Comparative Water-Quality Assessment of the Hai He River Basin in the People's Republic of China and Three Similar Basins in the United States

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ABSTRACT

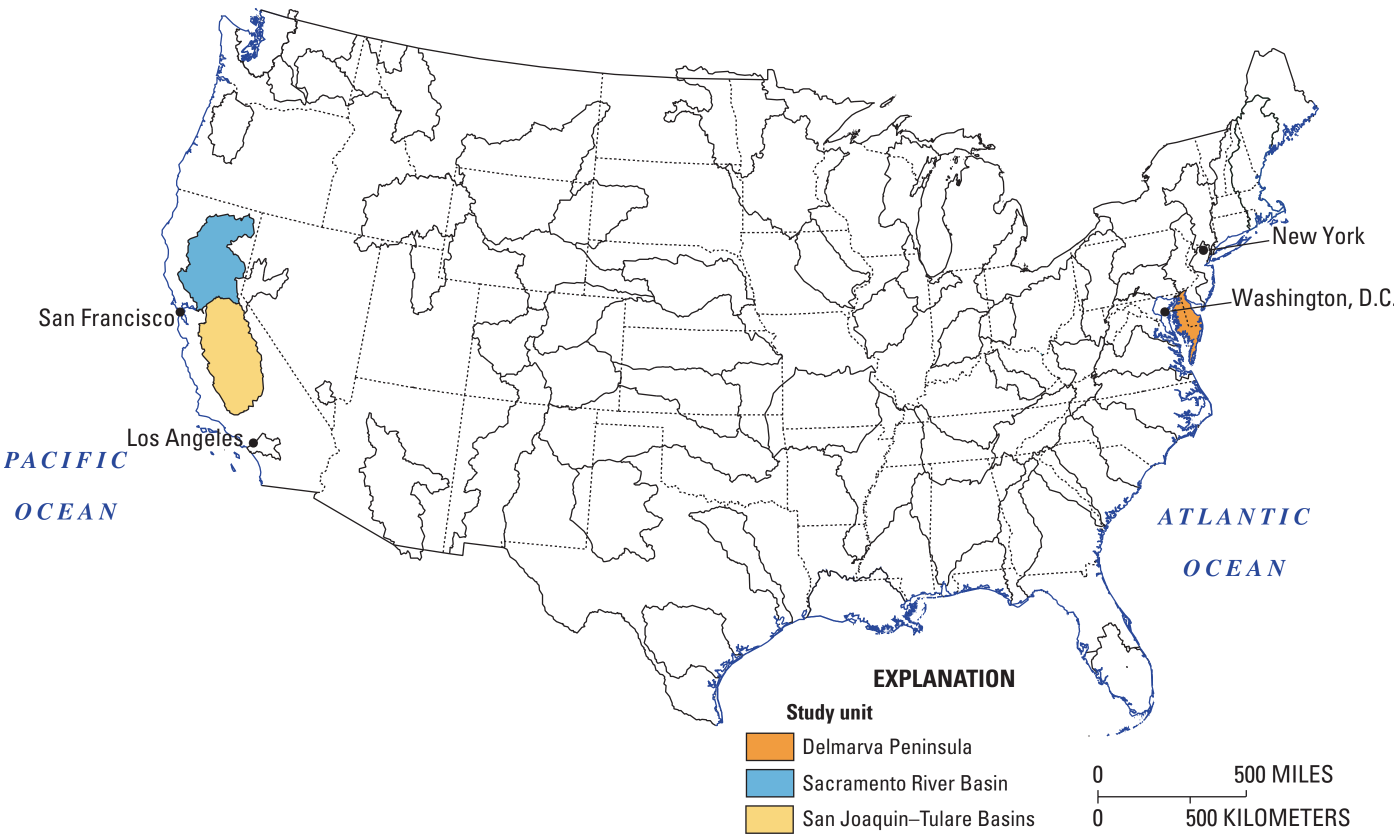
Ground-water quality with respect to nitrate, major inorganic constituents, pesticides, stable isotopes, and tritium was assessed in the agricultural Tangshan region in the Hai He River Basin of the People's Republic of China and compared with three similar regions in the United States: the Delmarva Peninsula of the states of Delaware, Maryland, and Virginia; and the San Joaquin and Sacramento Valleys of the state of California. These four regions are considered similar with respect to size, land use, or climate. Although the Tangshan region has been in agricultural production for a much longer time, probably several centuries, than the three regions of the United States, the widespread use of synthetic fertilizers and other soil amendments probably started at a similar time in all four regions. Median nitrate concentrations were found to be similar in the four regions in most instances, and those median concentrations were below the American nitrate drinking water standard of 10 milligrams per liter; however, higher concentrations, and a greater range of concentrations, were evident for the Tangshan region. In some water samples collected from a shallow aquifer in Tangshan, nitrate concentrations exceeded the Chinese standard of 20 milligrams per liter, whereas few comparative samples collected in the United States exceeded that standard. In Tangshan, recently recharged (early 1960s) water that was detected in wells drilled as deep as 150 meters was found to correlate with the elevated nitrate concentrations. Relatively low nitrate, which is indicative of natural water, was measured in older water of deeper wells. In addition to elevated nitrate concentrations, the agricultural area of the Tangshan region has been affected by an increase in the concentrations of total dissolved solids and iron. The increase in total dissolved solids of the Tangshan study unit could not be attributed to any one process. Increases in iron concentrations may be partly attributable to the widespread application of animal wastes and sewage as fertilizer, which could deplete oxygen concentrations in ground water and lead to dissolution of iron from various minerals. In contrast to the United States, pesticides were not detected in aquifers of the Tangshan region, which could be attributed to lower pesticide use in the People's Republic of China. Alternatively, pesticide use may be increasing in the People's Republic of China, but the pesticides would not yet have been detected in ground water because of the lag in travel time from soil horizons to the aquifer.

INTRODUCTION

In 1986, the U.S. Geological Survey (USGS) initiated a pilot program, the National Water-Quality Assessment (NAWQA), designed to assess the current water-quality conditions, to identify trends, and to describe the natural and anthropogenic factors affecting water-quality conditions on regional and national levels. Full-scale implementation of the NAWQA Program began in 1991. The goals and design of the NAWQA Program are described by Hirsch and others (1988) and by Gilliom and others (1995). The NAWQA Program has successfully described and identified the extent and causes of nitrate and other contamination in ground water and surface water on regional and national levels. This success is attributed to a uniform approach to study design, through understanding of the hydrological factors that affect contaminant concentrations and transport in aquifers and rivers, and to an adherence to strict quality control practices in the field and laboratory. Currently, the NAWQA Program is focusing on nonpoint sources of contamination, including nitrogen fertilizer and pesticides. To address these contamination problems in ground water, studies are designed on various spatial scales. Three types of ground-water studies are used in NAWQA ground-water investigations. The first is a study-unit survey whereby a randomly selected population of wells, in a defined part of a study unit and normally within a continuous aquifer system, is sampled for natural water and contaminant chemistry. The second is the land-use survey, which targets specific types of land uses within an aquifer setting. The third is the flow-path study, which addresses ground-water and surface-water interactions.

As a result of a rapidly developing economy and intensive agricultural land-use practices, some areas of the People's Republic of China have shown evidence of ground-water and surface-water quality degradation. In the People's Republic of China, water quality and availability can affect future economic growth, and the lack of clean water can have serious consequences for human health and agricultural production. To help address and better understand these problems, as well as to provide a framework for effective management, a cooperative research project was initiated in 1995 to utilize parts of the NAWQA approach to study the reasons for nitrate and other agricultural contamination problems within the region surrounding the city of Tangshan in the Hai He River Basin (Zhang, Suo Zhu, Hai He River Water Conservancy Commission, written commun., 1996) of the People's Republic of China (fig. 1). This project, hereinafter referred to as the "joint agreement," included an assessment of nitrate and other water-quality constituents of an agricultural region north of the city of Tangshan along with a comparative assessment of three similar agricultural regions of the United States—the Delmarva Peninsula, the San Joaquin–Tulare Basins, and the Sacramento River Basin (fig. 2). The joint agreement was designed to introduce methodologies of ground-water assessment not widely available in the People's Republic of China, such as stable isotope chemistry and methods of dating

Figure 1. People's Republic of China including the Hai He River Basin and the Tangshan study area (Xiudong, 1989).



map data: Environmental Systems Research Institute, 1998

Figure 2. United States including the Delmarva Peninsula, the Sacramento River Basin, and the San Joaquin–Tulare Basins study units. Other NAWQA study units are shown by the solid contours for comparison.

ground-water recharge. At the time of the writing of the joint agreement, the stable isotope and dating studies were considered to be among the most important work elements of the agreement. The joint agreement was also designed to introduce water-quality scientists in the People's Republic of China to the methods of land-use analysis using a Geographic Information System (GIS). It was anticipated that a similar approach to study design would allow for a direct comparison of the geochemical and hydrological conditions in the four study areas, and that this comparison would benefit researchers and scientists both in the United States and in the People's Republic of China.

Although information was available on the chemistry of ground water in the Tangshan region, information about Tangshan's ground-water flow system was scarce. Whereas the general direction of flow of predevelopment ground water was known or assumed, little was known about the effect of agricultural development and pumpage on the flow system and the areas of the aquifer that were most susceptible to contamination. Knowledge of the age distribution of ground water, and possibly the use of stable isotopes, could enable scientists and water managers of the People's Republic of China to determine these effects and to plan effective control strategies to protect water quality.

Three dating methods, tritium (^{3}H), tritium/helium-3 ($^{3}H/^{3}He$), and the chlorofluorocarbons (CFCs), were selected—in the joint agreement—to determine the age of recently recharged (less than 50 years) ground water. ^{3}H analysis is used to determine if recharge occurred before or after the 1950s (Plummer and others, 1993). $^{3}H/^{3}He$ analysis provides better temporal resolution than ^{3}H, especially for recharge that occurred in the decade after the 1950s. CFCs are organic compounds used as refrigerants and are globally distributed in the atmosphere. The partitioning of CFCs in rainwater is known, and the amounts of specific CFCs in the atmosphere, as a function of time, are known or have been calculated (Plummer and others, 1993). CFC analyses can provide even better temporal resolution on recharge date, but the method does not work for all ground-water systems. The method works best for sandy aquifers where dissolved oxygen is present. Complicating factors that arise when using CFC analysis include microbial degradation of the CFCs or contamination of the ground water with excess

CFCs, as happens near landfills. Therefore, a combination of dating techniques was used for the Tangshan region.

Stable isotope studies were restricted to hydrogen and oxygen isotopes (ratio of ^{2}H to ^{1}H, and the ratio of ^{16}O to ^{18}O) in water molecules, and nitrogen (ratio of ^{14}N to ^{15}N) and oxygen (ratio of ^{16}O to ^{18}O) isotopes in nitrate molecules. These isotopes can be related to precipitation and ground-water recharge flow paths and to the type or source of nitrogen in ground water (Coplen, 1993).

The purpose of this report is to compare data and interpretations of ground-water chemistry and agricultural contaminant chemistry for the Tangshan region of the People's Republic of China and three study units in the United States: Delmarva Peninsula, which includes parts of the states of Delaware, Maryland, and Virginia; and the San Joaquin and Sacramento Valleys in the central region of the state of California. This report presents new data collected in the Tangshan region during 1996 and 1997, and also includes a reexamination of data previously published for the three regions of the United States. The original data on the United States regions, or "study units," were collected between 1985 and 1997.

DESCRIPTION OF STUDY UNITS

The following sections describe the general environmental and land-use characteristics of the study units chosen for this joint agreement.

Hai He River Basin

The Hai He River Basin (figs. 1 and 3) is located in the northern part of the People's Republic of China (35°N to 41°N, and 112°E to 120°E). The basin consists of mountains and plateaus in the northern and western parts, and the North China Plain in the eastern and southern parts. The Hai He River Basin belongs to the semihumid climate in the monsoon region of the East Asia warm Temperate Zone (Edmonds, 1998). The winters are dry and cold, with low rainfall in the spring and heavy rainfall in the summer. The average annual precipitation is 548 mm, about 80 percent of which falls during June to September. The Hai He River Basin is composed of two large river systems: the Hai He River system and the Luan He River system. The Hai He River system includes the Hai He River and several major tributaries, and part of the South Grand Canal, a major canal. The Luan He River system includes the Luan He River and several tributaries. The Hai He River Basin includes two very large cities—Beijing and Tianjin—and numerous other cities, including Tangshan. The drainage basin is 318,800 km^2, of which 189,000 km^2 is mountainous and the remainder is plain (Lin Chao, Hai He River Water Conservancy Commission, written commun., 1998). The basin population is 118 million people and there are 110 million square hectometers of farmland (Lin Chao, Hai He River Water Conservancy Commission, written commun., 1998). The cropping patterns in the Tangshan study unit are diverse, and the major crops are wheat, rice, corn, sorghum, cotton, and peanuts. The population density is 370 people per square kilometer. Water resources, which are deficient in the basin, average 40.4 billion (40.4×10^9) cubic meters per year (Lin Chao, Hai He River Water Conservancy Commission, written commun., 1998). Surface runoff is 26.4 billion cubic meters. The average surface water per capita use is 251 m^3/yr (Lin Chao, Hai He River Water Conservancy Commission, written commun., 1998). This can be compared to a per capita usage in the United States (based on data collected in 1990) of 9,913 m^3/yr (Population Action International, 2000). As a result of the large population and the large amount of land in agriculture, water resource projects have been constructed to control floods, improve drainage, and provide for irrigation and water supply. Serious water contamination problems also exist in the basin. The annual amount of wastewater is about 4.71 billion megagrams, about 4 billion megagrams of which is discharged into rivers (Lin Chao, Hai He River Water Conservancy Commission, written commun., 1998). The combined problems of water shortage and water contamination limit economic and agricultural development.

The region chosen for the ground-water investigation, hereinafter called the "Tangshan study unit," is located within an area known as the North China Plain, about 160 km southeast of Beijing (fig. 3) (Xiudong, 1989). The 13,472 km^2 study unit is about 130 km from east to west and 150 km from north to south, and has 180 km of coastline. The study unit slopes from the front of the mountain region southward to the Bohai Sea, resulting in a general predevelopment direction of ground-water flow to the ocean (Zhang, Suo Zhu, Hai He River Water Conservancy Commission, written commun., 1996). Three physiographic regions are defined for this study: the mountain region of the north, the plain region in the center, and the coast region to the south (fig. 4) (Xiudong, 1989). The mountain region covers 4,620 km^2, the plain region 4,884 km^2, and the coast region 3,968 km^2. Several geomorphic zones are recognized (fig. 5) within these physiographic regions. The Tangshan study unit is characterized by the monsoon climate of the Asian warm Temperate Zone, with cold winters and hot wet summers. The average annual temperature is 10.5°C (Zhang, Suo Zhu, Hai He River Water Conservancy Commission, written commun.,

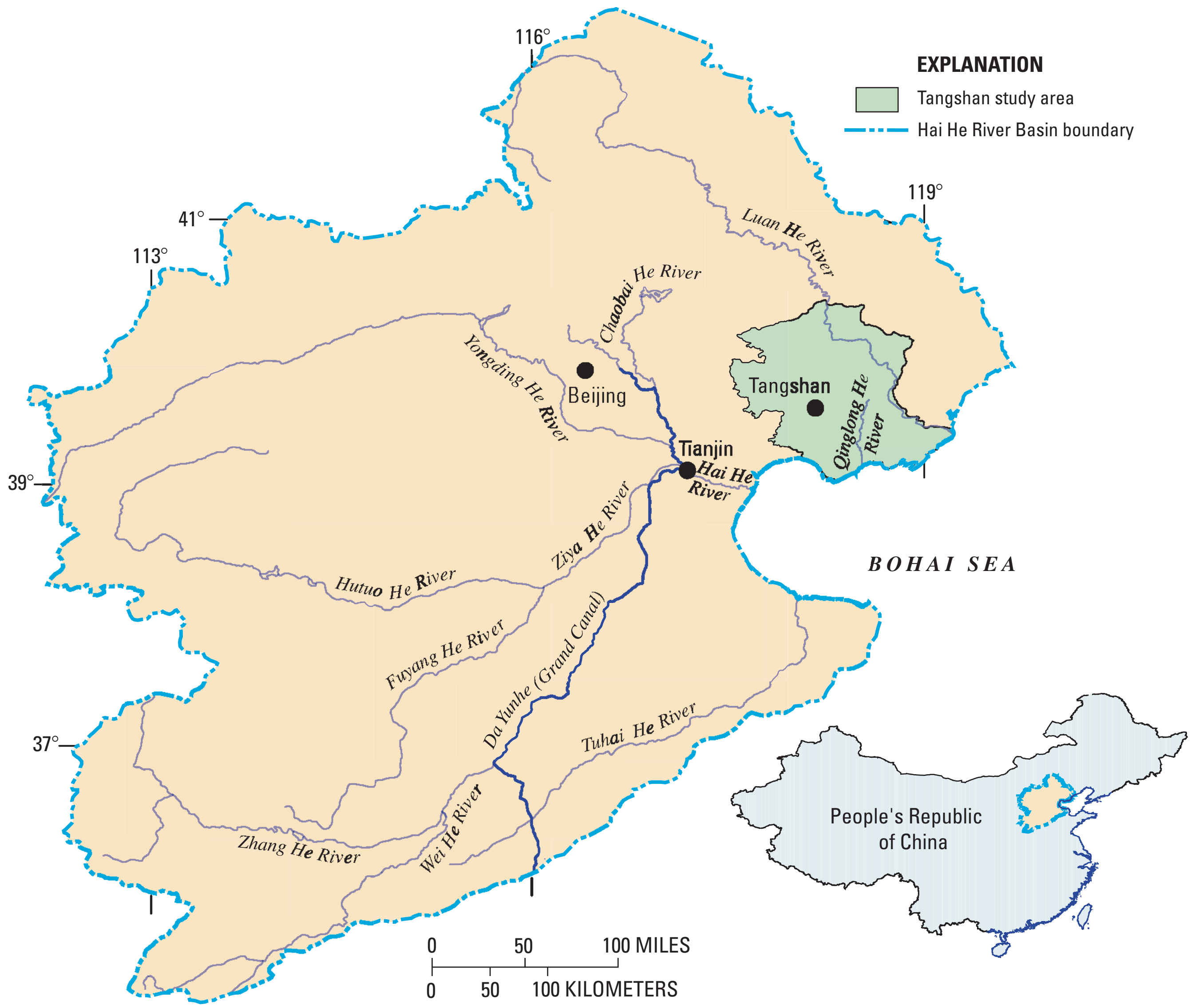


Figure 3. Hai He River Basin and Tangshan study area in the People's Republic of China.

1996). Annual precipitation decreases from 750 mm in the northern mountain region to 600 mm in the southern plain. The average precipitation in the study unit is 645 mm, most of which falls between June and September (Zhang, Suo Zhu, Hai He River Water Conservancy Commission, written commun., 1996). The Luan He River is the largest river in the study unit and has perennial flow. The study unit also includes many smaller rivers with seasonal or very low base flow. All rivers flow into the Bohai Sea from the north, southwest, and southeast. Water resources development is very important in the study unit, which includes 162 reservoirs with a total storage capacity of 4,361 billion cubic meters (Lin Chao, Hai He River Water Conservancy Commission, written commun., 1998).

Geologically, the Tangshan study unit lies at the corner of the North China Platform (Yang and others, 1986). This area has a complex geologic history, including folding and faulting of the nearby mountains. The area is also influenced by distant tectonic processes, including the movements of the Himalaya Mountains, which raised the mountains of the Tangshan study unit during the Cenozoic era. Movement along faults has resulted in serious earthquakes, including a devastating impact on the city of Tangshan during the 1970s. In the east, the bedrock comprises Archaean metamorphic and igneous rock (Yang and others, 1986). The mineralogy includes feldspars, quartz, and dolomite. The western and middle areas of the study unit have arenaceous rocks of the Permian,

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