LESSONS FROM THE PAST: THE DU JIANG YEN – CHINA'S ANCIENT IRRIGATION PROJECT

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Abstract

Development of the Cheng-du Plain, an alluvial plain located in the central western part of China's Sichuan Province, exemplifies the harmonious interactions of man and nature. This great plain underwent profound physical changes more than 2,000 years ago, largely brought about by man-made activities. Yet, careful planning focusing on working with nature saw profound benefits to the population and the economy, with changes on the face of the landscape. It involved the distribution of water by means of canals and waterways throughout the 9,600 square kilometer area. Known as the Du Jiang Yen, the project has transformed the Cheng-du Plain into one of the most productive agricultural areas in China. This paper is about the Du Jiang Yen and begins with a physical description of Sichuan and its physiographic regions. The paper includes a brief history of the Cheng-du Plain is included along with an investigation of the Du Jiang Yen, how it was built, how it works, its perpetual need for maintenance, and the impact it has made on the land and its people for twenty-two centuries.

Introduction

The man-environment theme is one of the core principles that define the geographic discipline and this has been manifested in many of the geographers' work in the past (Chan et al, 1994). Throughout the history of humankind, geographers have been researching and trying to resolve problems related to the relationships between man and his environment. According to Murphey (1973), the second function of the field of geography is the study of "inter-relationships between human society and its natural environment". According to Minshull (1970), one of the core objectives in geographic studies is the understanding of the influence of the environment on man. While Environmental Determinism or Environmentalism dominated geographic thinking in the past, scientific progress has brought about a whole new mindset of Possibilism whereby everything is possible (theoretically). It is this latter school of thought that has wrought havoc to the environment, especially in terms of environmental degradation since the mid-20th century till now. The development of the Du Jiang Yen, however, is a move away from either determinism or possibilism, taking the middle path whereby man works with nature and in the process benefits both. Inevitably, the Du Jiang Yen is a valuable lesson in historical geography as outlined in the work of Febvre (1925).

Much has been debated about the Three Gorges Dam and its negative effects (http://www.chinaonline.com/refer/ministry_profiles/threegorgesdam.asp). Evidently, both Chinese environmentalists and those abroad had protested vociferously, and human rights advocates had criticized the resettlement plan. Archeologists also lamented at the submergence of a huge number of historical sites. Nature lovers and all alike mourned the loss of some of the world's finest scenery. Flood managers also doubted whether the project would actually be able to control the Yangtze's floods. Ironically, even many engineers doubted whether the dam would actually achieve its stated purposes. It is strange that a country with such rich historical values and examples of successful irrigation projects have chosen to embark on this massive project while turning away from the example of the Du Jiang Yen. Perhaps circumstances and contexts have changed. So have many things in China since the Du Jiang Yen 2,000 years ago. This paper examines an ancient irrigation system located on the Cheng-du Plain in Sichuan, China. The system is called the Du Jiang Yen. For more than two thousand years, the project has had a great impact on the landscape, population, and economy of the area, as well as China in general. This paper describes that impact, and details when, why, and how the project was built. The recent 1949 enlargement under the direction of the PRC Army made significant changes in size and scope of this project. The initial philosophy behind the project's construction, formulated by the builder Li Bing, will be examined. Over time, this philosophy of "working with Nature" has transformed the system's necessary maintenance into a reverent duty. The descriptive analysis begins with an initial overview of the province, then looks at the general physical area of the Sichuan Basin, and ends with an examination of the Du Jiang Yen irrigation system.

The Geography of Sichuan Province

Sichuan Province is located in central southwestern China in the upper reaches of the Chang Jiang (River) drainage system and covers an area of approximately 304,000 sq. kilometers (Fig.1). Within Sichuan there are 11 districts and 3 politically autonomous sub-regions, 177 hsiens (counties) with 2 autonomous counties, 3 agricultural and industrial regions, and 13 cities. The major ethnic groups include Han, Yi, Tsung, Miao, Moslem Hwei, and Qiang. At 120 million, Sichuan's population is 10 percent of China's total and represents nearly half that of the U.S. (Fig.2).

Physical Description

The Chinese character "Si Chuan" translate to "four rivers." It is named after the four tributaries of the Chang Jiang (Yang-tse) which flow south through the province. These include the Jia Ling Jiang in the east, the Pu Jiang, the Tuo Jiang, and finally, the Min Jiang, a braided, near seasonal flow, stream which winds its way across the Cheng-du Plain.

The province is divided into three distinct physiographic regions:

1. On the east, formed by tectonic movement and positioned in a northeast to southwest direction, is a belt of folded anticlines known as the Sichuan Folded Belts.
2. Dome shaped anticlinal hills and mesa topography make up the south central and western portion of the province.
3. The Sichuan Basin is in the north central part of the province.

In the Tertiary Period, Sichuan's sedimentary basin underwent significant erosion, and during the Quaternary, an intermittent erosion cycle occurred. The exposed ferrous-laden shale and sandstone color the soil from red-yellow to purple, thus its name, the "Red Basin (Cressey, 1955, pg. 178)."

The hill and valley region has 20 such examples of the erosion cycle in progress. Limestone and shale over sandstone have created valleys with surrounding ridges at heights of 20 to 100 meters. The Min Jiang and Tuo Jiang valleys were formed by cuts in the anticlines. Mudstone, shale, and sandstone are somewhat predominate in those areas. Erosion is severe, and isolated hills and terraces have been formed. Terraces along the rivers edge and Karst topography in low-lying flatlands are also evident.

Fluvial deposits from the Min Jiang have formed an alluvial fan in the Red Basin near Cheng-du. Cressey (1955, pg. 179) noted that it was "so flat it almost resembles a lake bottom". The Min Jiang fan is one of three such alluvial fans in the valley which extend into the basin. The Min Jiang fan is by far the largest at about 42 kilometers wide and 200 kilometers in length. The fan is the most level land in Sichuan and has but a slight grade inclined toward the southeast, stretching from Du Yang Hsien in the north to Liu Shan in the south, a grade which was excellent for an irrigation project like the Du Jiang Yen.

Climate

According to Cressey (1955, pg. 180) "no sketch of Sichuan is complete without reference to its climate, for here is the basis of its phenomenal agriculture and in turn its dense population." Climate indeed plays an important role in the agriculture of Sichuan. Temperature and precipitation variance from plateau to basin floor is considerable. Basin temperatures in winter average 3 °C 9 °C and reach July highs of 25 to 29 °C (Cressey, 1955, pg. 181).

Plateau temperatures average -3 to 9 °C in winter with July highs of only 11 to 17 °C. Precipitation varies in comparison as well. Annual precipitation in the basin averages 1000 mm. The plateau receives considerably less with annual totals reaching 500 to 700 mm (Cressey, 1955, pg. 181).

The Sichuan Basin is surrounded by mountains and has a unique physiographic characteristic in that it is shaped somewhat like a bowl with a broken edge facing south. These southern mountains are low enough to allow seasonal monsoon influence to affect the weather patterns of the area (Fig. 3). While the Cheng-du Plain also receives Tibetan foegns in summer, the high mountains to the north act as a barrier to the very cold air of the continental areas in winter. As a result, winter temperatures are greatly modified by the high mountains, holding in southern warmth and keeping humidity high. Year round warm air temperatures in the basin are conducive to excellent agricultural conditions. February temperatures average about 10 °C in the Red Basin (Fig. 4), making it warmer in winter than the mid-section of the Chang Jiang to the south.

The steady cloud cover in the province is a result from this "bowl of humidity." In turn, the cloud cover reduces evapotranspiration and increases the effectiveness of precipitation during the growing season. Cloud cover is greater in the Red Basin than in any other part of China. Northern sections of the basin experience about 30 percent cloud cover annually. That computes to about 1300 hours of sunshine annually. December sunshine in Cheng-du averages 56.6 hours for the entire month, less than two hours a day (Fig. 5).

Spring generally comes a month earlier in the basin than in other agricultural areas of the province, with few frost days. Cheng-du averages only 12 days of frost per year, which permits an almost continuous growing season, yet enjoys moderate temperatures in July of about 26 °C. Along the mid-section of the Chang Jiang, high temperatues of 26 to 28 °C usually occur simultaneously with drought. The drought condition increases evapotranspiration and tends to damage rice crops if it occurs during crucial times of either planting or harvest (after the Summer Solstice and before the Fall Equinox). Grain development is hindered if drought occurs early on, and mature grain tends to drop prematurely if it happens during harvest.

Sichuan, especially the Cheng-du Plain, exhibits conditions favorable to growing many kinds of plants and vegetables, which makes it one of the most productive agricultural areas in China (Huang, 1985, pg. 220). More than 22 million tons of China's rice production grows there, as does almost 80 percent of the wheat grown in the southwest (Tuan, 1993, personal interview). In addition, due to the topography of the area and its amelioration of the climate, many different kinds of plants, fruits, and vegetables are produced there. Mulberry for silkworm propagation, apples, Irish potatoes, tobacco, sweet potatoes, and corn are grown on the hillsides where the air is cooler. Beans (soy and lima), oranges, pears, bananas, sugar cane, jute, tea, rice, and cotton are planted in the warm, humid valleys.

Early History

Eastern China is blessed with a great deal of water. Innovative agricultural practices taught ancient farmers that a stable supply of water was necessary for successful harvests. During the reign of the early ruler Chao (273 B.C.) the establishment and development of private land ownership, under the feudal system, became an established fact. Agriculture flourished in the areas of Kuan-chung (largely what is now Shaansi Province) and in the outlying areas to the west (western Sichuan Province). This vast expanse of fertile land was known as a "heavenly endowed place" (Li, 1975, pg. 60). Advanced farming methods (plows and threshing tools) came into the area with immigrants from Shaansi settling there in search of land ownership. The land was good, and the government levied taxes in the form of agricultural products.

The Cheng-du Plain, during the 3rd century B.C., was the province's least productive region. The Min Jiang is a braided, seasonally torrential stream generally overloaded and clogged with boulders and gravel (Cressey, 1955, pg. 179). The river seasonally ran unchecked, destroying life and crops alike, and prompted administrative action. The first attempt to control it was done at that time at the request of military generals wishing to attack the Shu by using flooded areas as tactical obstacles.

Du Jiang Yen

The Du Jiang Yen was built during the reign of the Emperor Qin Shi (261-206 B.C.). It was the type of project that mobilized hundreds of thousands, perhaps millions of corvee workers in the same manner as the construction of the Grand Canal did 800 years later (Wittfogel, 1957, pg. 14).

The Du Jiang yen was built for water conservancy and flood control. Li Bing, a member of the emperor's court, was made governor general of Sichuan after the defeat of the Shu, a defeat which resulted in China's unification. He was commissioned to devise and execute a plan to distribute the fluvial runoff from the Min Jiang throughout the Cheng-du Plain for the purpose of flood control. Through a concentrated effort of as many as 750,000 corvees, water was shifted from active flood areas into those lands which were away from the main stream and would benefit the most agriculturally.

Li Bing chose Kuan-hsien, in the Guan District, as the sight to begin this project (Fig. 6). The focal point of the system was the Du Jiang Dam at Kuan-hsien, about 60 kilometers from the city of Cheng-du. The dam divided the Min Jiang into two main channels. The channels are further divided into 9 major subchannels, then into 526 lateral canals and then into 2,200 sub-laterals. Later, the Cheng-du Plain was known as the "sea on land" because of the network of thousands of small irrigation ditches radiating in spider web fashion from the larger canals (Chi, 1970, pg. 97). The system of channels, dikes, dams, and canals radiates southward 700 kilometers from Kuan-hsien, a few kilometers from where it roars down from the 4000 meter-high Min Shan (mountains) and enters the Cheng-du Plain.

The name of the irrigation system has been changed many times throughout its history. Names like Ming Peng, and Chin Peng, had meaning, early on, but according to the Bei Xui Encyclopedia of Water (3rd century A.D.), the project was known at the time as the "Du An Da Yen." The name, "Du Jiang yen," was given during the Song Dynasty (1000 A.D.), a time when power was in the hands of an elite public service bureaucracy (Tang, 1986, pg. ii). Du means "capitol," Jiang means "river," and yen means "dam."

Construction

The original construction has been greatly enhanced since the beginning. When irrigation was first introduced to the area (200 B.C.), Wen Weng developed and enlarged the area irrigated to 755 hectares (1700 acrea). In the Shu Han Era (400 A.D.), Zhu Ge Liang, a military strategist, built dams across early man-made channels to enhance water management and protect tactical positions by using flooded areas as military obstacles. Later, in the Tang Dynasty, the name changed again; Zhang Chou Jian and Lu Yi added further development to the irrigation system. More development work went into the project, and the last name change was made in the South Song Dynasty, during the powerful civil servant era.

Prior to modern times, the greatest amount of work and improvement was conducted during the Qing (Manchu) Dynasty (1600-1800) when qiang Wang Tai made eight improvements. He dredged silted areas, dammed shallows and improved irrigation over a 14 county region, which was, until modern times, the largest area improvement in the project's history.

The construction and maintenance plan allows, even now, the natural flow of water to keep the river bed scoured. When construction began, workers used locally available materials to do the work. The Min Shan's great cedal forests and groves of large bamboo provided an excellent source of wood supply, saving time and expense in transportation. However, the forests were not destroyed by the logging but suitably conserved and replanted. Small boulders from the stream floor which had been swept down out of the mountains were plentiful and proved very useful. Maintenance done in contemporary times has employed the same materials used in the same manner and the many years of exploitation has no doubt resulted in some deforestation of cedar and bamboo groves in the upper regions of the Min Jiang which may have reduced flood-mitigation effect of these forests (Cai et al, 2001). The extent of deforestation and increase of the Min Jiang's bedload would make an excellent study in the future.

Cedar logs, twelve to fourteen inches in diameter, are cut from the upper reaches of the Min Jiang, floated downstream to the maintenance area, and collected by a device stretched across the stream to funnel the logs into a collection point. Once collected, they are used with stones and bamboo to construct a barricade. Logs, sharpened, driven into the stream bed, and tied with bamboo strips in tripod fashion, are used as anchor points at specific intervals along the barricade (Fig. 7). Additional logs are positioned horizontally between the tripod anchors and secured.

Stones, 30 to 40 centimeters (12-15 in.) in diameter, are placed into woven bamboo baskets 50 to 60 meters in length. The baskets are made from split bamboo and woven together in place as the stones are added (Fig. 8). To further stem the flow, the stone-filled baskets are positioned on the stream side of the barricade. This procedure was used by Li Bing as he began construction of his flood control strategy. Workers placed stone weirs into the channel against the log barriers at a point on the stream's cutbank, where the new channel was intended to intersect with the stream. As excavators reached a point behind the barricade, the log tripods were pulled away, allowing the water to breach the weir, and sweep into the new channel (Fig. 9). The same methods are employed by workers today.

How It Works

The Du Jiang Yen has 3 basic functional parts:

1. The Fish Mouth divides the main channel into two parts, the inner bound and the outer bound.
2. The Flying Sand Dam diverts excess water from the inner bound to the outer bound and maintains a level of two meters depth to assure a specific volume is directed to the Bao Ping Kou at the right time.
3. The Bao Ping Kou is the bottleneck located in the inner bound to assure that a certain amount of water passes through that point at a given time. It also causes an increase of velocity into the inner bound to assist in dispersing sediment.

Li Bing divided the Min Jiang into two channels at Kuan-hsien. The channel fork, known as the Fish Mouth (Fig 10), is important because it divides the stream into what is called the inner bound and the outer bound channels. The main channel is designated as the outer bound channel which now has a series of sluice gates and hydroelectric generators.

The Du Jiang Yen also has an additional flood-mitigation function as lessons of past floods have made the authorities realize the importance of vegetation conservation in the project area (Chan, 2003). During a flood, the main channel of the outer bound carries the peak flow (est. 115,000,000 cubic meters/sec. or 128,000,000 cubic yards/sec.). At high flow, 60 percent of water and 80 percent of the bed load will flow in the main channel (see Figures 11 and 12 for flow / suspended material relation).

At low flow the main channel carries about 60 percent of its bed load (Fig. 13). It is estimated that the Min Jiang carries an average of 152,500,000 Kg. (168,000,000 tons) of sediment annually (Tang, 1986 pg. 87).

Flood season (June to September) produces maximum water output. The water is diverted into the two largest channels and is dispersed throughout the system, which now covers almost 10,000 square kilometers (3,900 sq. mi.). Conversely, as the need for water increases in outlying regions, workers close the gates and force a change in stream direction, while still allowing enough water to flow through its generators to maintain power output.

The Flying Sand Dam, on the western side of the inner bound, is two meters higher than the stream bed. Its function is to divert excess floodwaters back into the main channel once the flow increases to a sufficient level at the Bao Ping Kou.

The Bao Ping Kou is a bottleneck that creates an increased flow through the inner bound channel to croplands on the plain. The bottleneck is a chute about 20 meters wide, cut through the bedrock, and helps regulate the flow of water dispersed to irrigated areas. When high flow occurs and raises the level of flow over the 2 meters height of the Flying Sand Dam, the Bao Ping Kou prohibits overflow into the inner bound. Any excess flow is routed over the two meter dam because of the bottleneck and is returned to the main channel. A natural rock formation in the inner bound channel acts to increase turbulence in front of the Bao Ping Kou entrance. This turbulence precipitates a scouring of the inner bound channel, and the current carries sediment-laden water over the Flying Sand Dam into the main channel.

The inner bound waters are destined for irrigation of the multitude of crops grown and harvested in the Du Jiang Yen's area of influence. As the dispersion continues to the lower levels, some farmers use Persian water wheels to lift the water onto the land, although mechanical pumps have now taken their place in most parts of the area. Average annual water usage and stream flow relation is illustrated in Figure 14.

The fact that flood control was the main reason for the project's construction gives way to the added attribute of transportation in a time when roads in the area were very poor. Many canals are large enough and continue to support a great deal of water transportation throughout the "sea on land" in the Cheng-du Plain. The waterways offer the local people an inexpensive method of shipping goods to market.

Administration

In 200 A.D., the East Han Dynasty established a minister of maintenance and allotted funds for the upkeep of the system. Two thousand years of meticulous record keeping with regard to repairs, as well as new methods of construction and water control, has given those who maintain this project a great deal of knowledge and understanding of the Min Jiang and the Du Jiang Yen.

There are continuous maintenance problems, however, and sediment is perhaps the largest. Channel sedimentation has become so large a problem (after the 1949 expansions), that the PRC Army has taken over the job of perpetual maintenance.

The use of concrete has greatly enhanced the control of the stream and the stabilization of its stream bed. Concrete was first used to stabilize the Fish Mouth in 1936. It was formed and poured to a depth of 3 meters below the bed level (Tang, 1986, pg. 5) (See Fig. 10 for a structural diagram).

In 1976, a series of expansions connected the Tuo Jiang and two other smaller streams (Qin Yu Jiang and Da Du He) into the system in the north. The smaller streams have produced alluvial fans which spread into the Red Basin, but neither compare in size to the fan of the Min Jiang. In the north, channels and canals are very densely distributed. Most are concentrated in the Jin Tang and Hsien Jin areas (Tang, 1986, pg. 10).

In addition, areas to the southwest and south of the original location were connected, and a tunnel was constructed through the Dragon Spring Mountain to link other sections in the southeast to the project. As late as 1988, area expansions were completed in the mountainous east, where the agricultrual land use is concentrated in the narrow river valleys.

Total canal lengths now reach more than 8100 kilometers (3,125 mi.). Irrigation area now covers more than 600,000 hectares (1,284,000 acres) and receives about 2 acre-meters (7 1/2 acre-feet) of water by means of the system (du Crespigney, 1971, pg. 141). Future expansions are planned for a final area east of the Dragon Spring Mountains.

As the engineer Li Bing had instructed, the canals are drained and allowed to dry in the winter by means of small dams built throughout the system. During the dry season, which lasts from December through March, a series of channels are blocked off and drained. Once drained, the channels are prepared for the approaching peak flow season in late spring. Silt is cleaned out of each channel and spread on the fields, adding fresh silt and organic matter to the soil (du Crespigney, 1971, pg. 141).

Philosophy

Li Bing, after studying the stream and its character, developed a three character proverb which roughly means to "work with nature rather than against it." Later a series of three character idioms was developed which prompted one to "know the stream before you move. Understand the water and how it works, then gently change it. Use time to control the bed and make the water flow smoothly."

Conclusion

For centuries, the Chinese people have been one with the land, yet the land has not always been kind. Floods and drought have been a part of the cultural fabric of China, and the Cheng-du Plain has played no less a part in weaving the fabric. From the beginning of the ancient city of Cheng-du, croplands on the plain around it were plagued with unsuccessful harvests. These crop failures and loss of life on the plain of the Min Jiang prompted action by the Emperor Qin Shi (261-206 B.C.).

The Du Jiang Yen is perhaps the most successful water project ever begun by an organizer of a hydraulic culture (Wittfogel, 1957, pg. 5). The fact that it is still operating after 2200 years is enough accomplishment, but the way it was constructed, without aid of modern surveying instruments, is most impressive.

The success goes to its initial planner, Li Bing, court architect / engineer, who studied the stream in an attempt to understand stream morphology. His philosophy of construction was developed, and he chose to "go with the flow" rather than against it. His maintenance plans were clear, even down to the manner in which the canals were to be cleaned and the disposition of the residual materials that were left after such a cleaning. His guidelines are still followed today be the PRC Army as they endeavor to follow in their predecessor's footsteps.

The Du Jiang Yen has been modified, enlaraged and improved over the preceding 2200 years. Its name has been changed many times until the Song Dynasty about 1200 years ago, when the project was finally given the name "Du Jiang Yen." The modifications continue, linking more areas to the network of prosperity begun as a flood control project 22 centuries hence. The Du Jiang Yen is successful for a number of reasons:

1. The design philosophy of Li Bing.
2. Design excellence, coupled with understanding the flow of the stream and its long recorded history. The major components, the Fish Mouth, Flying Sand Dam, and the Bao Ping Kou, are logically designed.
3. Constant, continuous maintenance and meticulous record keeping from the very beginning have afforded education and experience in water control.
4. Cost effectiveness and extremely high economic value to the region and to China.

As a result, the alluvial fan which makes up the Cheng-du Plain, and other areas in northwest central Sichuan Province, together have become one of the richest, most productive agricultural areas in China, delivering more than ten percent of the country's rice production, along with notable quantities of wheat, fruits and vegetables. The Du Jiang Yen has given much sustenance to China and will continue to do so for many centuries. The information about irrigation and water management it has to teach us has yet to be completely recognized.

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