THE WATER BALANCE ASSIGNMENT FOR THE HYDROLOGY MODULE

By Patrick Sheppard

The Water Balance Assignment for the Hydrology Module

Table of Contents

Introduction to the Hydrology Module

Hydrology, or the science of understanding earth's water systems to help solve water problems (USGS, 2013), will be vital for China to make these changes successfully. Hydrology with regards to water resource management in China is the topic of this module.

Specifically, this module contains projects, assignments, and resources to help students understand hydrological concepts while concurrently learning about China and the importance of local context when tackling engineering challenges. It focuses on the Heihe River Basin in Northern China, a large inland river basin that occupies an area of approximately 130,000 km^2. Over the past thirty years, population, pollution, and water use have boomed in the Heihe River Basin, leading to environmental degradation and regional and sectoral water-use conflicts

The module is flexible so Professors and educators can mold it to fit their class. All of the assignments, projects, and resources can be used, or only a single assignment can be used. Course work covers topics such as basic water balances to predictive modeling of stream flows and precipitation. This technical content is always supplemented by information about local Chinese context, helping students to learn to grapple with the non-technical implications of engineering decisions and to think critically.

The objectives for the module are listed below:

1. Help students to understand basic hydrological concepts, such as water balances and predictive modeling of stream flows and precipitation
2. Help students to understand that they should understand the social, environmental, and economic contexts of an engineering problem to develop successful solutions
3. Foster critical thinking skills necessary for addressing open-ended projects
4. Expose students to contemporary China and make them more informed global citizens
5. Show students that the skills they are learning as scientists and engineers are valuable and can be used to address important and fascinating global challenges

If accomplished, these objectives will help students become not only technically competent, but globally competent as well, an important quality in today's globalizing world.

References

USGS. (2013). What is hydrology and what do hydrologist do? Retrieved from http://ga.water.usgs.gov/edu/hydrology.html

Background Reading

For this assignment, students will be asked to read four sections on this website for background reading.

1. Water Scarcity in China
2. Water, the Economy, and the Environment in China
3. Agriculture in the Heihe River Basin – the Major Economic Driver
4. Environmental Degradation in the Heihe River Basin

In addition, they will be asked to consult three external sources (1 newspaper article and 2 videos)

1. *Sending Water North* – this New York Times video is named for the South-North Water Transfer Project. However, it does an excellent job covering some of the overarching challenges regarding water in China, from water pollution to regional variability. It also includes some discussion on the economic impacts of water scarcity.
   http://www.nytimes.com/interactive/2007/09/28/world/asia/choking_on_growth_2.html#story3
2. *A Symbol of Health and Longevity, on the Verge of Extinction* – This is another New York Times video. It is short, and discusses the impact of pollution – both agricultural and industrial – as well as water scarcity on biodiversity in China. It will help students to think about the environmental impacts of poor water resource management.
   http://www.nytimes.com/interactive/2007/12/05/world/asia/choking_on_growth_6.html#story2
3. *China Faces Tough Choices on Water* – This is an article in the Guardian that broadly addresses some of the water issues in China, including the conflict between industry and agriculture, scarcity and waste, and the issue of paying for water. It is general, but it provides a good overview of these issues.
   http://www.guardian.co.uk/sustainable-business/china-water-choices

Students should fill out the fact finding worksheet below based on what they learn from the above sources.

Fact Finding Worksheet

What percentage of the world's water resources are located in China? What percentage of the population?

What percentage of China's water resources are located in the South? What percentage of the population?

How does the United Nations classify water poverty?

List three types of environmental degradation in the Heihe River Basin.

1. -
2. -
3. -

What percentage of the population in the Heihe River basin is farmers?

How much virtual water is exported from the Heihe River Basin? What percentage of the regions' water resources is this?

How many gallons will the South-North Water Transfer Project transfer to northern China?

Name three of the competing uses for water in China?

1. -
2. -
3. -

What percentage of China's mammals, reptiles and amphibians are endangered?

Is water currently expensive in China?

In what sector is water use most expected to grow in the next thirty years?

Water Scarcity in China

Between 1982 and 2010, China's population grew by over 330 billion people (World Bank, 2013), and its economy grew on average by 9.5% annually (China Water Risk, 2010). With these increases in population and economy also came increases in water use: between 1949 and 2007, China's water use quintupled (Yardley, 2007). China, however, contains only 6.5% of the world's water resources. With these resources, it must feed 22% of the world's population and fuel the world's second largest economy (Peng, 2011). Vast water demand, inefficiency, scarcity, and overuse, however, threaten China's ability to accomplish these goals. In an average year, among 662 Chinese cities, 300 will have insufficient water supplies and 110 will experience severe shortages (Jiang, 2009). Pollution further exacerbates this water shortage. In 2009, 43% of China's seven major rivers were characterized as grade IV or worse – unsuitable for human consumption (China Water Risk, 2010).

Worse, water supply within China is not evenly distributed (see Figure 1). The South, with only 55% of the population, holds roughly 80% of the available fresh water resources (Jiang, 2009). Therefore, the North, a hub for economic development, is suffering even more than the overall statistics for water resources in China suggest. The water resources per capita in the North are approximately 830 m^3 per person (China Water Risk, 2010). The United Nations (2012) classifies a region as water scarce if it contains 1000-1700 m^3 of water per capita. A region is in water poverty if it contains less than 1000 m^3 per capita (United Nations, 2012). In other words, water availability in Northern China is dangerously low. In some places, the situation is even direr. The capital city of Beijing, for example, contains only 230 m^3 of water per capita (China Water Risk, 2010b).

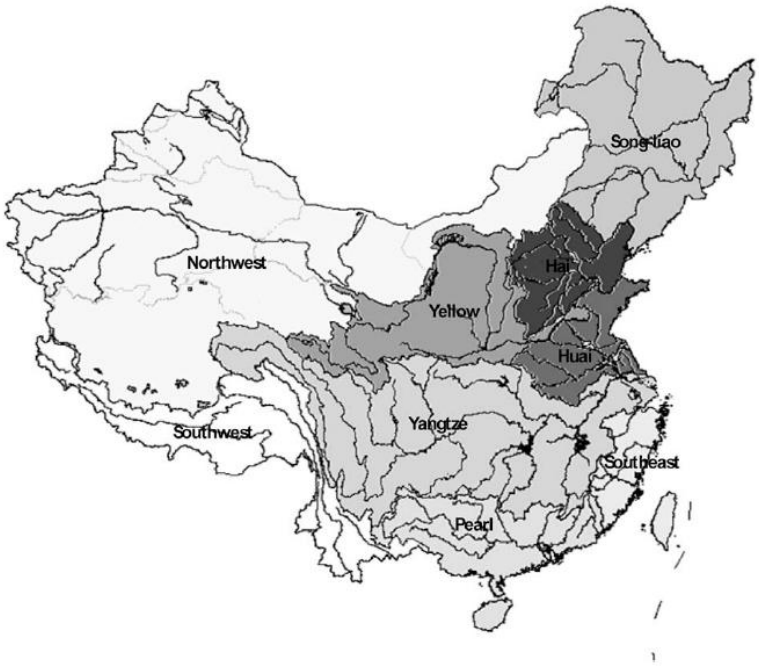

Figure 1: Map of China's major water sheds in China. Darker areas indicate areas of greater per capita water scarcity (Jiang, 2009)

Though bad now, these water issues are only expected to worsen. According to China Water Risk (2010a), China's population is expected to increase by 10% (150,000,000 more people) over the next ten

years, and by 2020, its GDP is expected to quadruple. For these reasons, water demand, exacerbated by increased standards of living, industry demands, and agriculture, will boom. Figure 2 shows both the expected water demand in 2015 and 2030 as well as the expected water supply gap should China's current water use practices continue. As the Figure demonstrates, an enormous area of China (all the dark blue) is not expected to meet between 20 and 80 percent of its water demands should current water resource management practices continue.

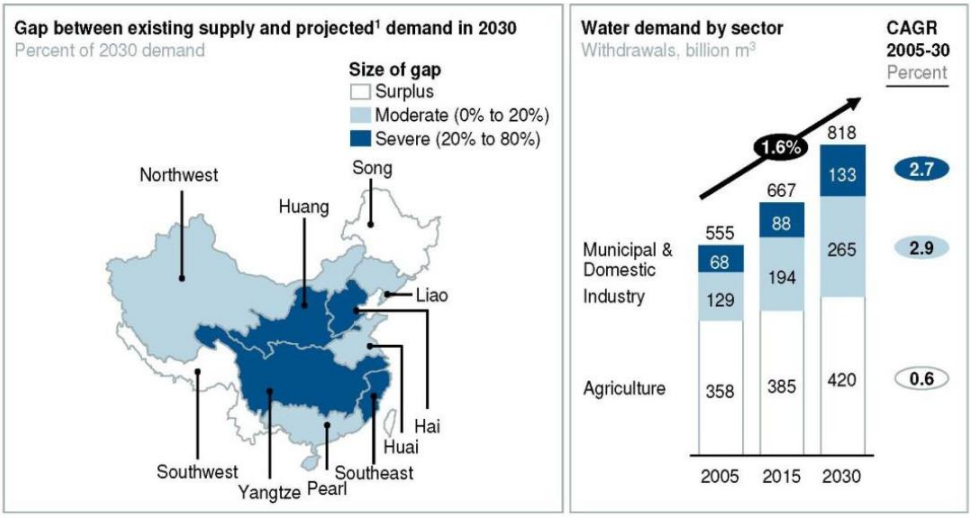

Figure 2: The image on the left illustrates projected water scarcity in China by 2030 should current water use practices continue. The image on the right shows projected water demand increases between 2005 and 2030 (Addams et al., 2009).

Because of these challenges, China needs to change the way it manages its water resources if it wants to avoid consequences to its food security, environment, and economic development as well as its citizen's quality of life.

References

Addams, L., Boccaletti, G., Kerlin, M., & Stuchtey, M. (2009). Charting our water future: Economic frameworks to inform decision-making. *New York, McKinsey & Company*

China Water Risk. (2010a). *China's water crisis part I -- introduction.*

China Water Risk. (2010b). *China's water crisis part II -- water facts at a glance.*

Jiang, Y. (2009). China's water scarcity. *Journal of Environmental Management, 90*(11), 3185-3196.

Peng, S. (2011). Water resources strategy and agricultural development in china. *Journal of Experimental Botany, 62*(6), 1709-1713.

United Nations. (2012). International decade for action 'water for life' 2005-2015. Retrieved from http://www.un.org/waterforlifedecade/scarcity.shtml

Yardley, J. (2007). Beneath booming cities, China's future is drying up. *New York Times, 28*

Environmental Degradation in the Heihe River Basin

The Heihe River Basin is not free of China's water problems. Over the past thirty years, the population and the economy of the Basin have boomed. Much of the economic growth in the economy resulted in increases in agricultural land and by increases in farming productivity. Figure 3 shows the increase in irrigated land in population between 1949 and 2002 (Tao, 2006).

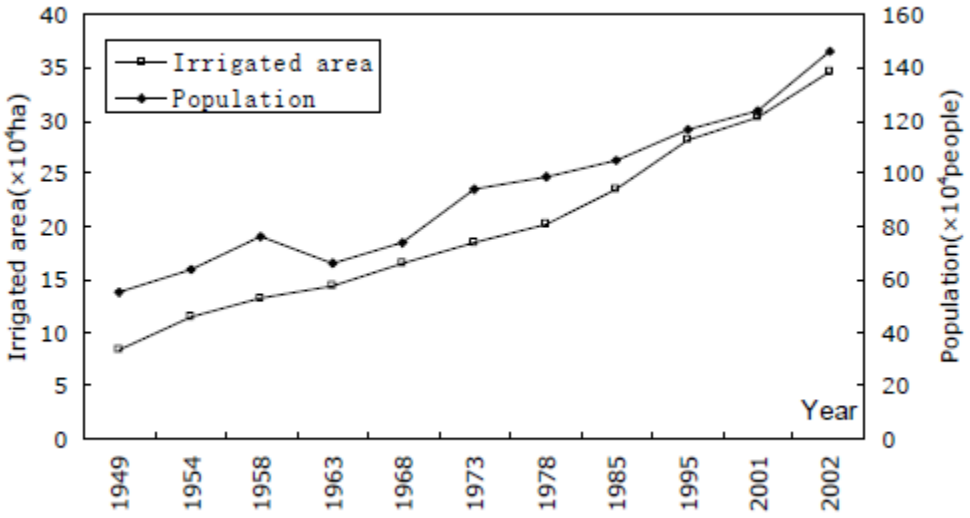

Figure 3: Increase in population and irrigated land between 1949 and 2002

As a result of this growth, water resources in the basin have become (1) increasingly scare and (2) increasingly polluted.

From your water balance, you should have determined that there is no longer enough water to meet demand in the Basin. This has resulted in extreme water shortages, which have caused surface water bodies to run dry, oases to shrink, biodiversity to decrease, salinization of soils, and desertification. Over the past 50 years, the Heihe River's two terminal lakes as well as 30 of its tributaries have run dry (Cheng, 2005). During the 1990s, flow into the Ejina Oasis decreased from more than 500-600 million m^3 per year to 300-400 million m^3 per year (Tao, 2006). This surface water scarcity has resulted in the overexploitation of groundwater resources, as shown in Table 1.

Table 1: Groundwater exploitation in the middle reaches of the Heihe River Basin for select years between 1980 and 1999 (Shanzhong, 2010)

Year	1980	1984	1986	1997	1998	1999
Water exploitation (10^8 m^3)	0.84	1.14	1.05	2.15	2.20	2.29

This water scarcity has adversely impacted the natural environment. Forest cover decreased by 343 km^2, degraded grassland increased by 3,498 km^2, desertified land expanded by 405 km^2, and salinized land increased by 835 km^2 (Tao, 2006).

In addition to water scarcity issues, the basin also faces extreme water pollution issues. The chemical composition of surface water in the middle and lower reaches has changed significantly. For example, according to Shanzhong (2010), ammonium nitrogen and potassium permanganate, from agricultural runoff, have exceeded the National Water Quality Standards of China in the Shandan River, a tributary of the Heihe River, by 87.5 and 50 percent, respectively. BOD content in this river exceeds water quality standards by 41% (Shanzhong, 2010). Development in the region is only expected to continue, and if current water resource management practices remain, the environment will degrade even further.

References

Chen, Y., Zhang, D., Sun, Y., Liu, X., Wang, N., & Savenije, H. H. (2005). Water demand management: A case study of the heihe river basin in china. *Physics and Chemistry of the Earth, Parts A/B/C, 30*(6), 408-419.

Shanzhong, Q. (2010). Land use induced water environment changes in the heihe river basin, arid northwestern china. Paper presented at the *Management and Service Science (MASS), 2010 International Conference on,* 1-4.

Tao, W. (2006). *Managing scarce water resources - China.*

Agriculture in the Heihe River Basin – the major economic driver

According to Tao (2006), the economy in the Heihe River is divided into three key zones: grazing in the mountainous regions of the upper reaches, small-scale intensive agriculture in the middle reaches, and large-scale extensive agriculture in the lower reaches. 83% of the population is farmers (Chen et al., 2005). The largest water demand comes from the middle reach, as this is where 90% of the irrigated farmland and 85% of the population is located (Tao, 2006).

As a result of this agriculture-based economy, the Heihe River Basin exports significant amounts of crops. Because crops consume water, then, this means that the Heihe River Basin also exports significant amounts of "virtual water." Virtual water is defined by the volume of freshwater required to produce a product (The Virtual Water Project, 2013). Crops that require more water for production, then, also contain more virtual water. Chen et al. (2005) attempted to quantify the amount of virtual water leaving the Heihe River Basin. As shown in Figure 4, they concluded that 823 Mm^3 were exported each year, 391 Mm^3 of which was green water (from precipitation) and 441 Mm^3 of which was blue water (from irrigation). Though the region exports a significant amount of virtual water, particularly for a water-scarce region, farmers' incomes are partly dependent on these exports (Chen et al., 2005). Is there a way to remedy this situation?

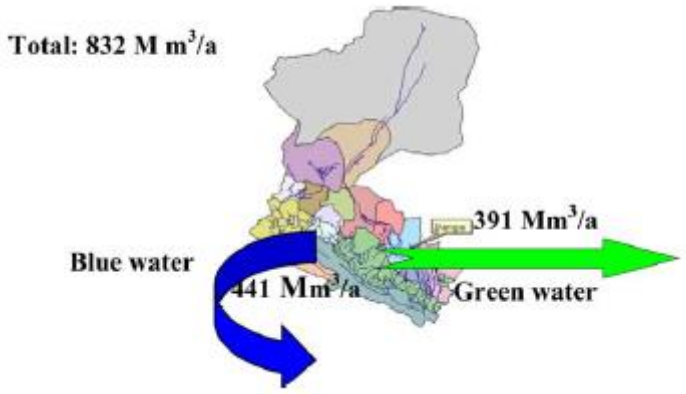

Figure 4: Total of average annual virtual water exported from the region

In addition to virtual water exports, another factor contributing to water scarcity in the Heihe River Basin is water use inefficiency. According to Jiang, 2009, current water resource management in the Heihe River Basin is typical of water resource management in China. Historically in China, peoples' water needs were met by large scale engineering projects, such as the construction of canals. This approach is supply-driven and makes no effort to reduce the demand for water (through increasing the price of water, restricting water rights, etc.) For example, in Northern China, less than 10 percent of well owners surveyed obtained permits for their well prior to drilling it (Jiang, 2009).

In the Heihe River Basin, water demand is not strictly enforced. Currently, there are no defined, enforceable water rights. There is no volumetric metering of water at the farm level. Instead, farmers pay for water based on the size of their farm, and water is inexpensive, both of which discourage efficiency upgrades (Jiang, 2009). Therefore, according to Chen et al. (2005), 97% of farmers use traditional, inefficient irrigation methods such as flood and furrow because of their low costs of adoption. Also, the canals that supply the

water for this irrigation are unlined and, as a result, 48-62% of the water transported in these canals is lost to seepage (Chen et al., 2005).

References

Chen, Y., Zhang, D., Sun, Y., Liu, X., Wang, N., & Savenije, H. H. (2005). Water demand management: A case study of the heihe river basin in china. *Physics and Chemistry of the Earth, Parts A/B/C, 30*(6), 408-419.

Jiang, Y. (2009). China's water scarcity. *Journal of Environmental Management, 90*(11), 3185-3196.

Tao, W. (2006). *Managing scarce water resources - china.*

The Virtual Water Project. (2013). Virtual water. Retrieved from http://virtualwater.eu/

Water Balance Assignment

The Problem

The Heihe River Basin, shown in Figure 5, is a large, inland river basin in northwestern China. It occupies an area of approximately 116,000 km² and contains three key areas: the upper reach, middle reach and lower reach. Most of the precipitation occurs in the mountainous upper reach, and runoff from this region supplies the majority of the water resources for the rest of the basin. The Heihe River spans the length of the basin and ends in two terminal lakes in the lower reach. The total population of the basin is 1.33 million, and there are 205,230 ha of irrigated land.

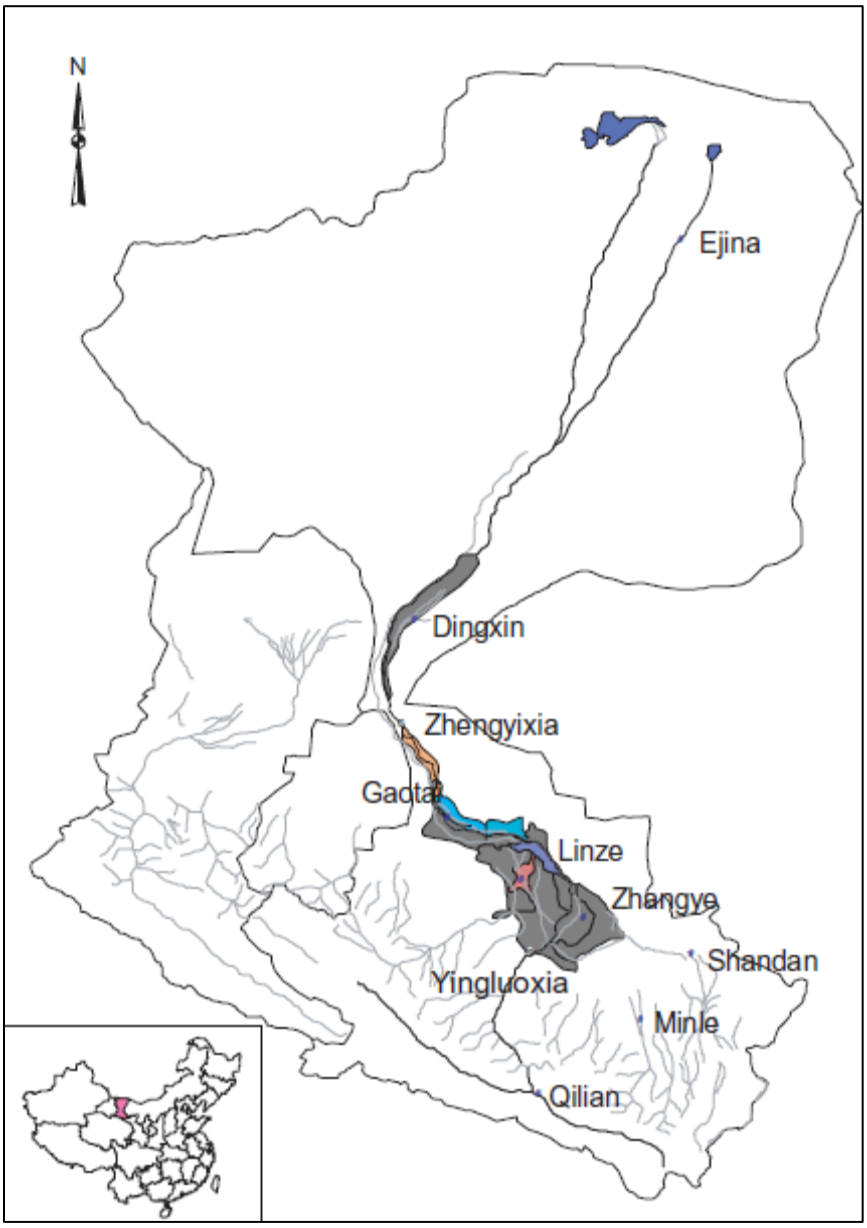

Figure 5: Map of the Heihe River Basin

Due to population growth and economic expansion, water use has increased significantly in this basin over the past 30 years. As a result, the region faces extreme water scarcity issues. The Heihe River now generally dries up before it reaches its terminal lakes, and groundwater levels have declined severely. Therefore, the Heihe River Basin Administrative Bureau (HRBAB) has commissioned you to assess the Basin's water resources and to offer recommendations for managing water demand. It provided you with the hydrological data shown in Table 2 and the water demand data shown in Table 3.

Table 2: Hydrological data for the Heihe River Basin

Area	Mean Runoff	Mean Annual Precipitation	Mean Annual Evaporation	Ground Water Resources	Heihe River Length
km^2	Mm^3/a	mm/a	mm/a	Mm^3	km
116000	2800	108	84	330	821

Table 3: Water demand data for the Heihe River Basin

Domestic Demand per capita per day	Industrial Demand	Ecosystem Demand	Livestock Demand	Agricultural Demand per unit Area
L/person/day	m^3	m^3	m^3	mm
91	95200000	510000000	333200000	1177.897968

Previous research conducted within the basin suggests that there is a large and regular exchange between groundwater and surface water, and therefore the two are impossible to be considered independently. With this information, the HRBAB has asked you to complete the following:

a. A schematic of the region that illustrates the flows entering and leaving the basin.
b. A water balance on the basin that determines if there are currently enough water resources to meet demand.

In addition to these technical deliverables, the HRBAB has also asked that you read two documents:

1. *Environmental Degradation in the Heihe River Basin*
2. *Agriculture in the Heihe River Basin – the major economic driver*

What do these two documents, as well as the three other sources you've been asked to reference, suggest about the relationship between agriculture, the economy, and the environment? Is this relationship sustainable? Should any of these be prioritized over the others? Provide some basic recommendations about future water resource management to the HRBAB based on what you have read about China and the basin.