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WARPING DAMS – Construction and its Effects on Environment, Economy, and Society in Loess Plateau Region of China

(Contribution to UNESCO-IHP project on International Sedimentation Initiative)

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FOREWORD

UNESCO Office Beijing was created in 1984 as the UNESCO Office in China for Science and Technology; since September 2004 it has become a Comprehensive Cluster Office for East Asia now covers all UNESCO programmes.

The IRTCES was jointly established by the Chinese Ministry of Water Resources and UNESCO in 1984. It aims at promoting the international exchange of knowledge, cooperation in the study of issues relating river regulation, soil erosion control, rational management and utilization of water and land resources.

It is well known that the total amount of fresh water on earth has remained virtually constant and geographically unevenly distributed. The rapid growth in population, extension of irrigated agriculture and industrial development, are putting stress on the natural ecosystem. Society has begun to realize that it can no longer subscribe to a “use and discard” philosophy as regard to natural resources such as water in concerned.

UNESCO, through its International Hydrological Programme (IHP), an intergovernmental scientific co-operative programme in water resources, carrying out hydrological research, education and training based on the needs of Member Sates. Although the IHP is basically a scientific and educational programme, UNESCO has been aware from the beginning of a need to direct its activities towards the practical solutions of the world’s very real water resources problem.

In consideration of the increasing importance of erosion and sedimentation processes for water resources management, the IHP Interngovernmental Council adopted a resolution during its 15^{th} session on the International Sedimentation Initiative (ISI). ISI Task Force has formulated a project proposal on Global Evaluation of Sediment Transport (GEST) in order to develop representative case studies to verify the socio-economic and environmental risks caused by erosion and sedimentation process.

Lessons learned from the case studies will have an essential role in developing scientific approaches to erosion and sediment processes in different natural and socio-economic settings. It will also raise awareness of erosion and sedimentation problems and of undertaking more detailed analysis. One of potential case study identified by the Task Force Group is Yellow River Basin of China.

At present IRTCES is carrying out detailed research under ISI on Yellow river basin, as part of this study the socio-economic impact of warping dames brought out as a report to minimize a soil loss due to erosion and convert them in to economical benefit to the local community in the loess plateau region of China. The loess plateau is located in the middle reaches of the Yellow River Basin and covers an area of 640,000 km^2 including seven provinces. The region is in central part of China and it was the cradle of Chinese and political, economical and cultural center in history. But, today, it lags behind due to fragile environment, shortage of farmland, lower yield of grain production, nature disasters and poverty.

The region is also the source of flood calamity of the Yellow River caused by sediment deposition. Soil erosion in the plateau is very serious, due to nature conditions and human activities. Construction of warping dams is not only can prohibit gully erosion, but also can gain large newly area of rich arable land in front of the dam. That is successful experience accumulated by local people to struggle against soil erosion over a long period of time for improving environment, mitigating disasters, and increasing grain yield.

In bringing out this volume, Mr. Hu Chunhong, Secretary General, IRTCES and his colleagues has played a key role and deserves all appreciation. I would like to acknowledge my colleagues from Science Sector Mr. R. Jayakumar and Mr. Shingo Ajisawa in editing this document in the final form.

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1. Background

The loess plateau is located in the middle reaches of the Yellow River Basin and covers an area of 640,000 km^2 including seven provinces (Qinghai, Gansu, Ningxia, Inner Mongolia, Shanxi, Shaanxi, and Henan), 46 prefectures, cities and autonomous, 306 counties and townships with 72.69 million population. The region is in central part of China and it was the cradle of Chinese and political, economical and cultural center in history. But, today, it lags behind due to fragile environment, shortage of farmland, lower yield of grain production, nature disasters and poverty. The main constrain is serious soil erosion and water loss. The region is also the source of flood calamity of the Yellow River caused by sediment deposition. Therefore, the problem of soil erosion and water conservation in the area has been paid great attention in China.

There are many tributaries of the Yellow River in the plateau, and the main tributaries are Weihe, Jinhe, Luohe, Yanhe, Wudinghe, Kuyehe, etc.

It differs greatly in climate from semi-arid in the north to semi-humid in the south. The annual precipitation is 636 mm, the distribution of precipitation is uneven; more is summer and less in winter and spring. Nature disasters like rainstorms, drought, flood, cold wave, hail and frost often occur and droughts during spring and summer is common in these areas.

The plateau has complex landform and geology, hilly ridges (Liang) and mounds (Mao), dissected plateau, and crisscrossing ravines. The main layers of loess deposits are: Holocene loess, 2-3m thick; Malan loess, 10-30 m thick with loose texture and high erodaibility; the lower layer is Fucheng loess, 40-100 m thick. The plateau situated in temperate and sub-tropic zones and has varied types of vegetation cover. The forest cover has spares vegetation, average area of forest per person is 0.17 ha only much lower than world level.

Soil erosion in the plateau is very serious, due to natural conditions and human interferences. The sediment yield modulus is over 1,000 tons; the maximum value reaches 7,076 tons in Lueyang County. Soil erosion and water loss are most serious in this part of the world as it favors the occurrences of dry and flood disasters frequently.

Where is the main source of sediment transported into the Yellow River?

The annual sediment load carried by the Yellow River is about $16x10^9$ ton. Sediment deposits on the riverbed forming flood disaster threaten along the riparian of the Yellow River. According to the data, the elevation of the riverbed is even higher than the surrounding ground more than 10 m in the lower reaches of the Yellow River. This degree of erosion is very rare in the world. Severe loss of soil and water has brought devastating impacting on farming, forest, stock–breeding and ecological environment.

Construction of warping dams is not only can prohibit gully erosion, but also can gain large newly area of rich arable land in front of the dam. That is successful experience accumulated by local people to struggle against soil erosion over a long period of time for improving environment, mitigating disasters, and increasing grain yield. More than million warping dams have been constructed in the area. The main advantages for warping dam construction in the plateau are: (i). there have abundant soil resources; (ii). local farmers and local government has enthusiastic support to built warping dam as it caters the livelihood of the local people; and (iii). there is traditional knowledge and practice available for construction and operation of warping dam for a long time. Ministry of Water Resources, China proposed construction of warping of warping dames as its one of the national strategy for West China Development Plan. This is obviously benefited for sustainable development in the Loess Plateau region. According to the plan, 163 $x10^3$ warping dams will be built in the comming 20 years for restoring natural ecosystem by implementing the approach of trans-steep slope farm lands into forest lands. For summarizing experiences and lessons of construction of warping dam and providing technique support to the project, it is necessary to conduct the study.

2. The Current Situation of Existing Warping Dam in Loess Plateau

2.1. Existing warping dam in the plateau

Warping dam is a dam built on gully in soil and water loss area for the purpose of creating newly arable land by silt deposition in front of dam, decreasing gully slope, and mitigating gully erosion by gully bed raised step by step. According to literature record, the first warping dam originated by nature landslide in Zizhou County, Shanxi Province 400 years ago.

Warping land was formed which was caused by silt deposition in front of the dam. High grain yield was obtained due to humus-rich soil carried by flood and runoff. After that, it was heightened to 60 m by local people and more than 53.3 ha farm land was formed. In 1950s, the Department of Soil and Water Conservation, Ministry of Water Resources summarized the experience and constructed a warping dam to trip silt for experiment and demonstration. In the 1960s, construction of warping dams was popularized subsequently in 1970s, 1980s, warping dam has been employed as major engineering measures for gully erosion control and high yield farming land construction. According to investigation, after 50 years efforts up to now, there are more than 110,000 warping dams in the gullies and more than 30 million ha newly farming land have been gained in the plateau because of it 210 x 10^9 tons of silt has been detained. 36,816 dams have been built in Shaanxi, 37,820 dams in Shanxi, 6,630 in Gansu, 17,819 in Inner Mongolia, 4,936 in Qinghai, and 4,147 in Henan etc provinces. Up to the end of 2002, 90% of 1,528 key dams with total storage capacity of 15.13x10^9 m^3 have been constructed on two or three stage gullies where is coarse soil particle region and the erosion modulus is above 5,000 t/km^2. They have brought the following benefits: (i). Detain silt 11.5x10^9 ton; (ii). Control soil and water loss area 9,992 km^2; (iii). Develop irrigation area 25.5x 10^3 hm^2; (iv). Relieve down stream area of 19.8 x10^3 hm^2 from flood disaster; (v). Increase newly warping arable lands 14.5 x10^3 hm^2. The total investment is 5.33 x10^9 yuan, out of which 3.45 x10^9yuan is founded by government. Photos 1 to 5 can show the typical situation of warping dam system built on gullies in the plateau.

Photo 1 Land newly created in gully in Shide, Shaanxi Province

Photo 2 Warping Dam System in Kanghe Gully, Shanxi Province China

Photo 3 Warping dam just completed on Gully, Shaanxi province

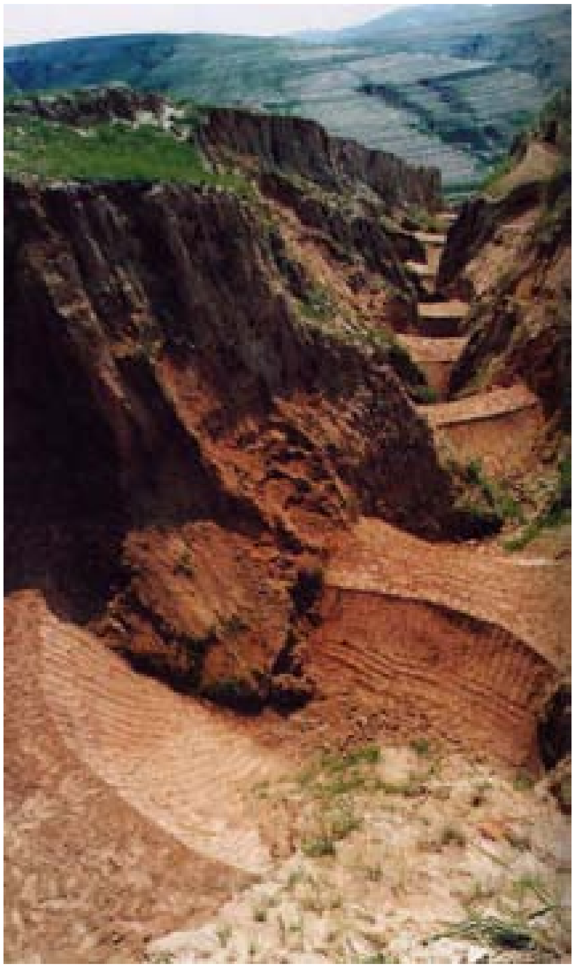

Photo 4 Earth check dam in Shanxi Province

Photo 5 Hydraulic fill dam in Shanxi Province

2.2. Functions of warping dam

Warping dam system constructed on gullies are transverse structures intended to perform the following three functions:

(i). Stabilization of gully bed against cut-down, preventing retrogressive erosion in gully head and bank collapse by scouring in gully bank. This is referred to as a consolidation dam shown as Figure 1 and Photo 5;

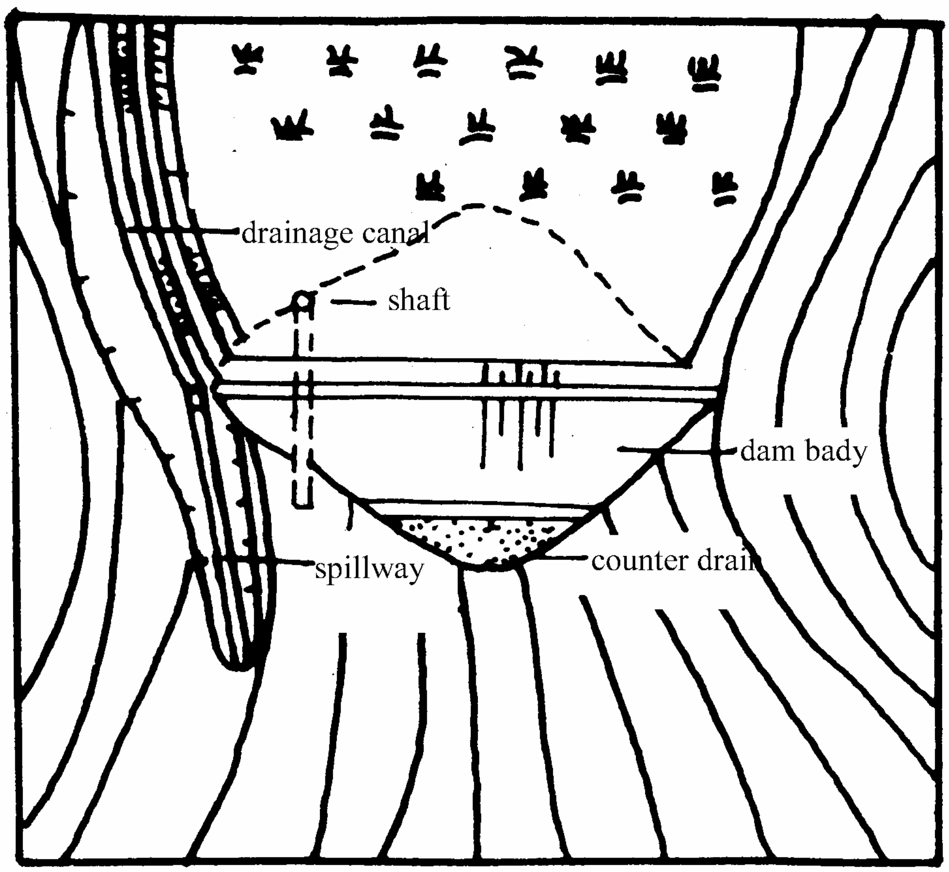

Figure 1 Sketch map of Warping dam

(ii). Reduction of muddy flood peaks coming from upper gullies and detain sediment for decrease reservoir sedimentation and flood defense of lower reaches of gullies, after decrease gully slope shown as Fig.2 ;

Figure 2 Small Water Pond

(iii). Trap silt to form newly land for farming. Change gullies into fertile terrace land to solve food problem in order to create conditions to plant forest on slope land and to develop animal husbandry and sideline.

2.3. Types of warping dams

If classification is based on gullies, warping dam can be classified into the following three types.

(i). The small dam which is built on the first stage gullies with length about 300m, steep slope, narrow V ship cross section and no branch of gully. The storage capacity is about 10-100x 10^3 m^3. Local materials like soil, rock even brushwood have been used.

(ii). The middle size of warping dam which is built on the secondary stage gullies, which are confluent of two first stage gullies with 3-5 km^2 in length and U ship cross section. The storage capacity is 100-500 x 10^3 m^3 and 3-5 km^2 of small watershed area have been controlled. Based local conditions different kinds of dams such as earth dam shown as photo5, composite earth-rock-fill dam, masonry dam, hydraulic fill dam shown as Photo 5, arch dam and tailing dam have been adopted. Most warping dams in plateau are earth dams, due to rich earth resources in local area.

(iii). the key dam or middle size of warping dams which are built on gullies large than the third stage gully with storage capacity of 500-5000 x $10^3 m^3$. According to local nature and economic conditions, different kinds of dams have been built.

If according to the function of the dam in a dam system arranged in a watershed, it can be classified into three types

(i). Warping dam for creating newly farm land shown as photo 1;

(ii). Key dam for flood control shown as figure 3;

Figure 3 Key Dams for Gully Erosion Control

(iii). Key dam for irrigation and water supply shown as figure 2.

2.4. Principals of planning

For key dam funded by government, the following principals considered for planning:

(i). Key area-coarse silt region: Soil and water loss in the watershed of coarse silt region is the key area to be harnessed. The key dam groups should be constructed on gullies in coarse silt region, because erosion modulus in the area is higher than 5,000

T/km^2/year. Most of sediment transported into and deposited on the Yellow River is coming from this region. Therefore, coarse silt region is the key area to be regulated for mitigating sediment deposition of the Yellow River and improving ecological environment shown as Fig.4.

(ii). Reasonable combination of small warping dams and key dams: Small warping dams and key dams should be well combined and reasonable arranged on branches and main stem of gullies to form a dam system for gully erosion control, food security, and flood mitigation network. Key dams are the backbone of warping dam groups. Thus, the stability and safety of dam groups from destroyed by flood is increase.

(iii). Take small watershed as a plan unit: Reasonable planning work should be carried out in accordance with the nature conditions, strategic targets of the national modernization and construction and the requirement of the economic development. Possibilities concerning finance, manpower, material, science and technology should be all taken into consideration. A plan of scientific proposition on land use respectively for farming, forestry, animal husbandry, fishery and sideline are taken full consideration to lay solid foundation for the sustainable development shown as figure 4 and figure 5.

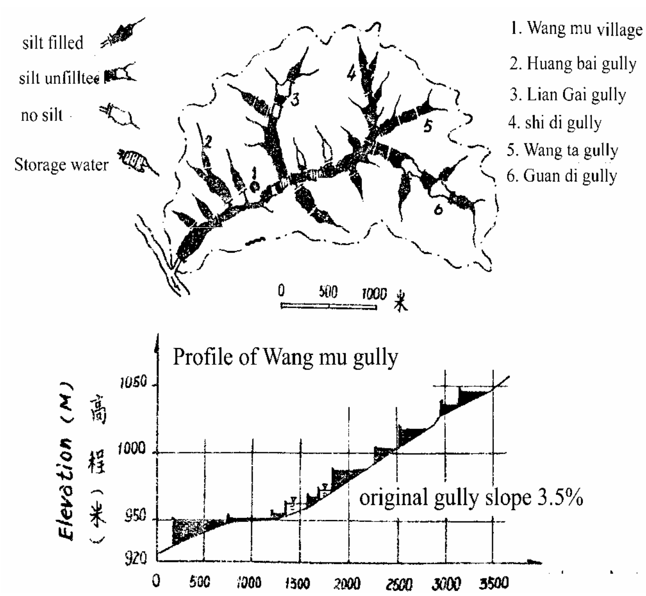

Figure 4 Sketch Map of Warping dams on Wangmu Gully

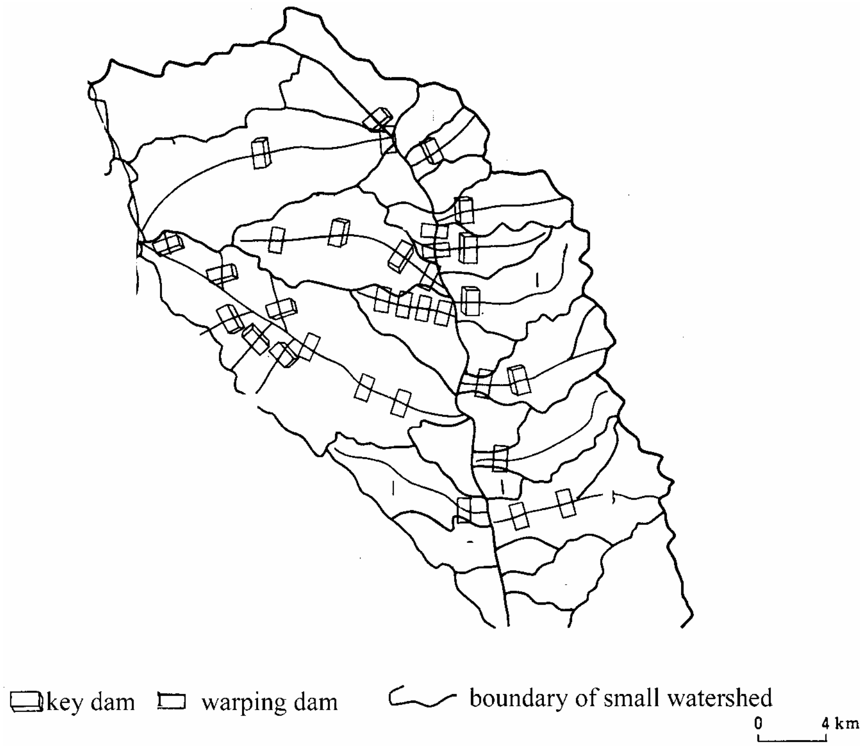

Figure 5 Sketch map of warping dams and key dams built on Huangpuchuan watershed

(iv). Combining measures for gully erosion control and slope land protection: Besides gully fixing by warping dams, the slope land on both sides of the gully should be protected also. Because protection measures such as terraces, tillage measures, and vegetative measures not only can increase water infiltration into the ground, but also can improve ecological environment.

2.5. Arrangement of dam system

A warping dam system consists of a group of warping dams and key dams for multi-purposes such as farm production, flood defense and water supply shown as figure 6. Arrangement of dam system is decided by the local gully landform, the purpose of dams and economic conditions. There are several arrangement styles in the plateau:

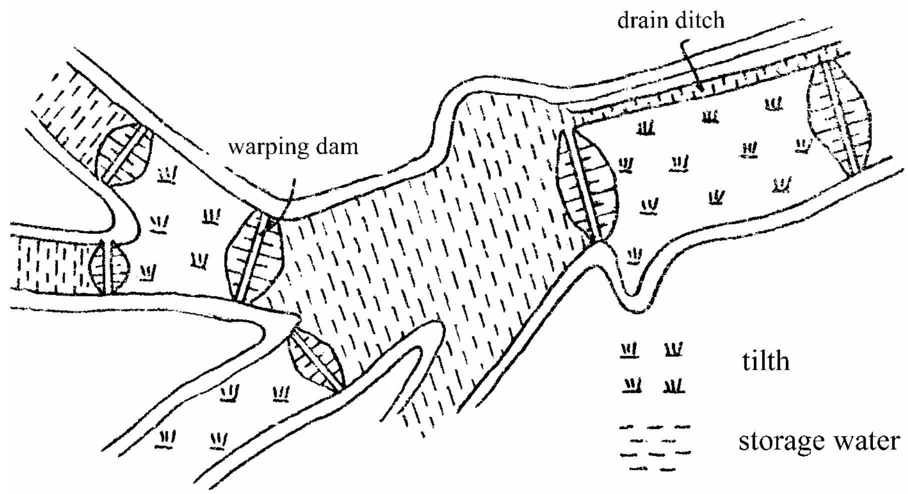

Figure 6 Sketch map of Comprehensive Utilization of Warping dams

(i). While the upper dam is farming, the lower dam is arranged for detaining silt shown as figure 7;

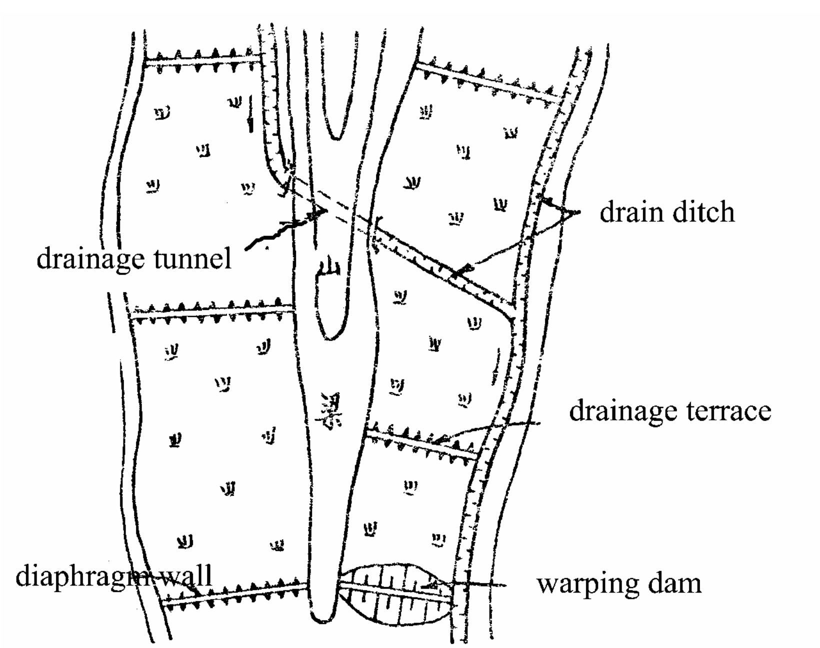

Figure 7 Diverting flood into Drain Ditch on Neighbors Gully

(ii). While the upper dam is detaining silt, the lower dam is used for farm shown as figure 8;

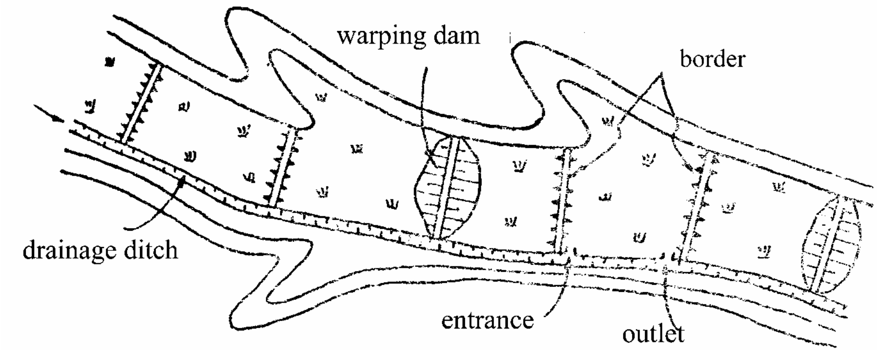

Figure 8 Scheme of Diverting Flood Water to Warping Land flood

(iii). The upper dam is used for detaining silt and the lower dam is used as farming in turn;

(iv). Dams built on tributaries are arranged for storage flood and dams built on main gully are used for farm;

(v). Warping dam used for farm is alternating with small reservoir formed by key dam for flood defense;

(vi). Warping dams are built in one gully and flood flow is drained into the neighbor gully through tunnel and canal system as shown in figure 7;

(vii). Warping dams built in tributaries for farm production and key dams built on main gully for flood defense and irrigation.

2.6. Design flood standard

Design flood standard of warping dam and key dam in gully is as follows:

Table 1 Generic classification

classification	Storage capacity 10^4 m^3	Height of dam m	Warping area
Large size Middle size Small size	50-10 10-1 < 1	1. 30 30-15 < 15	2. 150 15-1 < 1

Table 2 Classification of Warping dam and its Design Flood Standard

Storage capacity $10^4 m^3$		1-10	10-50	50-100	100-500
Types of ramping dam		Small	Middle	Large type I	Large type II
Flood frequency	Design	10-20	20-30	30-50	30-50
	Calibration	30	50	50-100	100-300
Years of storage silt designed (yr)		5	5-10	10- 20	20-30

Table 3 Classification of Key Dams for Gully Regulation and its Design Flood Standard

Total storage capacity $10^4 m^3$		50-100	100- 500
Type of Classification		V	IV
Flood frequency	Design	20-30	30-50
	Calibration	200-300	300-500
Years of storage silt designed (yr)		10-20	20-30

Table 4 Classification of Small Hydro-project and its Design Flood Standard

Total storage capacity 10^4 m		10-100	100-1000	1000-10000
Type of Classification		V	IV	III
Flood frequency	Design	20-30	30-50	50-100
	Calibration	200-300	300-1000	1000-2000

2.7. Management

Development of different system of warping dam management responsibility through contract by household, village, township, and enterprises with government agency of soil and water conservation has been implemented. In fact, it is the combination of labor, income of broad masses and has aroused enthusiasm of thousands of families to manage thousands of dams on gullies. The principal is that who makes contribution to the dam including fund, labor, maintenance and management, who can share the benefits brought by the projects. According to investigation in six provinces in the plateau at present, the property right of small warping dams belongs to village authority. There are three ways to solve the management and maintenance of dams in the plateau; (i). Village authority is in charge of more small dams; (ii). Contract is signed between household and local government; (iii). Put the dam sale for auction or lease to enterprises or private person. Among three ways, more than 85% key dams are in charged of their management and maintenance by village authority, because the way is convenient, lower cost and easy to raise fund. If for key dams which benefits can be developed in the near future, the ways to sign contract to household, to suction or to lease the dam are warmly welcome by local farmers. For example, nowadays, 1.7×10^3 key dams have been leased; as a result, about 1,000 key dams have been repaired and consolidated. The benefits of dams have been developed and 40×10^6 yuan fund has been raised.

3. Evaluation of existing warping dams

3.1. Advantages of warping dams

(i). Reducing sediment transported into the Yellow River

According to investigation in typical small watershed in gully hilly loess region with coarse sediment particle area, the data shows that:

There are 73,000 gullies in the investigating area; each covers area of 0.5-3 km^2, the density of gully reaches 5-6 km / km^2. About 60% sediment is transported by flood coming from gully erosion. Constructing warping dam system for mitigating gully erosion and detaining sediment is an important approach to reduce sediment transported into the Yellow River. Analyzing the data from 1,073 checked and accepted warping dams by local government, 2.78×10^9 m^3 of sediment has been detained. On average, each warping dam can detain sediment quantity amount to 8,000-10,000 ton, among which 1/2 sediment quantity is coarse particle and should deposit on the river-bed as usual, if there is no dams. If so, it is easy to estimate that 1.4×10^9 m^3 of the coarse sediment detained by dams. This is equal to sediment reduced entering into the lower reaches of the Yellow River, after dams constructed. Comparing the data from San Chuanhe, Shaanxi province before and after construction of warping dam system in 1967-1976 and 1987-1996 shows that under the similar hydrological conditions the amount of sediment transported into the Yellow River reduced to 51%, equal to 0.08×10^9 tons.

(ii). Increasing food security

Since construction of warping dam system, newly warping land reaches $53.8x10^3$ ha and newly arable land increases $40.3\ x10^3$ ha in north Shaanxi. Warping land is formed by mud coming from land surface with rich organic matters. According to data from Suide Experimental Station, water content contained in warping soil is 1.86 times higher than that in steep slope land. Therefore, the land is drought-enduring, rich organic, convenient to management, and high yield. Warping land has become stable high yield land in plateau. According to investigation of 7 provinces, grain yields from warping land is 2-3 times higher than that from terrace land and 6-10 times higher then from slope land. Average long-term yield of warping land is 4,500 kg/ ha, the highest one reaches 10,500 kg/ ha. Kanghegou watershed, Fengxi County, Shanxi province, newly warping land is account for 28% of the total arable land only, but grain yield is 65% of the total output. At present, the plateau has $37.7\ x\ 10^3$ ha warping land with annual output reaches $1.6\ x10^9$ kg. The newly warping land makes up 9% of the total arable land, but grain output is 20.5% of the total. In Hongmao village, Hengshan County, there has warping land 39 ha, accounting for 10.6 % of total arable land, but output is 35% of the total.

(iii). Remedying inadequate water resources

Warping dams can be used as water ponds cascade built along a gully before they are full, and key dams are constructed as small ponds or reservoirs on lower reach of the secondary and third large gullies. When flood is coming, hyper-concentration flow can be detained by warping dams stage by stage. After silt settles down, clear water is released through canal flowing into ponds and small reservoirs and stored. Obviously, ponds, reservoirs and canal system can regulate flood, remedy the shortage of water resources, and replenish groundwater as well. Warping dam system built on the middle reaches of the Yellow River has provided water resources to meet the requirement of 10 million people. Warping dams cascade built on gullies in Huanqi County, Gansu province have provided more than 1.60 million m^3 water resources to meet the demand of enterprises and 4 villages.

(iv). Optimum land use

Warping land can produce high gain output due to rich in organic fertilizer, and more soil moisture contained. Therefore, it can be constructed as high and stable yield arable land instead of steep slope land. This creates possibility to implement the approach to resume nature ecological system by transforming slope land from farming into planting forest and grass. With the change of land use more reasonable, it can promote comprehensive developing agriculture economy of farming, forest, animal husbandry and fishery etc and rise living standard of farmer households.

(v). Forming transportation network

In the plateau, communication and transportation is a constraint due to crisscrossing ravens and gullies among villages and lands. The crest of warping dams can be open as road for traffic. Dams connecting roads in villages and lands forms transportation network have brought convenience to promote commercial economy development.

3.2. Lessons of warping dam

(i). The stabilization of warping dams: The discharge standard for flood control is lower in the design of most of warping dams. According to investigation carried out in 13 Counties in the three provinces (Shaanxi, Shanxi, and Gansu) by The Yellow River Water Conservancy Commission after torrential flood in 1997, it was inferred that 32.7×10^3 dams were destroyed, 0nly 50% of key dams and 47% of warping dams were preserved well. The situation of dams destroyed in varying extent. Most part of the dam body destroyed was account for 34%, small part of the dam body destroyed was 27%, and 39% was only spillway destroyed and the remaining dam’s body was preserved well.

(ii). Soil in warping lands was eroded and loss in different extent. Gully erosion in different serious extent took place in some warping lands above the damaged dam area.

(iii). The quality of dams constructed was not very good. Because most of dams built on the smallest gullies were constructed by farmer households and were constrained by technology and capital.

(iv). Water and soil conservation measures were not taken enough on the slope land surface of the watershed for retarding flood. Consequently, after rainstorm, runoff concentrated flowing into gullies and increase flood discharge in the gullies.

(v). Salinization of warping lands: Salinization takes place in soil of warping land and canals. This has become one of the serious problems to effect on the grain yield of the warping land. Because some of the dams were short of drainage facilities or the drainage capacity were lower.

(vi). Deficient in coordination and unified management mechanism for different administrative agencies: There is deficient coordination and unified management mechanism for some middle and large warping dams, because their area of backwater and warping lands are related to more villages or townships and there is short of unified and well-coordinated management mechanism among different administrative agencies. As a result, for those dams, there was no one in charge of their management operation, no one responsible for repairing in time, if they were needed and on one knew the needs and was responsible to add some facilitates to form complete sets of equipment. Therefore, potential risk is hid in some dams.

3.3. Successful marketing and participating mechanism

According to investigation in Qinghai, Gansu, Ningxia, Inner mongolia, Shanxi, and Shanxi provinces, the distinct property right and consummate responsibility mechanism are key problems to be paid and reformed successful. The ways of open the constructing market of the dam such as invite public bidding, hire, auction for dam construction, useable right of the dam, and responsibility management mechanism is successful experience for dam construction and management. The basic policy is that whoever makes contract to invest, and to maintain, who will get the benefits bringing from the project. The contract is an effectual without change for a long term and permitted to be inherited or transferred by contract to the others. It has solved the problem of contradiction of among responsibility, authority, and benefit and of construction, management and use. In fact, it is the combination of labor and income of broad masses and has aroused enthusiasm of households, communities, NGO and GO. They insist on the principle that the scope of contract should be according to the ability of the contractor.

4. Recommendations of construction of warping dams

4.1. Principals of planning

Dams with different purpose constructed in a watershed to form a dam system including warping dams for farm, key dams as small reservoirs for flood defense or storage ponds for irrigation etc. A dam system consists of dams built on branch gullies and main gullies. The responsibilities of dam system are that: it should have the functions of storage and drainage water, retaining silt for land forming to increase food security. A reasonable plan should be to meet the purpose of full use of water and soil resource and change the gully landform into terraced land with irrigation and drainage canals. The cost to build the dam should be as less as possible. Therefore, a rational and comprehensive plan is more important. The principles of plan are:

(i). The plan of warping dams should be integrated into the comprehensive management and rational use water and soil resource plan of the entire watershed. It should take the situation of upper and lower reaches, branches and main gullies, gullies and sloping lands into account in the plan. Biological measures, engineering measures and tillage measures should be employed, according to the local situation. Reforestation, planting grass, change sloping land into terraced land, warping dams built on gullies should be combined to form a soil and water conservation system.

(ii). It should be to bring the dam systems to full play the role of protecting and rational use the natural resources and regulating water and detaining silt.

(iii). Different size of dam system should be to form a complete independent, several dam systems should be integrated to form a large dam system and coordinated each other by united operation, regulate storage and discharge water flow in order to guarantee safe of dam system.

(iv). Dam system plan should include rural road plan. It is necessary to make the plan to protect and to storage local water resource including spring and river source etc.

(v). Measures to prevent soil from salinization should be included into the plan.

4.2. Density of dams built on different size of gullies

A small watershed covers different size of gullies, according to geometry quantity analysis in geomorphology, A.N. Strahler proposed a mathamectial model for classification of gullies is that: The first stage gully (I stage gully) is the smallest one without any branches. Two of the first stage gullies confluent to form a larger gully in terms of the second stage gully (II stage gully). Two of the second stage gullies confluent to form the third stage gully (III stage gully) and so on, until all gullies confluent as a main gully. About 50%-60% of I stage gullies are suitable to build small warping dams only, the others is suitable to build terraces, because they are short, steep slope, and small area. Middle type of warping dam is suitable to select at the lower reach of the confluence of two of the second stage gullies; if the area of the first stage gully is larger, middle dam can also be built on the lower reach of two of the first gullies confluence. Large key dam is suitable to build at the confluence of the third gullies with the length of 3-5 km. At beginning, 2-3 key dams and middle dams to be built is better. IV stage of gully usually is the main gully of the small watershed, which is 10-15 km in length, 5-8 key dams can be arranged, storage pond or small reservoir can be built. VI stage of gully usually is not included in small watershed area, it should take dams arranged on IV and V stage gullies into account as a complete dams system.

The density of dams should be arranged based on the local natural conditions, such as slope of gully, the density of gullies, the possibility of detaining silt for farm, and location for cascade construction warping dams. According to the experience in practice in the loess plateau, the density of dams arranged is as follows:

a. For loess hilly gully area, the slope of gully is 2%-3%, the density of gully is 5-7 km/km^2, 3-5 warping dams arranged is suitable;
b. For gully area in plateau, the slope of gully is 2%-3%, the density of gully is 3-5 km/km^2, 2-4 warping dams built is suitable;
c. For large gully in soil rack area, 5-8 dams can be constructed.

4.3. Ratio of warping dams and key dams

The composition of a dam system consists of small warping dams for farming and key dams for storing water for flood defense and water supply. What is the rational ratio between the two? There are more factors impacting on the density of the dam arrangement. The main factors are density of gullies, slope of gullies, length of gullies, erosion modulus, situation of soil and water conservation, density of rainfall etc. Besides, natural conditions of dam site location, area submerged by backwater, natural conditions of watershed, social, economic and society in local area and erosion type etc are all important factors also. The ratio between warping dams and key dams is 9:1 in the north of Shaanxi; 7:1 in Shaxi; 2:1 in the south of Mongulia; 1:1 in the east of Gansu; and 4:1 in the west of Henan. The shape of cross section of gully is a factor effecting on the ratio also. For the narrow gully with "V" shape of the cross section, it is suitable for arrangement of more small and middle type dams, for "U" shape gully with wide cross section, middle and large size of key dams arranged is suitable, but the number of key dams is less. If a dam system required to against high flood, the key dams need higher design standard. Therefore, less small and middle warping dams is suitable; if the requirement of arable land forming by warping dams rapidly, more small and middle warping dams are needed. The principal of a dam system arrangement is that water and soil resources in the watershed can be detained in the gully area. For the arrangement of key dams in a dam system, three principals should be taken into account, which are: (a). The size of back water area of each dam should be similar equal; (b). The area of branches and main gully controlled by each dam is relatively proportionate; and (c). The ratio of back water area and watershed area controlled by each dam should be similar. Warping dams on the branch and key dam in the lower reaches of the branch or at the confluent should be forming a complete system for warping land, flood defense and water supply independently. According to investigation and analysis of 21 typical gullies with different erosion intensity in Yanan city, the ratio of small, middle warping dams and key dams can be calculated by the following expression [(2)]:

$$N = \sum_{i=1-5}\left[\sum_{j=1-2}\left(\sum_{k=1-3} d_i a_j r_k\right)\right] \quad (1)$$

In which: N – the number of potential warping dams;

d_i - density of dams (n /Km^2), N is number of dams. The value varies with different extent erosion area such as light erosion area; medium erosion area; intensity erosion area and most intensity erosion area;

a_j - different erosion intensity area including hilly area and plain area;

r_k - ratio of small dams, middle dams and key dam.

4.4. Stabilization of warping dams

(i). Extending drain discharge of spillway or shaft

According to investigation of existing warping dams and some of key dams in the plateau, it reveals that: The designing flood frequency for some warping dams is less than that of required, because some of them had been constructed before the required flood standard issued. For some dams, they have been operating more than 10 years, but the silting is still going on, when the silt is up to and exceeding the design silt storage capacity, the available storage is reducing gradually. Nowadays, lots of warping dams have been full filled, the elevation of warping land surface in front of the dam is even up to the crest of the dam. Especially, for some dams, the scale of spillway designed is too small to release designed flood when available storage is reduced. Therefore, the risk of stabilization for dams is existed, if designed flood is coming. In this case, measures to solve the stabilization problem of dam are proposed that:

One is to add the dam height; the other is to extend the discharge capability of spillway or shaft. There are four measures proposed to increase drainage capacity in the following:

(a). Change the square shape cross section of shaft into circle

At present, shaft spillway with multi-level outlets in square shape cross section is widely used for drainage flood in the plateau. Two measures are proposed for increasing drainage capacity of a dam.

For example, the cross section of shaft is 120 cm x 120 cm with the thickness 50cm, the rock material needs $3.4m^3$. If change the cross section shape of shaft from square into circle, thickness can be reduced to 30cm, because circle shape can bear heavier force than square one.

The equal quantity of rock material can meet the need to build a circle shape cross section with inner diameter of 1.5m, outer diameter of 1.8m shown as figure 9 and figure 10. The spectacular change is that the drainage capacity is 4.9 times than square shape cross section. If the inner diameter adopted as 1.0 m, the cross section is still 2.18 times larger then square one, besides, the rock material can be safe 44%.

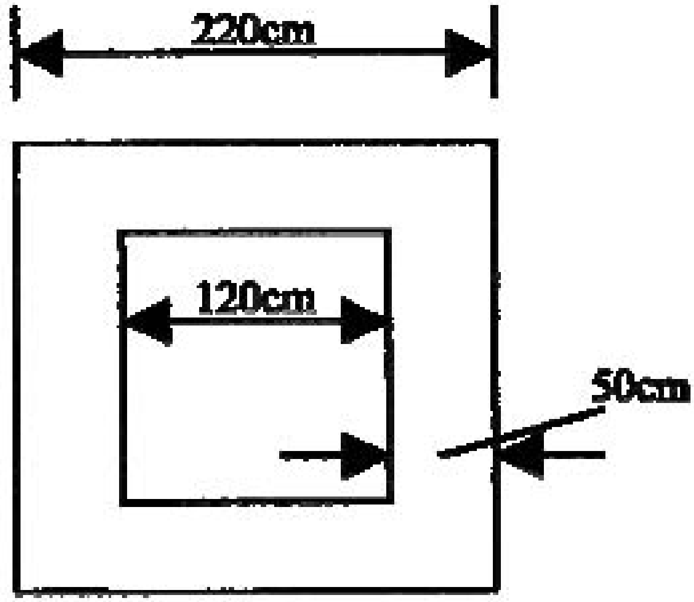

Figure 9 Sketch Map of Rectangular Cross-section of Shaft

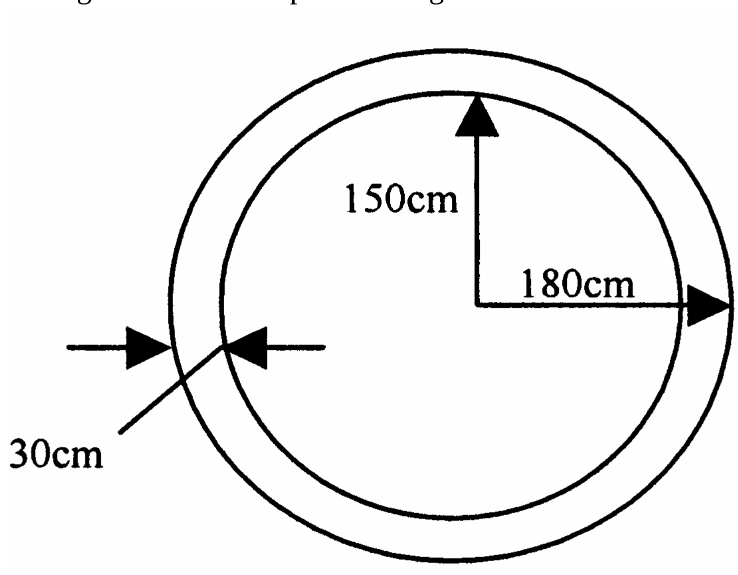

Figure 10 Sketch Map of Circular Cross-section of Shaft

(b). Designing the top of shaft as spillway

At present, the top of shaft is as high as the dam crest and can not be allowed to overflow. Water entrance is set on the side of shaft. If the top of shaft can be changed to reduce its height and designed the top as curve shape as spillway for increase drainage capacity. There are abundant experiences of crest spillway of tailings dam being taken as reference. The simple way is to reduce the height of shaft 2m, and to smooth the top of shaft as curve. Piers diverting flow is better to set for entranced air and improve the safe operation.

The above measures can improve the drainage capacity from present 2.5 m^3/s to 10 m^3/s. The advantage is not only increase the drainage capacity, but reduces the size of shaft.

(c). Construction of side spillway

It is need to build side spillway for security of key dams. Especially, it has the possibility to utilize the rock foundation.

(d). Designing earth dam as overflow dam

At the beginning for 1-2 years after earth dam completed and operation, it is not need spillway, due to large storage capacity to regulate flood. After two years operation, the earth dam has sunk, measures can be taken on the surface of earth dam for protecting during overflow. There are many ways to protect surface of overflow earth dam. The key problems are that it should prevent water from penetrating into the earth dam during overflow; overflow dam should be well conjunction with other part of the dam as a whole; and it should be well constructed for the conjunction place.

(ii). Index of stabilization of warping dam

There are many factors effect on stabilization of warping dams, such as rainfall, flood, sediment, landform, soil property, erosion type, soil and water conservation measures and harness extent, ways of management, crops, and drainage capability etc.

With the increase of land area created by dam, the sloping area of the watershed controlled by dam reducing gradually, the capability of runoff from sloping area of the watershed reduces gradually also. Therefore, the capability of regulating flood flow and detaining silt is increasing. When the newly land in front of the dam is increase to relatively large, the capability of water and soil lose of the watershed can be controlled.

According to the experience, stabilization of warping dam is close related with the ratio of area of newly land created by dam and watershed area controlled by the warping dam, which can be expressed as

$$I = 0.01 \frac{A}{F} \tag{2}$$

In which

I—The ratio of total land area created by dam system (hm^2) and watershed area controlled by the dam system (km^2).

A—Total area of newly land created by dam system (hm^2)

F---Area of watershed controlled by dam system (km^2).

The ratio of backwater area of allowed depth of water flow stored by the dam system and area of watershed controlled by dam system is in terms of relatively stabilization critical value Ic. In which, depth allowed of back water is the water depth of flow stored by dam under a certain flood frequency. That is

$$I_c = 0.01 \frac{W_p}{dF} \tag{3}$$

In which, W_p -- amount of a flood flow of flood frequency, P, ($10^4 m^3$);

d -- allowed depth of water stored by dam system, (m);

When $I > I_c$, the dam system is stabilization. When $I < I_c$, the dams are not safe.

Analyzing a lot of data investigated in typical small watersheds, it shows that when the ratio of land area formed by silt detained by dams and watershed area controlled by the dam system is 1/25 – 1/20, the dam system is relatively stabilization.

4.5. Newly warping land used for farming activities in advance

The main purpose of warping dam is to create newly land for farming by detain silt. If the land can be used until the small pond is full of silt, it needs to wait at least several years even more than ten years. This way is suitable to operate the dam in water shortage area, because in earlier stage of the operation, more water can be stored in the small pond for water supply. But on the other hand, the water will be great loss by reservoir evaporation. Obviously, it is need to avoid wasting water resource in the arid and semi- arid region. If farm activity can be carried out while the earlier operation of warping dam before the silt full up in the small pond, it can gain benefit of land utilization in advance. For example, it needs to gain land 82.8 mu for 10 years in a plan, on average, 2.8 ha of land will be gained and can be used as farm land each year, and the economic value is great obviously. At present, this way is not to be adopted in the plateau. Because there are two constraints to limit farming activity; one is the elevation of outlet of shaft is higher, after a flood, it needs three days to drain water, if so, crops can not bear submerged for such a long time. The other is drain discharge is too small to drain water rapidly. The ways to solve those problems are proposed that: for the first one, a pipe with diameter about 20 cm can be buried on the lower elevation through the dam as outlet to drain water. The elevation of the pipe can be added with raising of silt deposition until to the elevation of outlet of shaft. The other one is better to plant fodder to develop animal husbandry, before the surface of silt depositing up to the elevation of outlet. For most of warping dam in the plateau, if the diameter of shaft increase to 8 m^3/s, drain designed flood needs only less than one day. If so, farming activity can be carried out while the process of deposition raise up to the storage.

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