Yellow River at Risk
An Assessment of the Impacts of Climate Change
on the Yellow River Source Region
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For Greenpeace
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Climate change is a reality. Today, our world is hotter than it has been in two thousand years. The 1990's was the hottest decade in recorded history, nine of the ten hottest years on record have occurred since 1995 with 1998, 2001, 2002, 2003 and 2004 being the five hottest years ever recorded. By the end of the century, if current trends continue, the global temperature will climb higher than at any time in the past two million years. The global scientific consensus is clear - that humanity is in large part responsible for this change, and that choices we make today will decide the climate of the future.

According to The Chinese Academy of Sciences in a joint statement issued on June 7th 2005 jointly with 10 other national science academies from around the world:

"there is now strong evidence that significant global warming is occurring. The evidence comes from direct measurements of rising surface air temperatures and subsurface ocean temperatures and from phenomena such as increases in average global sea levels, retreating glaciers, and changes to many physical and biological systems. It is likely that most of the warming in recent decades can be attributed to human activities. This warming has already led to changes in the Earth's climate."
Climate scientists and world leaders alike acknowledge that climate change is the greatest threat facing the world today. Global warming is already pushing the Earth's climate systems into changes that are wreaking havoc environmentally, socially and economically. Worse is predicted to come with potentially tens of millions of lives at risk and the very real threat of our global climate changing faster than what we can ever hope to adapt if no immediate action is taken.

In the same Chinese Academy of Sciences joint statement:

"human activities are now causing atmospheric concentrations of greenhouse gases - including carbon dioxide, methane, tropospheric ozone, and nitrous oxide - to rise well above pre-industrial levels... Carbon dioxide levels have increased ...higher than any previous levels that can be reliably measured (i.e. in the last 420,000 years). Increasing greenhouse gases are causing temperatures to rise; the Earth's surface warmed by approximately 0.6 centigrade degrees over the twentieth century."

The Intergovernmental Panel on Climate Change (IPCC) is the globally recognized body of the world’s top climate scientists. Founded by the World Meteorological Organization and the United Nations Environment Programme in 1988 in response to growing global concern over the threat of climate change, it reports to world leaders, advising on the scientific basis for assessing climate change, on the actual and potential impacts of climate change and on the options for mitigating and adapting to climate change. Over 2500 climate scientists contribute to the IPCC’s Assessment Reports. The last of these - the Third Assessment Report (TAR) was published in 2001. The fourth is due to be published in 2007.

The TAR finds that climate change presents a threat to most natural systems. The natural systems threatened include glaciers and permafrost, coral reefs, mangroves, arctic ecosystems, alpine ecosystems, prairie wetlands, native grasslands, and biodiversity “hotspots”.

Climate change will increase existing risks of species extinction and biodiversity loss in ecosystems at every latitude and in each region. The level of damage will increase with the magnitude and rate of global warming. A landmark study published in Nature last year predicted that global temperature rise of less than 2 degrees could result in the extinction of up to a quarter of all terrestrial species.

It identifies the threats to human systems, beyond the loss of natural ecosystems, as deriving from threats to water resources, agriculture, forestry, health, settlements, energy, industry, and financial services.

The IPCC TAR finds that developing countries are
most at risk from climate change. This means potentially very serious consequences for China and China’s development goals, since not only the species and distinctive environments of China are threatened, but also the lives and livelihood of the people and the wealth of the nation.

According to the 2004 Initial National Communications on Climate Change, People’s Republic of China:

- The results from 40 different global climate change simulation models suggest that the ground temperature in China could rise by 1.5-2.8 °C by 2030; 2.3-3.3 °C by 2050; and 3.9-6.0 °C by 2100.

- If the temperature rises by 3 °C, the permafrost of the Tibetan Plateau would undergo severe loss, with 58% of it disappearing. Most of the permafrost in the east and south of the Plateau would be lost.

- The glaciers in the western part of China would be reduced by 27.2% by 2050. This means the ice storage in the high mountainous areas in western China would decrease significantly. The seasonal regulating capacity of the glacier for the water flows to rivers would be seriously damaged.

- In the next 50-100 years, climate change will not fundamentally relieve China from the water shortage caused by population growth and socio-economic development. On the contrary, it would further aggravate the per capita water shortage problem in Ning Xia, Gan Su, Qing hai, Xin Jiang, Shan Xi, Shaan Xi and elsewhere. The decrease in water availability could reach 20%-40%.

- Due to climate change and extreme weather, by 2030-2050, total agricultural output could decrease by about 10%, including decreases in the three major staples: wheat, rice and corn.

As a developing country, China has achieved widely recognized economic success in the past 20 years. However, "the effects of climate change are expected to be greatest in developing countries in terms of loss of life and relative effects on investment and the economy. For example, the relative percentage damages to GDP from climate extremes have been substantially greater in developing countries than in developed countries... The projected distribution of economic impacts is such that it would increase the disparity in well-being between developed countries and developing countries, with disparity growing for higher projected temperature increases". The challenge of climate change poses a serious problem to China, a threat probably greater than any other challenges in China’s future economic development.

Greenpeace has been documenting the impacts of climate change for many years and all over the world. Working with scientists to support, co-operate or disseminate independent scientific studies of the impacts of climate change on the real world Greenpeace advocates action to mitigate the worst of the predicted climate chaos. By traveling to places affected by climate change to record first hand in images, film and stories what climate change means for the environments and people that it affects Greenpeace bears witness to the harm unfolding worldwide and uses the testimony to call for more solid action from the
international community to reduce greenhouse gas emissions and keep the warming with bounds that allow humans and the environment a chance to adapt to the changes.

Greenpeace hopes that this study of the impacts of climate change on the source region of the Yellow River will add to the global understanding of the damage and challenge that climate change poses to China. Climate change is happening today and the Yellow River plight is but one among the visible threats around the world which highlight the enormous magnitude and international significance of climate change as the common threat. The time for debate is past, now we must act.

Greenpeace Chief Advisor on Global Climate Change and Renewable Energy Policy

Steve Sawyer

Reference

i Joint science academies' statement: Global response to climate change, issued 7th June 2005, signed by national science academies of China, Brazil, Canada, France, Germany, India, Italy, Japan, Russia, UK and USA. http://nationalacademies.org/orpi/06072005.pdf

ii Comments made while Dr Pachauri addressed international conference attended by 114 governments in Mauritius. Reported in The Independent (U.K.), (2005), Pachauri: Climate Approaching Point of "No Return": Global Warming Approaching Point of No Return, Warns Leading Climate Expert by Geoffrey Lean, January 23rd.


iv Dangerous Interference with the Climate System: Implications of the IPCC Third Assessment Report for Article 2 of the Climate Convention, Greenpeace Briefing Paper, published at the Sixth Session (Part Two) of the Conference of the Parties to the United Nations Framework Convention on Climate Change 16-27 July, 2001 Bonn, Germany - Greenpeace International

v Ibid. The briefing paper summarizes the debate thus: "There is mainstream scientific agreement on the key facts: Certain gases, such as carbon dioxide, in the atmosphere create a "greenhouse effect", trapping heat and keeping the Earth warm enough to sustain life as we know it. Burning fossil fuels (coal, oil, etc.) releases more carbon dioxide into the atmosphere. Although not the most potent greenhouse gas, carbon dioxide is the most significant in terms of human effects because of the large quantities emitted. There is also widespread agreement that: A certain amount of additional warming - about 1.3°C (2.3°F) Fahrenheit compared to pre-industrial levels - is probably inevitable because of emissions so far. Limiting warming to under 2°C (3.6°F) is considered vital to preventing the worst effects of climate change. If our greenhouse gas emissions are not brought under control, the speed of climate change over the next hundred years will be faster than anything known since the last ice age."

vi IPCC Working Group II - Third Assessment Report on Climate Change 2001: Impacts, Adaptation, and Vulnerability

vii Thomas, C. D., Cameron, A. et al., "Extinction Risk from Climate Change", NATURE |VOL 427 | 8 JANUARY 2004, p. 145


The Yellow River source region, about 45,000 km² in area, is generally defined as the riverhead area above the Darlag hydrological station and covering Maduo County, Darlag County, Maqen county and part of Gade county in Qinghai province. As the birthplace and ‘water tower’ of the great watercourse, the region plays a vital role in regulating the water volume in the Yellow River. Changes in the stream discharges of the Yellow River source region directly affect the water resources of the middle and lower reaches of the river. In recent years, due to climate change, the glaciers, permafrost, lakes and wetlands, and the hydrological and ecological environments in this region have undergone dramatic changes that have far-reaching implications for the economic and social conditions of people’s lives not only in the source region itself, but also in the middle and low reaches of the Yellow River.

Climate change is the driving force of the ecological and environmental degradation of Yellow River source region.

During the last 50 years, statistics show that there is an apparent trend of warming and decreased precipitation in the Yellow River source region. The regional climate is becoming warmer and drier. This change leads to a series of ecological and environmental problems, such as glacier retreat, permafrost thawing, wetland and marshland drainage, lake shrinkage and soil deterioration. The area of glaciers, for example, in the A’nyamagun Mountains, has decreased by 17% from 1966-2000, ten times faster than in the previous 300 years. The combined effect of rising temperature, permafrost degradation, overgrazing and rodent plague has led to severe ecological deterioration. Grassland coverage has degraded alarmingly; 'Black soil erosion' and desertification have increased at a devastating rate. In the 1990s as the temperature rose, the major tributaries in the Yellow River source region frequently suffered dry periods, which led to a drop in water resources in the region and across the entire Yellow River basin. From the changes in the glaciers, permafrost and the pattern of land coverage, we can conclude that climate change is the major factor leading to the overall ecological degradation in this region while localized human activities, like industry and agriculture have

Abstract

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aggravated the situation. Meanwhile the river itself is under threat from this deterioration in its birthplace. Above Lanzhou is the area most significant for runoff formation for the Yellow River, with its annual water flow counting 55.6% of the total volume of the river; for the last decade, the Yellow River section above Lanzhou suffered from consistent decreases in runoff. During the late 1980’s, the Yellow River above Lanzhou lost water at an average annual rate of 13%. In 2002 the water flow above Lanzhou dropped by 46% compared with the average annual volume of water in the river.

Under climate change, the plight of the Yellow River and its source region is a clear and urgent warning to the world that global warming is harming us now and is going to get worse. To tackle climate change and especially to mitigate the part human activity played in causing climate change is not a task for the people of Yellow River source region alone. It requires the concerted effort of China and all other countries in the world to act now.
Chapter 1
Climate Change in China and the Yellow River source region

As with global climate change, the climate in China has also become warmer in the last century. The 1990s were the warmest decade in the last two thousand years. Climate change varied in different regions. Study shows that the difference in climate change between the eastern and the western part of China lies in the “Middle Age Warm Period” (9th -11th century) ¹, when the temperature rise in eastern China was greater than in western China. Similarly, although the climate in the northwestern part of China became warmer and more humid, the Yellow River source region’s predominant trend is to become warmer and dryer.

During the last 50 years, the climate in the Yellow River source region is becoming warmer and drier. Both annual average temperature and seasonal average temperature are on the rise. Especially after 1986, the temperature quickly climbed. In the 1990s, the precipitation dropped sharply. This clearly shows that the climate is becoming warmer and drier.

According to statistics, both the western and the eastern part of China have become warmer since the 1950s (Figure 1.1) and the rates of warming are both around 0.2°C /10a (0.2°C every ten years). In 1998 registered as the warmest year during the last 50 years; the temperature was 1.3~1.4°C higher than average both in the eastern and in the western part of China. Since the mid-1950s, the

Fig.1.1 Variations in average air temperature and precipitation in China during 1951-2000 (Ding Yongjian et al., 2005)
temperature in the Qinghai-Tibetan Plateau has been rising sharply, 0.16°C/10a during 1955~1966. During the past 30 years, the plateau has seen a drastic average temperature rise of nearly 1 degree Celsius. And the higher the altitude is, the faster the temperature rises. Generally speaking, the changes in the rainfall between the east and the west are different during the last 50 years (Figure 1.1). The 105°E line represents the division. To the west of this line, rainfall has become more frequent, 5%/10a~10%/10a. Rainfall has been increasing in the northwestern region while in northern China, it is becoming drier.

IPCC (2001) has developed various climate models with different emissions projections to make an assessment of future climate change. It predicts that the global average temperature will increase by 1.4~5.8°C According to Prediction on the Climate Evolution in the Western Part of China by Qin Dahe (2002), the temperature in the Tibetan Plateau will increase by 2.0~2.6°C and the precipitation will increase by 18%; the temperature in the northwestern part will increase by 1.9~2.3°C and the precipitation will increase by 19%. It is projected that due to temperature increase and glacier melt, there will be more frequent glacier related floods and mudslides in the short term. In the long term, glacial retreat will play a decisive role in the decrease of runoff in major rivers in northwestern China which rely heavily on the water supply from glaciers.

Climate changes in the Yellow River source region

During the recent 50 years, the climate in the Yellow River Source region has become warmer and drier. Both annual average temperature and seasonal average temperature are on the rise (Figure 1.2), up by 0.88°C during the last 50 years, at an annual rate of 0.021°C·a⁻¹ (Xie Changwei, 2003). Generally speaking, in the 1960s, YRS experienced a low temperature period whereas in the 1970s, the temperature rose again. Due to heavy snow in 1977/78, 1983, and 1985/86 in the Yellow River source region, the region experienced a lower temperature period from the late 1970s to the mid 1980s; but after 1986, the temperature quickly climbed.

During the last 40 years, the annual minimum temperature has increased by 1.2°C mostly due to increases in spring and winter; rising 1.6°C and 1.5°C respectively. Autumn temperature rose 1.1°C, with summer temperature contributing least to the overall average rise; increasing only by 0.16°C.
Generally speaking, the minimum temperature in this region has increased, mainly due to the increases in spring and winter, and less so to autumn and summer. The increase in minimum temperature has the most far-reaching consequences for permafrost regions.

Recent data (Figure 1.3) shows that precipitation was abundant in the 1960s and 1980s, but scarce in the 1950s, 1970s and 1990s. Especially in the 1990s, most stations recorded sharp precipitation drop. In Jiuzhi and Banma townships, the figure in 1991-2001 was 80–100 mm less than that from 1950s to the 1980s, and precipitation suffered a 20% drop at Jiuzhi station, the biggest in this region. As for the precipitation distribution, it is no longer concentrated in July, August and September; instead, the precipitation in other months has increased slightly relative to the previous norm. Combined with the temperature change, we can see that in May, June and during winter, it is warmer and more humid; whereas in July and August, it is warmer and drier. The latter change also embodies the major trend in this region in last 50 years. In May and June, the warm and humid weather is conducive to plants but contributes less to the water supply. Also from the evaporation data, we can see that the evaporation rate is at its peak during these two months. Combined with the minimal precipitation from July to September this directly leads to decreases in groundwater (Figure 1.3).

On one hand, the overall level of precipitation in this region is decreasing. On the other hand, incidences of rainfall have become more intense, with extremely heavy rain and blizzards becoming more frequent. This combination gives rise to more water and soil erosion, floods, landslide and avalanche. For instance, on March 18th 2004, a rare snow and ice avalanche (glacier and snow pack avalanche) took place in the northwestern side of the A’nyê maqên
Fig. 1.4 The ice and snowslide in a glacierised area in the western A'ny ê maq ên Mountains and the glacial block-lake arising from the avalanche.

Mountains (see Figure 1.4). The fallen glacier and snow, together with a lot of moraine peeled off and landed in the watercourse of the Qingshui River, and several other watercourses, forming a block-lake. In June 2005, during our field trip, the lake was still there. But on July 4th, 2005, it burst in a glacial lake outburst flood causing a dramatic impact on the land, agriculture and people living downstream. Fortunately it seems that no-one was killed in this case. As a result of climate change, we can expect that in future in the Yellow River source region there will be more frequent extreme weather events with increasing intensity. As a result there is likely to be, for example: more severe water and soil erosion, rainstorms, floods and snow and ice collapses; all with the potential to be disastrous.
Chapter 2
The Yellow River source region and its importance

The Yellow River source region plays a vital role in supplying and regulating water to the entire river basin, with its length above Lanzhou providing 55.6% of the total river water flow. Fluctuations in the run-off of Yellow River in the source region can have a direct impact on the water resource in the middle and lower reaches of the river. During the last 50 years, the warm and dry effects in the source region have led to significant hydrological, ecological and environmental changes and have produced far reaching impact on people’s lives and economic development in the river’s source region and middle and lower reaches alike.

The first trickle of the Yellow River starts from the wetland on the northern slope of Yueguzonglie Mountain, which belongs to the Bayankala Mountains in Qinghai Province; meeting other trickles of melted glacier water in an increasing creek. Then it runs into the Zhaling Lake, Eling Lake and runs through the Longyang Dam. From here it winds through different climate belts and nine provinces: Qinghai, Sichuan, Gansu, Ningxia, Inner Mongolia, Shaanxi, Shanxi, Henan and Shandong, and finally merges into the Bo Sea. It extends 5,482 km, the second longest in China after the Yangtze river; and covers an area of 7.5x10^5 km². Known as China’s mother river, it serves as an important water source in the northwest and northern part of China for industrial and agricultural activities. Its climate background is considerably different from other rivers. Comparatively speaking, the water is not abundant in this river, and the annual runoff averages 5.8x10^10 m³, 2% of the total runoff in China, about 1/17 of the Yangtze River and 1/6 of the Pearl River. In the Yellow River basin area, the per capita water availability is only a quarter of the national total. The per unit arable land water resource is less than 1/5 of the national average. Comparatively speaking, the water volume of the Yellow River is not as abundant as the others, but 1/10 of China’s population depends on the limited water resource in it.

Since 55% of the Yellow River’s runoff comes from above the Hekou Township in Inner Mongolia while 90% of the sand comes from below the Hekou Township, we can divide the Yellow River into...
upper, middle and lower reaches. The upper reach is from the source to the Hekou Township; the middle reach is from Hekou Township to Huayuankou in Henan Province and the rest is the lower reach. The upper reach extends 3472 km with a 3846 m fall. The water is more abundant in this part, which covers an area of 4.28x10⁴ km² (including 4.2x10⁴ km² inflow area). The average annual runoff is 384.2x10⁸ m³, 3/5 of the total water volume of the river. The water mainly comes from the Tibetan Plateau especially beyond Longyang Dam: the Yellow River source region. Although the annual precipitation is no more than 400mm, due to the high altitude and the vast permafrost distribution, evaporation is low. These conditions are conducive to the formation of the runoff. The Yellow River source region produces the greater part of the water flow in the river. Its role is predominant in the river.

The Yellow River source region is generally defined as the riverhead area above the Darlag hydrological station covering Madoi County, Darlag County, Maqen county and part of Gade county in Qinghai province and ranging about 4.49x10⁴ km² (Ding Yongjian et al., 2003) (Figure 2.1). The annual runoff at Tangnag station in the Yellow River source region is about 209.3x10⁸ m³ (Xie Changwei, 2003): 38.5% of the overall runoff for the whole river. The runoff modulus (5.44 L/km.s) is twicethat of the overall basin area figure (2.2 L/km.s). The source region plays an important role in regulating the runoff for the whole river basin. Whether the water is abundant at the source region will directly influence the middle and the lower reaches.
During the last 50 years, the climate in the Yellow River source region has become warmer and drier, causing a profound effect upon the glaciers, permafrost, rivers, lakes, wetlands, and other hydrological bodies in the region. The changes are also closely related to the variation of runoff of the whole river. In the most important water source area above Lanzhou, which accounts for over half of the entire river (55.6%), the water source has been declining in recent years (Fig.2.2) (Wang Sumin and Liu Shiyin, 2005). From the 1980s to the present, the average annual decrease in runoff in the river section above Lanzhou was 13%.

Due to the sharp decrease in runoff within the source region and water consumption increase in the middle and lower reaches (according to statistics from the Yellow River Water Resource Committee, in the entire basin area the annual water volume taken for usage amounts to 500x10^8 m^3 and the actual water consumption on yearly basis is 400x10^8 m^3), during low water season, no-flow events take place more frequently, begin much earlier and last much longer (Figure 2.4). From 1972 to 1996, no-flow events occurred in 19 years out of 25 years, totaling 682 days; 36 days per year (Jing Min, 1998). In the 1990s, no-flow events occurred every year and even started as early as February and March. The starting point was 600km higher up the river than before and the runoff at the source region has dropped sharply. Fig.2.3 is the secular variation of runoff at the Tangnag station. From this figure we can see that the runoff of the Yellow River has experienced the low-high-low process during the last 40 years. At the source region, the runoff in the 1990s was at a very low level, for the annual average figure from 1990-1999 is 17% than that from 1956-1989 (Xie Changwei, 2003). Since the 1970s, the runoff of the Yellow River at the Huangheyan station has dropped at 4.4 m³·s⁻¹/10 years while at the Tangnag station, it dropped at about 30 m³·s⁻¹/10 years.

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number of the days of no-flow reached 100-200. In 1995 and 1996, the no-flow event in the Lijin section lasted 120 days and 132 days respectively. In 1997, the Lijin section suffered 13 no-flows, totaling 226 days. This time the first no-flow event came on April 7th. Right after the flooding season, on September 3rd, the river stopped flowing again, setting historical records on both occasions respectively (Wang Sumin, 2002).

Flowing for thousands of millions of years, the Yellow River is a very special river. In China, it is a long but low-flow river. Compared with the Min River, the Yellow River runoff is roughly the same, but the Min River is less than 1000 km while the Yellow River is 5,482 km. Because the Yellow River source functions as a ‘water tower’ at high altitude, the river is able to flow much further than other rivers. It starts from the Qinghai-Tibetan Plateau, the world third pole to the Loess Plateau and then to the Huabei Plain (northern china plain). It crosses 3 or even 4 kinds of climate regions like dry region, half dry region, half humid region and so on. It serves as an important water source in the northern part of China. Therefore, if there is any change in the water runoff and the ecosystem at the source region of the Yellow River, it will certainly produce far-reaching effects upon the lower reaches.

- (1) The national economy suffers huge losses. No-flow events have caused huge economic losses and environmental pressure for the lower reaches of the river. Industry suffers more than agriculture in economic terms. According to statistics, due to water shortage and no-flow events, from 1972 to 1996, industrial and agricultural loss (oil fields included) amounted to 25.7 billion Yuan; 1.35 billion per year on average (calculated at 1995 prices). The economic loss in 1995 was 6.37 billion Yuan and it was 5.09 billion Yuan in 1996. Also, according to incomplete statistics, in 1995, no-flow events caused 6 billion Yuan losses in Dongying, Zibo, Binzhou, Jinan in Shandong Province. In 1997, the loss reached 10 billion Yuan. In 1995, the industrial loss was 8 times more than the agricultural sector (Deng Yingtao, Wang Xiaoqiang, 1999). The frequent no-flow events in the Yellow River threaten drinking water access for people and cattle; and severely threaten the economic development and survival of local communities. Thus the situation could obstruct the strategic shift of our national economic focus from the east to the middle and the west (Yao Wenyi, 1999).

- (2) It will aggravate floods. Due to the lack of water, a huge amount of mud and sand have piled in the main water channel, adding more danger during flood seasons. In 1950, 70% of the mud and sand could be brought to the beach while now 90% is piled in the water channel. Therefore, the water channel is higher than the beach and the beach is higher than the living areas outside of the banks. There is the constant potential threat of a disastrous flood. It is reported that the Inner Mongolian section at the middle and upper reaches...
Under the effect of rising temperature and decreasing rainfall, Yellow River source lost 23% of its water during the past 10 years.

has risen by over 2 meters during the past decade, forming a third "hanging river above the ground" next to the Henan section and Shandong section. This can be partially attributed to the fact that the middle reaches have consumed more water for irrigation than before, but one of the main reasons is that the water comes from the source and the upper reaches has dropped sharply.

(3) The eco-system is deteriorating. Generally speaking, situated in the humid region, the lower reaches don’t have to face the danger of desertification. However, due to the lack of water from the source, huge amounts of mud and sand deposit so that the banks are bare in the sun. When it dries up in winter and heavy winds blows, the sand on the riverbed will be blown to the neighboring regions, which may expose the lower reaches to the danger of desertification . (Qu Yaoguang, 2001). In the river mouth area, no-flow events have led to the absorption of sea water, resulting in soil salinization. The lack of fresh water has disrupted the ecosystem in the wetland and poses a threat to the survival of more than 8000 aquatic species, several hundred wetland plants and more than 180 kinds of birds (Yao Wenyi, 1999).
Chapter 3
Ecological changes in the Yellow River source region in the last 50 years

3.1 Changes in Glaciers and Permafrost

Glacier retreat

Since the Little Ice Age (around 1500-1920), and especially since the 1950s, with the effect of global warming, glaciers across the world are retreating steadily and continuously (Ding Yongjian, 1995). In China, the vast majority of alpine glaciers on medium and low altitude are retreating too. (Wang Zongtai, 1991; Ding Yongjian, 1996). Global warming is the decisive factor for glacier retreat, causing more melting of the ice, withdrawing of the ice tongue, shrinkage of the glacier area and ascending snowlines. Glacier change is a strong indicator of climate change. On the other hand glaciers also exert considerable influence upon the local climate, ecosystem, water resources and changing sea levels.

Since the 1950s, both the mean annual and seasonal temperature in this region has been on the rise (Xie Changwei, 2003; Yang Jianping, 2004). With the warming effects, the glaciers are clearly retreating (Liu Shiyin, 2002). Most of the glaciers in the source region are in the A'ny ē maq ēn Mountains and Bayankala Mountains. The volume of glaciers in the A'ny ē maq ēn Mountains account for over 96% of the total volume of glaciers that feed the Yellow River source water. Ranging from 34°20’~35°N, and 99°10’~100°E, the A'ny ē maq ēn Mountains are 120 km long and 40 km wide (Fig. 3.1), with the highest altitude being 6282m. There are 58 glaciers in this region; covering an area of 125 km². Three of them are over 10 km², and 7-10 km long, distributed on the east side of the mountain; in the west, cirque glaciers and hanging glaciers are more common. The snowline on the east side is between 4990-5190 m, and on the west around 5160m.

With global warming, the glaciers and permafrost in the Yellow River source region have undergone significant changes. Study shows that the glacier area decreased 17% in 2000 compared with that in 1966. In the last 30 years, the shrinkage rate of the glacier is 10 times faster than that of the previous 300 years. Comparison of the satellite maps from the 1970s to those from the 1990s clearly shows that permafrost has shrunk significantly. Meanwhile the edge of the sporadically distributed permafrost has moved up by 50-70 m.
Fig. 3.1 Map showing the glacier distribution in the A'nyémön Mountains, 1966 (Liu Shiyin et al., 2002).

Our study shows that during 1966-2000, most of the glaciers have retreated. Yehelong Glacier retreated 1950 m from 1966 to 2000; the biggest change relative to its peers. In 2000, its length was only 23.2% of the original in 1966. The second biggest change is in 5J352E20 Glacier, which has retreated 43% in length compared with 1966. Although small glaciers did not retreat as much as bigger ones in absolute length, the retreat percentage is quite high. During 1966-2000, the 5J 352E13 Glacier, a relatively small one, retreated 77%. In addition, the glaciers in 5J 351D facing south and southeast shrank 20% in length, those in 5J 352E area west and northwest decreased 27% in length.

In 1966, the glaciers covered an area of 125 km², accounting for 95.8% of the total glacier area in the source region of the Yellow River. This area in 1966 is 17.5% less than that during the coldest period of Little Ice Age and the glacier area in 2000 is a further 17% less than that in 1966. Since 1966, the retreat-rate of the glacier in this region is 10 times greater than that in the past 300 years, which demonstrates that the glacier is not only retreating, but also the retreat is accelerating (Table 1 and Figure 3.2) (Liu Shiyin et al., 2002). Since 1966, the glacier area has decreased by 22.74 km², and suffered ice storage loss of 2.66 km³ and water resource loss of 2.9x10⁸ m³. This accounts for the loss of around 10% of the yearly stream flow of the Lanzhou Section of the Yellow River.

### Table 3.1 Area change of glaciers in different time periods in the typical glacierised areas of the source region of the Yellow River (Liu Shiyin et al., 2002).

<table>
<thead>
<tr>
<th>Time</th>
<th>Glacier area (km²)</th>
<th>Area change (km²)</th>
<th>Area change ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Last Ice Age</td>
<td>391.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Little Ice Age  (roughly 1500-1920)</td>
<td>147.8</td>
<td>-234.8</td>
<td>-62.0</td>
</tr>
<tr>
<td>1966</td>
<td>125.5</td>
<td>-22.3</td>
<td>-15.1</td>
</tr>
<tr>
<td>2000</td>
<td>103.8</td>
<td>-21.7</td>
<td>-17.3</td>
</tr>
</tbody>
</table>
In northwest China, water plays a pivotal role in the ecosystem, social and economic development. Acting as a ‘solid water reservoir’, the glaciers constitute an important part of the water source in this region. The water derived from the glaciers is a significant component in the northwest arid area and could supply as much as 80% of the water source to inland bodies of water in the region.

The glaciers can effectively regulate the runoff of the river. During a dry period with high temperature and low rainfall, more ice will melt and discharge more water into the river; while during a wet period with lower temperature and more precipitation, more of the rainfall will freeze into the glacier, becoming ‘stored’, and the stream flow will drop accordingly. The alpine glacier area, with its high altitude tends to create so-called "wet island" effects where precipitation is higher in the high altitude area than in the low altitude area. Its runoff modulus is also comparatively high. Therefore, the alpine glacierised area is the most significant region producing stream flow. Such phenomenon is particularly apparent in arid and inland river basins.

From the micro-climate perspective, it is still uncertain whether glacier retreat will change such "wet island" effects. However, glacier retreat and the reduced area generating runoff in the source region will definitely reduce the river’s water supply. The regulating role of glaciers on the river’s seasonal flow and cross-year flow will be undermined and the whole hydrological circulation of the Yellow River source region will be affected.

Additionally, the retreat of the glaciers has left a build up of moraine at the glacier termini. These stony masses are loose and unstable, with little vegetation. When it rains heavily, glacial lake outburst floods or debris flow (land slides) may be triggered. Besides the immediate damage, such events bring more sand and sediment into the Yellow River and the reservoirs along the upper reaches of the river.
A comparison of the terminus variations of the Halong Glacier.

Upper panel photo:
June 1981,
Professor Dr. Matthias Kuhle.

Lower panel photo:
September 2005,
John Novis, Greenpeace.

From analysis of the comparative location of terminus, its depth and moraine coverage, it is evident that in the last 25 years, the Halong glacier has undergone significant retreat.
Permafrost Deterioration

With the effects of global warming, the area of permafrost has shrunk considerably. Meanwhile the annual mean earth-temperature is rising, the frozen layer is becoming thinner and the melting layer is becoming thicker. The edges of the permafrost areas are disintegrating with actual permafrost becoming patchy and breaking up into isolated blocks divorced from the main permafrost zone.

(1) Earth temperature is rising.
The earth temperature is an important feature of the permafrost; its change is a response to climate change. During the past 20 years, the earth temperature of the permafrost area in the northern part of this region has increased by about 0.4~0.6°C.

(2) Disintegrated permafrost and the active layer.
When the frozen depth is reduced and the active layer moves deeper in the vertical direction, permafrost and the seasonal frozen layers are separated by the melting layer, resulting in the ‘sandwich effect’ of discontinuous permafrost. Discontinuous permafrost and melting layers of frozen earth are widespread in the source region.

For example, there is melting all along the Qingkang Road (214 national road), in particular at the A’nyemaqên Mountains, Huashi Gorges, Madoi County and the Qingshui River. According to geological surveys and statistical analysis, the depth of the permafrost’s upper limit is 4~7 m; the thickness of seasonal permafrost is 2~3 m and that of the melting layer is 1~4 m (Yang Jianping et.al, 2003). For example, in the #2 hole at the south slope of the A’nyêmaqên Mountains, at an altitude of 4180 m, the depth of the hole is 4.5 m. Of this 0-1.1 m is seasonal frozen layer;
1.1-2.9 m is melting layer and 2.9-4.5 m is permafrost layer (Yao Tan dong et al., 2002). This shows that under climate change, permafrost is increasingly unstable and that the permafrost is increasingly discontinuous.

(3) The permafrost base is moving upwards.
Comparing the figures from the 1970s and the 1990s, it is found that at the edge of the permafrost zone, the base of sporadically distributed permafrost has climbed up by 50~70 m (Wang Shaoling et al., 1997).

(4) The area of permafrost is decreasing correspondingly.
Due to the rising earth temperature there is widespread permafrost melting. The thickness of the permafrost has decreased by 5-7m on the margin, and the overall area of permafrost has shrunk correspondingly. As a result, the outer boundary of 'island-shaped' permafrost areas has contracted towards the centre. For example, in Madoi County, the boundary of the permafrost has contracted by 15km towards the centre. In some places, permafrost melts simultaneously from the surface downwards and from below, upwards towards the surface.
Permafrost degradation has caused visible impacts upon the hydrological and ecological conditions in the region notably:

(1) Changes in the flow-system of generated groundwater affect the runoff of the Yellow River. With the rise of the lower boundaries of permafrost and the thickening of the active layer or intensive thawing at the upper limit of the permafrost, the ground water table will fall if there is no sufficient water supply from rainfall. In addition, the ground water system in the active layer will combine with the lower ground water system when the permafrost degrades completely into a thawed permeable soil. Such a change in permafrost leads to the moisture seepage in the active layer down to the ground water and the surface soil layers will become dry. At its most extreme this change has reversed the relationship between river runoff and underground water such that sometimes the river feeds back to the underground water rather than drawing water from it. Permafrost thawing has disrupted the underground water cycle and can further drain the Yellow River at its source.

(2) Increased greenhouse gas emissions.

In the permafrost layer, there are significant carbon stores, in particular in the form of methane (CH₄). When the permafrost melts these greenhouse gases are released into the atmosphere, further contributing to global warming. In the past five decades, due to the temperature increase and permafrost degradation in this source region, the ensuing impact of the greenhouse gas emission is potentially devastating and deserves more research immediately.

(3) Impact on construction projects in cold regions.

Swelling of frozen ground and ground-collapse from melting are two major problems affecting construction projects such as road building and maintenance in cold regions like the Qinghai-Tibetan Plateau. For example, in road building the thickness of the active layer of permafrost under the asphalt is normally 1.5~2.0m more than the natural active layer due to the changes in the surface albedo and evaporation conditions caused by the asphalt layer. The heat in the road combined with the changes in average earth temperature prevent proper re-freezing of the active layer. The permafrost is left in a disintegrated state beneath the road causing the road itself to deteriorate and...

Fig 3.3 The influence of thawing: frozen landslide and collapse of permafrost on side slope and pasture land.

---

In the permafrost layer, there are significant carbon stores, in particular in the form of methane (CH₄). When the permafrost melts these greenhouse gases are released into the atmosphere, further contributing to global warming. In the past five decades, due to the temperature increase and permafrost degradation in this source region, the ensuing impact of the greenhouse gas emission is potentially devastating and deserves more research immediately.
subside. In the case of Qingkang Road (214 national road), the southern lower boundary of the continuous permafrost has moved 10 km northward whereas the lower boundary under the asphalt has moved 15 km northward (Yao Tandong et al., 2002). Therefore permafrost degradation has caused serious damage to bridges and bridge arches along the line.

(4) Decreasing vegetation coverage, expanding “black soil erosion” and desertification. Permafrost can store and regulate water and nutrition supply for vegetation at high altitude. However, in the last 40 years the upper limit of the permafrost layer has dropped deeper under the surface, and the moisture content in the topsoil has dropped correspondingly. Meanwhile, the soil temperature rise has accelerated decomposition of organic material, making more nutrients available in the soil. Some original plants have thus been replaced by new species more suited to the newly emergent conditions. According to field research, permafrost degradation has caused the alteration of land from bog meadow to grassland meadow. Though this has increased biodiversity, the coverage of the vegetation and the yield of grasses have declined correspondingly. Over time the permafrost degradation will cause grassland
deterioration due to the further decreasing moisture content in the soil. Meanwhile the thawed soil provides a more benign environment for rodents, which pose a serious threat to the grazing land for cattle. Moreover rodent inhabitation and digging have changed the structure of the soil; for example the holes they dig further reducing water retention in the upper soil layers. The long term effect has increased “black soil erosion”, which in turn most often leads to desertification. The final step in the destructive cycle is that the newly formed desert, in turn, will further absorb water from the soil around it and cause more permafrost retreat. Climate change in the Yellow River source region is therefore driving a vicious cycle of ecological degradation (Fig. 3.3 and 3.4).

Hua Shi Xia Township, Qinghai, CHINA In the Qinghai permafrost region, 59 km from the Hua Shixia Township, stand deserted living quarters built for road construction workers. Foundations of the buildings are unsafe and main walls are prone to cracking and tilting due to permafrost thawing.
3.2 Changes in Lakes and Stream Discharge

In the source region, the area of rivers and lakes has been decreasing, leaving dry riverbeds and lakebeds the threat of further ecological degradation. The water area, including rivers, lakes and reservoirs measured 2474.5 km² in 2000. From 1986-2000, the lake area decreased by 5.3% of the entire lake area in 1986, of which outflow lake shrinkage accounts for 71% of the total lake shrinkage. Wetland basin shrinkage accounts for 13.4%. Runoff has continued to drop in recent years. There have been frequent no-flow events since 1990s, signaling that the source region is not maintaining or supplying as much water as before into the Yellow River.

Yellow River Township, Qinghai, CHINA
Small dried up lake. Once the small lakes and grassland disappear, nothing can hold back desertification.
In the source region, the area of rivers and lakes has decreased significantly in recent years, leaving dry riverbeds and lakebeds and the threat of further ecological degradation. According to Wang Genxu (2004), the Landset TM analytical data in 2000 demonstrated that the water area in this region was 2474.5 km² (including rivers, lakes and reservoirs). During the 15 years from 1986 to 2000, the lake area decreased by 81.7 km², 5.3% of the total lake area in 1986. The lost area in outflow lakes accounted for 71% of the total, many outflow lakes have become isolated and land-locked, a change that directly reduces water feeding into the Yellow River and its tributaries. The river basin also shrunk by 9% in 15 years, accounting for 92.4% of the total water area lost and leading to a significant increase in dry riverbeds (Figure 3.6). The dry riverbeds and bare lake bottoms not only create critical problems for the Yellow River but have been factors in the severe desertification and salinization in the area and have themselves given rise to many sandstorms.

Madoi County, known as the First County of the Yellow River, used to have 4077 lakes. Now more than 3000 small lakes have disappeared, and in quite a number of the remaining lakes the water have been salinized. Many lakes in the river valley between Madoi County and Zhaling Village have dried to the extent that the new road could go directly through the major lake in that area. The famous lake cluster at the Star Sea has largely drained away and become bog (figure 3.7). The inland lake Lungma Tso has shrunk by almost half.

In the Zhaling Lake and Eling Lake, the biggest sister lakes in the source region, the water level has dropped significantly, leaving more than 300 km² of bare sand newly uncovered at its
margins. Such shrinkage has not only affected the surrounding ecosystems, but also reduced the supply of underground water, the level of which continued to drop in recent years. Since the 1980s, the level of underground water in this region has dropped by 7~8 m, in some areas, more than 10 m. The drop of the underground water level has made the soil drier and further caused permafrost retreat and withered surface vegetation.

Recently, on the basis of aerial photos in 1969, TM remote sensing data in 1994 and 2001, Lu Anxin studied the changes of the major lakes in the source region. Despite 4km² expansion of Eling Lake from 1994-2000, other major lakes shrunk in the period from 1969-2001 (Table3.2). Zhaling Lake and Eling Lake are outflow lakes so that the changes in area are not obvious, but a significant change is that during the past 50 years, their water level has dropped by 3~4 meters (Table3.2). Moreover, due to rising temperature and the accompanying drop of the water level, the Star Sea Lakes which used to be connected to the Yellow River have now become isolated inland lakes, without water
exchange with the Yellow River. These lakes have undergone dramatic changes and shrinkage in recent years. In turn the loss of water supply from these lakes also contributed to the lowering of the Yellow River’s runoff (Figure 3.8 and 3.9). From our investigation, we conclude that the minor expansion of Eling Lake is due to a water conservation project which was built nearby and thus raised the water level. From 1994-2001, the Longria Lake has totally disappeared, which may be related to the exploration of salt mines nearby.

The bog and wetland ecosystem plays an important role in the Yellow River source region. According to remote sensing images in 2000, the area of bog and wetland in the source region of the Yellow River totaled 2,473.3 km². This area was mainly distributed in the delta river basin formed by the Andringitra Mountains, Bayankala Mountains,

<table>
<thead>
<tr>
<th>Table 3.2</th>
<th>The water area of selected lakes in different years in the source region of Yellow River (Lu Anxin et al., 2005)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake</td>
<td>Area (km²)</td>
</tr>
<tr>
<td>Zhaling Lake</td>
<td>528.1</td>
</tr>
<tr>
<td>Zhuo Rongcuo</td>
<td>12.6</td>
</tr>
<tr>
<td>Eling Lake</td>
<td>613.6</td>
</tr>
<tr>
<td>Upper Star sea</td>
<td>29.0</td>
</tr>
<tr>
<td>Middle Star sea</td>
<td>38.1</td>
</tr>
<tr>
<td>Lower Star sea</td>
<td>22.2</td>
</tr>
<tr>
<td>Longria Lake</td>
<td>18.9</td>
</tr>
</tbody>
</table>
Fig. 3.8 The remote sensing image of Star Sea Lakes in the source region of Yellow River (Lu Anxin et al., 2005).

Fig. 3.9 The percentage change in area of the main lakes in the source of Yellow River (Lu Anxin et al., 2005).

and Buqin Mountain and among a number of rivers in this region. During the 15 years from 1986-2000, the bog and wetland area declined by 13.4%; a decrease in area of 332km². In this decline the alpine peat bog suffered the most significant loss, with 44.2% of the original area in 1986 disappearing (Table 3.3).

Rivers, lakes and wetlands maintain the most abundant vegetation and animal resources in the region and display the most distinct features of biodiversity in the region. The deterioration of

<table>
<thead>
<tr>
<th>Types of wetland</th>
<th>1986</th>
<th>2000</th>
<th>Changes in area (km²)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bog meadow</td>
<td>2073.5</td>
<td>1918.7</td>
<td>-154.8</td>
<td>-7.5</td>
</tr>
<tr>
<td>Alpine peat bog</td>
<td>399.8</td>
<td>223.0</td>
<td>-176.7</td>
<td>-44.2</td>
</tr>
<tr>
<td>Total</td>
<td>2473.3</td>
<td>-331.6</td>
<td>-13.4</td>
<td></td>
</tr>
</tbody>
</table>

Table 3.3 Changes in bogs and wetlands area over 15 years (1986-2000)
this ecosystem will directly reduce the surface water supply, affecting vegetation and animal resources accordingly. At the same time the deterioration also prevents the Yellow River source region from playing an effective role in regulating the water resources in the region and in the Yellow River basin. Climate change has played a very significant role in the deteriorating conditions. Decreased precipitation is the major cause of the shrinkage of lakes and rivers in the region. In addition, temperature rises are increasing the volume and rate of evaporation and thereby removing more water from lakes, rivers and the soil.

Runoff changes

The river area in the source region has been shrinking, with a 9% decrease in area during 1986-2000 (Figure 3.6) (Wang Genxu, 2004). This has created many dry river beds and affected the river runoff. The decisive factor for the decreasing runoff however is lessening rainfall and the change in rainfall patterns. In terms of annual runoff, since the middle of 1980s, there has been a gradual decrease. The runoff in autumn has dropped dramatically (figure 3.10) and the annual runoff has thus changed. In the past, the precipitation in spring and autumn formed two peaks in annual runoff; however, at present, it has reduced to only one peak in a year (figure 3.11) without the autumn peak anymore. This signals an important change and a dwindling stream flow.
3.3 Grassland Changes

In the last 30 years, the consistent temperature rise in the Yellow River source region has caused significant permafrost degradation and lake and wetland drainage. As a result the moisture content in soil has fallen and led to grassland deterioration. High coverage grassland with high productivity has deteriorated significantly while low coverage grassland (namely that with sparse distribution of flora) is expanding. Alpine meadow, highly sensitive to climate change, has been shrinking.

Grassland deterioration is mainly demonstrated by low coverage grassland and "black soil erosion". Simultaneously desertification is getting worse. The degraded land area of this region is as much as 31,646.8km², 34.4% of the total source region. Each year the land deteriorates 3%~10% more on the 1980 basis, which means by 2020 degraded land will exceed 60% of usable land in the Yellow River source region.

Grassland is an essential element of the ecosystem in this region. The changes in its structure, function and material circulation directly impact on the entire region. In the grassland ecosystem, the alpine steppe and alpine meadow are most common, and are vital for cattle and sheep. Meanwhile bog meadow maintains the water source and supports wider biodiversity.

For convenient analysis, the alpine steppe is divided into three categories: high-coverage alpine steppe (with more than 50% coverage), mid-coverage alpine steppe (30-50% coverage) and low-coverage alpine steppe (with less than 30% coverage). Similarly the alpine meadow has three categories: high-coverage alpine meadow (with more than 70% coverage), mid-coverage alpine meadow (50-70% coverage) and low-coverage alpine meadow (less than 50% coverage).

On the basis of TM and ETM satellite data from 1986 and 2000 (Wang Genxu, 2004), the alpine grassland has drastically deteriorated; primarily this has manifested in the deterioration of alpine meadow with coverage over 30% (Table 4) by 2,250.11km²; a 1.58% decrease annually. Correspondingly, low-coverage alpine steppe has increased,
expanding 1,964.97 km². Meanwhile, high-coverage alpine meadow has decreased significantly; a 66.75 km² decrease annually. The mid- and low-coverage meadow expanded 145.97 km² and 864.85 km² correspondingly.

Alpine bog meadow is highly sensitive to climate change. In the last 15 years, bog meadow decreased by 13.41%; a 22.11 km² annual decrease.

To summarize: the changes in the grassland in the source region could be characterized as high-coverage grassland shrinking, low-coverage grassland expanding and bog meadow decreasing (figure 3.12).

<table>
<thead>
<tr>
<th>Time and change rate</th>
<th>High and middle coverage alpine steppe</th>
<th>Low coverage alpine steppe</th>
<th>High coverage alpine meadow</th>
<th>Middle coverage alpine meadow</th>
<th>Low coverage alpine meadow</th>
<th>Bog meadow</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986</td>
<td>9513.05</td>
<td>5417.74</td>
<td>14473.83</td>
<td>7799.22</td>
<td>6571.94</td>
<td>2473.29</td>
</tr>
<tr>
<td>2000</td>
<td>7262.92</td>
<td>7382.71</td>
<td>13472.63</td>
<td>7912.19</td>
<td>7436.79</td>
<td>2141.70</td>
</tr>
<tr>
<td>Change rate (%)</td>
<td>-23.65</td>
<td>36.27</td>
<td>-6.85</td>
<td>1.88</td>
<td>13.16</td>
<td>-13.41</td>
</tr>
</tbody>
</table>

The “black soil erosion” (Figure 3.13) and rodents are two major threats to the grassland. The formation of black soil erosion is closely related to permafrost retreat (see chapter 3.1 glacier and permafrost).

At present in the plateau area, 65% of the natural grassland is affected by rodents; accounting for 20-30% of the grassland loss. In places the rodent burrows are as concentrated as densely as 600-700 in one hectare. This means that rainfall drains quickly into the ground at a lower level and cannot form surface rivers. The result is that the runoff to the Yellow River is reduced and local environment is further affected by water deprivation. At present, there is no effective way to turn it back. Considering the above factors, it is estimated that in the next decades, the environment will further deteriorate.
Human activities have also directly influenced the ecosystem. Since the 1950s and especially in the 1970s, the population has rocketed and the livestock numbers have increased, which has generated serious ecological problems. Desertification caused by overgrazing is quite common in this region. According to Wang Genxu's research during 1994–1996, in winter and spring the grass is of low quality; while in summer and autumn it is of high quality (Wang Genxu et al., 2001). Theoretically, Madoi farmland could support 667 thousand sheep units in winter and 3048.9 thousand sheep units in summer. Thus livestock grow well in autumn but then die in spring as the numbers can no longer be supported. Such a situation not only impedes sustainable development of the local economy, but also causes serious grassland degradation and desertification as the pasture is pushed to its limits in the spring season. This vicious cycle of human activity has aggravated grassland deterioration in the source region, compounding the effects of regional drying and grassland loss caused by climatic change. Thus climate change and localized human activity form a more deadly combination. Climate change reduces the viability of the grassland as its coverage declines and thus puts more pressure on remaining pasture, accelerating the decline of the remaining grassland areas. With less water and higher evaporation, as well as reduced run off and degradation caused by permafrost melting, the grazed land is even more sensitive to the damage and declines further under the pressure.

![Alpine meadow, grassland degradation: "Black-soil erosion".](image-url)
Nomadic mother and child, Madoi county, Qinghai, CHINA
3.4 Soil Deterioration

According to remote sensing data, in the last 15 years, the soil pattern and its ecological distribution in this region have undergone drastic changes. A great proportion of soil has deteriorated, and the desertification rate reached 1.83% annually. The high-coverage alpine steppe has become low-coverage or turned completely to desert, and the same is occurring with alpine meadow and bog meadow. These are major trends in soil deterioration, which trigger further changes in soil cover patterns and lead to ecological deterioration.

In land usage, land degradation happens when one or more effects leads to decreases in biological complexity or economic productivity of rainfall-irrigated land, irrigated land, grassland and forest in the arid, semiarid and half humid arid regions, including:

1. **soil substance loss due to water erosion and wind erosion**
2. **the deterioration of physical, chemical or biological features**
3. **long-term loss of natural vegetation** (Qin Dahe, 2002).

According to relevant definitions given, there are five types of soil deterioration at the source region of the Yellow River: water erosion, glacial erosion, soil salinization, sandy desertification, and vegetation degradation. If we consider a larger area (the entire area before the Longyang Gorges), remote sensing surveys found that the soil deterioration area reached 31,646.8km², 34.4% of the total region. Within this area, desertification accounts for 13,434.8km², vegetation degradation for 7,636.5km², water erosion for 7,101.7km², glacial erosion for 3,084.5km² and soil salinity for 389.3km² (Feng Jianmin, 2004) (Figure 3.14). In the last 15 years, desertification increased by 6.4%, namely at the rate of 1.83% annually; higher than the average desertification rate in the Hexi area. In the same
Evolution of soil pattern

According to TM and ETM data collected in 1986 and 2000, we can see that the soil pattern in the Yellow River source region has changed dramatically. High-coverage alpine steppe became low-coverage and desert; and the same with the alpine meadow and bog meadow. These are major trends in soil deterioration. For instance, 15% of high-coverage alpine steppe and 29% of mid-coverage period the salinization rate was 0.49 km² per year, twice than that in the Yangtze River source region. Bare rock, sand and beach with coverage of less than 5% have expanded 3.95% in the last 15 years, and its distribution area ranks second only to alpine steppe and alpine meadow (Table 5) (Wang Genxu, 2004).
steppe turned into low-coverage alpine steppe and 8% of high-coverage alpine steppe turned into mid-coverage alpine steppe (Wang Genxu, 2004).

During the last 15 years in the Yellow River source region, other types of soil have also undergone significant changes. As much as 18% and 15% of the river basin and lake area have transformed respectively, mainly into sand (54.6 km²) and bare rock (86.8km²). Additionally, 12% of desertified area has transformed, of which 10% changed into fixed and half-fixed dunes, reaching an area of 149.0 km²; and another 34.1km² transformed into bare rock. In the same period, 682.3 km² of other types of land have transformed into desert; more than 4 times the scale of the transformation from desert to steppe. Historically the region has had very little salinized soil, but during the last 15 years, other types of land, like rivers, lakes and desert have been transformed into salinized soil, reaching 5.4 km² in total; almost double of the original area. In the same period, 17.2% of the glaciers in the region have melted to expose bare rock.

Table 3.5 The area changes of selected land types in the source region of Yellow River between 1986 and 2000 (Wang Genxu et al., 2004).

<table>
<thead>
<tr>
<th>Types of land</th>
<th>1986</th>
<th>2000</th>
<th>Change rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>1565.68</td>
<td>1968.09</td>
<td>25.65</td>
</tr>
<tr>
<td>Salinized land</td>
<td>6.48</td>
<td>13.39</td>
<td>106.63</td>
</tr>
<tr>
<td>Bare rock, sand and beaches</td>
<td>12522.77</td>
<td>13006.91</td>
<td>3.95</td>
</tr>
</tbody>
</table>
3.5 Biodiversity Changes

The unique geographical and ecological conditions in this region have cultivated numerous rare species. This region, together with the Yangtze River source region is one of the most biodiversity-rich regions in the world. In recent years, due to climate change and human activities, the region has suffered great losses in biodiversity. As the climate turns warmer and drier, the grassland ecosystem continues to deteriorate and the wetland has also been shrinking.

**Species diversity**

In the UN Environment and Development Conference held in Brazil, 1992, all state leaders present signed the Convention on Biodiversity. In this convention, under Article 2: The Use of Terms, the concept of biodiversity is defined as the following:

"Biological diversity" means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems.

Biodiversity has three dimensions: species diversity, inheritance diversity and ecosystem diversity (Glowka et al., 1994). Human beings are dependent on a healthy global biodiversity. Human development cannot be separated from the conservation of biodiversity.

The unique geographical and ecological conditions in this region have cultivated numerous rare species. This region, together with the Yangtze River source region, has highly concentrated biodiversity at this high altitude (Chen Lingzhi and Wang Zuwang, 1999; Wu Yuhu and Mei Lijuan, 2001). In these two source regions, there are 133 mammal species, of which a third belong to a carnivore subclass and a quarter belong to a rodentia subclass. In the vertebrate class, there are 249 kinds of birds. Of these 147 kinds are living in the Yangtze River area, covering 15 subclasses 34 families. Amphibians and reptiles are rare in the source regions. As for the flora, the natural vegetation is always flourishing. There are over 800 Poaceae and Cyperaceae (Wu Yuhu and Mei Lijuan, 2001). The wormwood and moss are
abundant, providing ideal fodder for cattle and representing unique feature in the alpine grassland.

In recent years, due to climate change and biodiversity degradation, combined with human activities, the number of species in this region has declined sharply. Many valuable herbal medicines such as *rheum tanguticum*, *scutellaria baicalensis* in Qinghai and Chinese Caterpillar Fungus are already on the verge of extinction (Wu Yuhu and Mei Lijuan, 2001). In the source regions, many animal species have also been in grave danger. Due to massive commercial interest, a large number of wild yak and Tibetan Antelope have been slaughtered. In the 1980s and 1990s, the number of wild yak and Tibetan Antelope dropped by 33% and 54.7% respectively (Wang Genxu et al., 2001). Snow Leopard, Lynx, Tibetan Gazelle, Argali used to be very common in the source region, but now they have almost disappeared due to over-hunting. (Wang Genxu et al., 2001).

**Ecosystem diversity**

The local landscape is complex and features mountains, rivers, lakes and valleys. The geographical conditions, climate and soil type combined have produced this local natural environment characterized by wetland, desert, grassland, forests and other alpine vegetations. Such an ecosystem provides ideal habitat for various wild animals and plants, therefore, this region has become an important one demonstrating the biodiversity in China (Chen Lingzhi and Wang Zuwang, 1999).

In the last 40 years, with the warming trend, the grassland and wetland in this region continue to deteriorate. The alpine steppe, alpine meadow and bog meadow have all been shrinking, 2.63%, 3.74% and 24.53% respectively from the 1970s to the 1980s and 6.64%, 24.21% and 34.45% from the 1980s to the 1990s. Since the 1970s, a number of bogs have been drained and turned into meadows. The plants fit for dry climate have moved into this region. Wetland and lakes have retreated (Wang Genxu, 2001). All these changes combined with destructive human activity to compound the threat to the regions rich diversity of flora and fauna.
Chapter 4

Conclusion

The effects of climate change are sweeping the globe, from polar melting to drought, flooding to sea level rise, spreading disease and increasing to extreme weather like heat waves and hurricanes. China is no exception and Chinese scientists identify many effects of climate change in the weather and ‘natural’ disasters affecting the country in recent years.

Scientific consensus is clear that anthropomorphic emissions of greenhouse gases are causing the Earth to heat up. Polar regions and high altitude regions in the northern hemisphere are especially sensitive to the warming that the world is now experiencing. The Tibetan Plateau, known as the world’s third pole or the roof of the world, has seen an overall temperature rise of nearly 1 degree Celsius during the past 30 years. And the higher the altitude, the faster the temperature rises.

Looking at the region around the source of the Yellow River - China’s mother river - the extent and significance of the changes is painfully clear. The ecological fabric of the region is being torn apart by a series of compounding effects, each triggering or reinforcing the others such that complete breakdown is threatened. The hydrological stability, biodiversity, and agricultural and economic status of the region are all under threat.

As the origin of China’s great watercourse, the Yellow River source region plays a vital role in regulating the streamflow in the middle and lower reaches of the river. The Yellow River source region plays the major role in supplying the whole river basin, providing 38.5% of total river runoff at Tangnaila hydro station and 55.6% for the length of the river above Lanzhou. Water shortage and reduced run off at the source will have far-reaching impacts upon the economy, society and people’s life not only in the source region, but in the middle and low reaches of the Yellow River - in short, all across China.

The analysis in this report and the studies it draws upon clearly shows that the hydrological and ecological integrity of the Yellow River source region is in grave danger. The region suffers from permafrost retreat, glacier retreat, river and lake shrinkage, grassland deterioration and even desertification. This survey of the environmental changes in the Yellow River source region shows that the main threats to the region, and thus to the river itself, are predominantly driven and worsened...
AnyÄ•maqÄ•n Mountain Range, Qinghai, China. Evidence of Glacial Retreat.

During the past 30 years, Tibetan plateau has been heated up for 1 degree. Glacier melts are sped up. From 1966 to 2000, glaciers in yellow river source region retreated by 17% in area, causing loss of 2.39 billion m³ of water from yellow river source.
by global warming or climatic changes associated with increased global temperatures. Specifically:

- In the last 50 years, the climate has become warmer and drier. Both annual average temperature and seasonal average temperature are on the rise. Especially after 1986, the temperature quickly climbed. In the 1990s, the precipitation dropped sharply. This clearly indicates that the climate in the Yellow River source region has become warmer and drier.

- The rising temperatures are causing glaciers in the Yellow River source region to thaw faster on an expedited track. The A’ny’aq Mountain in the Qinghai-Tibetan Plateau is home to the majority of glaciers that feed water into the Yellow River. By 2000, the area of the glaciers in the mountains had shrunk by 17% in comparison to 1966, melting 10 times faster than the previous 300 years. The most seriously declining is the Yehelong glacier, which retreated by 77% between 1966 and 2000.

- Permafrost is degrading considerably in response to the temperature changes. Permafrost thickness and distribution have all undergone profound reduction. The active layers penetrate deeper, and the time for seasonal frozen duration is shortened. Permafrost, with its distinctive nature and wide distribution, is a vital factor in the vicious circle of ecological deterioration of the Yellow River source region. The permafrost decline is having a significant impact on the hydrology, ecological system and construction projects alike in the region.

- Meanwhile, compounding the water shortage effect, the lakes in the Yellow River source region are shrinking through a combination of increased evaporation caused by higher temperature and a decline in rainfall. For example, about 3,000 of the small lakes of the 4,077 lakes in Madoi County have now completely disappeared, leaving nearly 600 households, 3000 people and 119,000 cattle without easy access to water. The twin lakes - Zhaling and Eling lakes also in Madoi, which are the official source of the Yellow River, have water levels down by three to four metres on average over the past 50 years. During the 15 years from 1986 to 2000, the total lake area in the region decreased by 5.3%. Outflow lake shrinkage accounted for 71% of the total lake shrinkage. Meanwhile wetland and marshland in the Yellow River source region have shrunk by 13.4%. The runoff into the Yellow River continued to drop, signaling that the source region cannot maintain as much water as before.

- Changing temperatures combined with the loss of moisture and change in soil nutrients arising from permafrost loss is affecting regional flora. In the last 30 years, high coverage grassland with high productivity has deteriorated sharply while the low coverage grassland has expanded. Alpine meadows, highly sensitive to climate change, have shrunk significantly too. Grassland deterioration is widespread and low grassland coverage and “black soil erosion” are becoming ubiquitous in the region.

- Desertification is increasing with unprecedented speed. With the rising temperature, vegetation degradation and desertification became more severe. In the last 15 years, the soil pattern and its ecological distribution in this region have undergone drastic changes. A great proportion of the soil has deteriorated, and the desertification rate has registered at 1.83% annually. High-coverage alpine steppe has become low-coverage or turned to desert, and the same with the alpine
meadow and bog meadow. The overall land degradation area amounts to 34.4% of the total area of Yellow River source region.

Climate change is warming and drying the Yellow River source region. The effect is combined with the glacial loss and permafrost melting - which undermines two crucial water regulating features of the region. Meanwhile land degradation, desertification and the changes in the water table produced by permafrost loss undermine the runoff formation in the region. As lakes and exposed water bodies dry up from increased evaporation and reduced rainfall many outflow sources are either disappearing or becoming landlocked which further prevents run off.

There are some steps that can be taken to adapt to these changes and to mitigate at the local level the negative impact brought by climatic disruption. We could for example seek to improve agricultural and industrial activity in the source region to reduce its impact on the sensitized environment. Restrictions on overgrazing, inappropriate cultivation and some infrastructure construction could help. Efforts to address the desertification problem and more active conservation of the ecological environment in the source region would also help.

However, it is clear: the efforts of the local people; provincial or national efforts at the local level; or efforts combining projects at the upper, middle and lower reaches of the river, are not enough alone to protect the deteriorating ecosystem at the Yellow River source or the river itself. The underlying problem of climate change will, if left unchecked, ultimately overcome any other measures to tackle the problems.
Reference

Endnote 1

Climate means the comprehensive description of weather features from a long term perspective. It is defined as the statistical characteristics reflecting extremums, averages and changing rates of meteorological and climate factors in certain region or on the global level, for instance, the global average temperature, the monthly average temperature in the Yellow River source region and its annual precipitation and so on. Climate change means the change of the climate during a certain time period, for instance, the changes of the average temperature or precipitation in 30 years. Thus, climate change can be classified as the following four categories: 1. ice age alternation in 10-100 thousand years; 2. climate oscillation in a thousand years; 3. climate oscillation in 10 or 100 years; 4. annual climate changes.

Anthropomorphic climate change denotes what is triggered by human activity. In this report the use of the phrase ‘climate change’ commonly refers to anthropomorphic climate change.

According to historical literature and biological data, the records of loess, lake, ice core, tree and other substitute indexes, the Middle Age Warm Period and the cold period in the Little Ice Age were two significant events during the recent one thousand years. During the recent 500 years, the western part of China seemed to have experienced five drought periods, which commenced respectively from 1480, 1580, 1710, 1830 and 1900. During the recent 100 years, more records are available for comprehensive analysis. It is concluded that there has been a warming trend and there are 4-5 drought periods, i.e. the end of 19th century, 1910s-20s, 1940s, 1960-70s and the late 1980s (Wang Shaowu, Dong Guangrong, 2002). Shi Yafeng (1999) compared the Guliya ice core data from Tibetan plateau and corresponding literature in the east. He concluded that the climate changes in the...
eastern and the western part of China have a lot in common but still differ visibly. The major difference is that during the Middle Age Warm Period (9th-11th century), the east was becoming warmer in a more significant way than western China. Based on meteorological data, ice core, tree rings and other substitute indexes (see the graphics (figure 1.5), Wang Shaowu and Gong Daoyi (2000) found the above conclusion is applicable to the climate change in the last 140 years. From figure 2.1, we noted that both the east and the west have experienced four fluctuations in temperature, but from 1920-1955, the east witnessed bigger fluctuation; since 1983, both the warm and cold trends in the west is faster than that in the east.

Endnote 2
Through Kp analysis (the ratio between annual runoff and secular runoff) (Yang Zhenniang, Zeng Quzhu, 2001), it is found that the runoff was high during 1960s and 1980s while it was low during 1970s and 1990s. Such conclusion is in line with the above description. The average water runoff statistics at the Tangnag station shows that there are more dry years than moist years, for the coefficient of variation is 0.90.

Endnote 3
Permafrost is defined as various soil/rock with ice below or at 0°C. It can be further classified in accordance with its duration as permafrost, seasonally frozen ground and instant frozen soil. Permafrost is the soil layer frozen for 3 or above 3 years. Seasonally frozen ground is the soil layer frozen in winter for more than one month but melted in summer, the average annual temperature of which ranging from 8.0-14°C and lowest monthly temperature below 0°C. Instant permafrost lasts less than one month in winter, and its average annual temperature ranges from 18.5-20.0°C. There is 2.15 million km² of permafrost in China, 22.3% of the total territory of China. It can be further classified into two types: high-latitude permafrost and high-altitude permafrost. In recent years, global warming has had a profound influence upon the permafrost, changing its temperature, depth and distribution.

Permafrost in the source region of the Yellow River is largely distributed in the Buerhanbuda Mountains, the A'nyam Mountains and the Bayankala Mountains. The lower boundaries of permafrost vary in different regions. Generally, it is around 4215 m above sea level, and about 30 m thick. The thickness increases when altitude rises (Zhang Senqi et al, 2004). Seasonal permafrost is common in the entire region. The thickness is usually 3 m and it increases with higher altitude and changes in different seasons (Wang Shaoling et al, 1991) (Figure 3.5).
Bibliography


