humans and livestock within the basin.

NEWater: high-quality reclaimed water promoted by Singapore. The treatment of NEWater relies on two advanced techniques, micro-filtration and reverse osmosis, to filter out small impurities such as dissolved salts, drugs, chemical substances and viruses. The final step is UV sterilization, and the result is NEWater, which can be recycled and reused. The quality of NEWater meets the drinking water standard defined by the World Health Organization.

Total Water Consumption Index: the amount of surface water, groundwater and external diversion water available for development and utilization in a certain area and within a certain time period. Reclaimed wastewater and seawater desalination are not controlled by the limits of the water consumption control index in the planning period and annual water consumption control index.

Reclaimed Water: treated water that meets the requirement for a certain type of application, and reaches some kind of water quality standard after appropriate treatment.

ENDNOTES

1. US' urban population percentage increased from 15.4% in the year 1850 to 39.6% in the year 1900 accounting to US Census Bureau (see: http://www.census.gov/population/www/censusdata/files/table-4.pdf). The Great Britain's urban population rate was estimated at 17.4% in the year of 1801 and at 34% in the year of 1881 according to the historical population of England (see: https://en.wikipedia.org/wiki/Demography_of_England) and the towns and cities in England by historical population (see: https://en.wikipedia.org/wiki/List_of_towns_and_cities_in_England_by_historical_population)

2. Speech of Mr.Wu Guihui, Vice Administrator of National Energy Administration of National Development and Reform Commission, at the China Rural Energy Development Forum, 2007. See http://www.china.com.cn/zhibo/2007-11/23/content_9276077.htm

3. Vice Minister Hu Siyi of the Ministry of Water Resources said that 2/3 of the cities in China were facing water shortage problem. Chinanews Net, 16 Feb 2012, see: http://finance.chinanews.com/ny/2012/02-16/3673445.shtml

4. It was reported that nearly 90 percent of coastal cities in China were in short of water. Xinhua Net, 28 Oct 2012, see: http://news.xinhuanet.com/politics/2012-10/28/c_123878813.htm

5. Information from the website of California Public Utilities Commission. http://www.cpuc.ca.gov/PUC/Water/oeep/

6. Take the US for example, the total energy consumption of its urban water system is 3-4% of the national energy consumption, see: http://water.epa.gov/infrastructure/sustain/waterefficiency.cfm

7. Information from the website of Qingdao City Government, see: www.qingdao.gov.cn/

8. *Reply to the Approval of Administrative Divisions Adjustments of Qingdao, Shandong Province,* the No.153 National Letter of the State Council, 2012

9. Laoshan district is analyzed separately in this study since this district is designated as a tourism area. If not specified, "East bank area" refers to Shibei District (previous Shibei District and previous Sifang District), Shinan District and Licang District.

10. According to the *Implement Actively the Strictest Water Resource Management Mechanism to Assure the Sustainable Development of Economy and Society,* Qingdao Water Resource Bureau, 7 May 2012. See: http://www.mwr.gov.cn/ztpd/2012ztbd/qgszygzhyt/jlfy2/201205/t20120507_320890.html

11. The raw water price for projects include two part, basic water price and measured water price. The basic water price is used for operational management, project maintenance and repayment of the project construction investment that needs paying no matter water is used or not. While measured water price includes other costs such as electricity cost for drawing water and material cost which will be paid according to the actual used amount.

12. According to the *Notice about the Policy on Water Price in the Initial Operation Phase of the Main Project of the East Line Phase I of South-to-North Water Diversion,* No.30 Price Policy Paper of the National Development and Reform Commission, 2014.

13. Reported news at People.cn, *Dilemma Faced by East Line in South-to-North Water Diversion: Using Water or Not, Jiangsu Needs to Pay over a Billion RMB. 2014.* See: http://sc.people.com.cn/n/2014/0114/c345460- 20385647.html

14. It is calculated according to various years of Qingdao Statistical Yearbook and Qingdao Water Resource Bulletin.

15. According to the *11th Five-Year Planning for the Construction of Water Saving Society,* No.236 Policy Paper for Environment and Nature Resources by the Development and Reform Committee, the Ministry of Water Resources, and the Ministry of Construction, 2007.

16. It was estimated according to various years of Qingdao Water Resource Bulletin

17. According to *China Urban Construction Statistical Yearbook 2010,* the eastern region includes Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Guangxi and Hainan.

18. The water quality and energy consumption of wastewater utilization depend on what the water is used for and treatment ways. For example, as the water quality standard of municipal miscellaneous water is lower than that of drinking water, the energy consumption of the former is lower. In contrast, the energy consumption of NEWater is relatively high treated by ultrafiltration and RO techniques, but the water quality is beyond the drinking water standard recommended by WHO.

19. It was estimated according to Qingdao Water Resource Bulletin 2011.

20. Data provided by Qingdao Sino-French Baisha River Water Treatment Plant

21. Currently, the cost for pumping water for irrigation on 1 mu land is around 7 RMB, and the electricity cost is 1.2 RMB/kWh (including administration fee). About 6 kWh is required for irrigating 1 mu of land and the water used for 1 mu of land is 15 m^3, so that it is calculated out that the unit electricity consumption is 0.4 kWh/m^3.

22. According to the *Master Planning of South-to-North Water Diversion Project,* National Development and Planning Committee and Ministry of Water Resources, 2002

23. It was reported that the South-to-North Diversion Project started to transfer water to Yantai and Qingdao in 2015, 7 May 2015. See: http://qingdao.benshixinwen. com/2015_05/77899.html

24. It was estimated that 600 million cubic meter water transferred to Shandong via the Eastern Line of the South-to-North Division Project. South-to-North Water Diversion Office, 27 May 2016. See: http://www.nsbd.gov.cn/zx/mtgz/201605/t20160530_441699.html

25. Texas Water Development Board. Brackish FAQs. http://www.twdb.state.tx.us/innovativewater/desal/faqbrackish.asp

26. http://www.pecc.org/resources/doc_view/1091-public-health-and-recycling

27. http://www.pub.gov.sg/water/newater/Pages/default.aspx

28. Interview with water resource expert by the author. It is also suggested by other scholars that the utilization rate of surface water resources can be kept between 60-70 due to the water resource shortage in Northern China (Qian and Zhang, 2001).

29. Due to the significantly uneven seasonal precipitation distribution in Qingdao as well as the heavy impacts on reservoir storage by drought seasons, it is suggested in this report to determine the upper limit of utilization rate of surface water resource at 0.55 of the long-time average surface water amount, which is less than the 0.905 billion m^3 (utilization rate at 0.57) mentioned in Qingdao's 11th Five-Year Plan for the Comprehensive Utilization and Development of Water Resources.

30. Modernization Planning of Water Conservancy in Qingdao, 2012, http://slj.qingdao.gov.cn/Item/6205.aspx

31. http://www.watereuse.org/sites/default/files/u3/Reza 20Sob-hani_0.pdf

32. Interviews with the staff of Huangdao Power Plant Seawater Desalination Plant

33. At the end of 2012, the application to adjust its administrative divisions to 6 districts and four county-level cities was approved by the State Council. Since then, Sifang District was included into Shibei District; Huangdao District and the county-level city Jiaonan were merged into a new Huangdao District

34. Qingdao Animal Husbandry Bureau, the 12th Five-Year Planning for the Development of Livestock Husbandry in Qingdao, 2011

35. Shandong Bureau of Quality and Technical Supervision. Irrigation Quota of Main Crops of Shandong Province. 2010

36. The valid utilization factor of irrigation refers to the ratio of water volume flowed into the field to be used by the crops to the total irrigation volume used by the irrigation system. It is related to the natural conditions in the irrigation area, engineering status, water consumption management and irrigation technique, etc., and it is an important index to assess the irrigation water consumption efficiency.

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