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2 Executive summary

The preceding project (ADP/2002/021) on the Conversion of Cropland to Forest and Grassland Program (CCFGP) in China focused on elements of a cost benefit analysis of the Program. However, due to the limitation of time available for the preceding project, the impact of the CCFGP on watershed protection, especially on flood mitigation, was not quantified and evaluated. The lack of information on the flood mitigation impact of the CCFGP and the associated economic benefits so derived has constrained the comprehensive assessment of the Program.

The extension phase of the preceding project aimed to fill this information gap through an analysis of the flood mitigation effect of the CCFGP in the Yellow River Basin. The economic value so estimated can be integrated into the cost benefit analysis framework of the implementation of the Program. This enables a more comprehensive policy analysis and will provide better indicators of the appropriate direction for the land use change policy.

In this extension, a physically-based distributed hydrological model, WEP-L model is applied to simulate the natural hydrological processes from 1956 to 2000 in the Yellow River Basin. Frequency analysis is conducted to derive maximum daily runoff discharges for floods of various sizes “with” and “without” the CCFGP in place. The marginal change in flood flows arising from the CCFGP during 2010-2020 is hence derived, and reductions in the probability of flood occurrences estimated. Valuation of the economic benefits from reduced flooding is then conducted on the basis of the biophysical information.

It is found that the CCFGP has a relatively small potential impact on flood reductions in the Yellow River Basin. The economic benefits from flood reductions total CNY 362 million. Compared to the total investment of around CNY 65.5 billion in the region under the CCFGP, these benefits are small. Based on research findings from the preceding project, the potential economic benefits from flood reductions will be offset by the potential economic losses from agricultural production (CNY 667 million) with reduced runoff under the Program.

The research has contributed to the knowledge base of current research work on the CCFGP. It addresses the priority issue around the implementation of the CCFGP which is the quantification of its ecological impacts, identifies key areas for further research, and assists to improve decision-making in the CCFGP policy context. It also has implications for the ranking of the management options (either structural or non-structural) to mitigate flood disasters in the Yellow River Basin.

The other two tasks undertaken during the extension phase of the preceding project, namely compiling a book based on the research reports produced alongside the implementation of the research project (ADP/2002/021) and scoping of a new research report as a continuation of the collaboration between ANU and the State Forestry Administration in China, have also been completed successfully. The book, entitled “Environmental Protection in China: land use management”, will be published by Edward Elgar in 2008. The proposal for the new research project, which focuses on improving the

efficiency of land use policy in China, is now being reviewed by ACIAR. It is anticipated the new project will start in early 2008. Both these activities will also have impacts on the development of land use policy in China, local capacity building and information dissemination. The research will help China to achieve the goal of building a sustainable society.

3 Background

The preceding project (ADP/2002/021) focused on elements of a cost benefit analysis of the Conversion of Cropland to Forest and Grassland Program (also known as the Green for Grain Program or the Sloped Land Conversion Program), the largest ecological restoration program in China. Under the preceding project, the following work was conducted:

- Farmer livelihood analysis and welfare assessment of the Program through its impacts on agricultural production.
- The estimation of non-market environmental benefits.
- The estimation of economic losses from foregone agricultural production due to reduced runoff.
- Integration of the research results into a partial cost-benefit analysis of the Program.
- Policy analysis and recommendations.

Due to the limitation of time available for the preceding project, the task of estimating all the impacts of the CCFGP was not fully completed. Specifically, the impacts of reduced runoff on flooding behaviour, hydropower generation, aquaculture and coastal fishery production were not valued. Both time and resources, especially the technical inputs from the hydrologists, are required to build these value components into a more comprehensive cost benefit analysis.

The review report of the preceding project proposed a number of research areas to be followed-up. However, the modelling of flooding behaviour in the Yellow River and its value estimation was identified as a priority. Flooding damage brings significant economic losses to the Chinese society and is a threat to the sustainable development of the nation. It is also one of the main drivers for the implementation of the CCFGP. Therefore a good understanding of the impact of the CCFGP on flooding behaviour and the consequent avoided costs is crucial in the policy context. The importance of estimating reduced flooding risks was emphasised by all parties attending the preceding project’s completion symposium held in Beijing in July, 2006.

The research undertaken for the extension phase of the project involved hydrological modelling of flooding behaviour in the Yellow River and estimation of avoided flood damages under the CCFGP. The estimation of the value of reduced flooding risks contributes to a more complete cost-benefit analysis of the CCFGP and hence provides a more thorough policy analysis of the CCFGP. According to the State Forestry Administration, the executing agency of the CCFGP, the CCFGP will continue to be implemented and supported by the Chinese Government. In addition, the importance of ecological monitoring of the Program and the development of alternative policy alternatives were highlighted. The extension period research therefore has important implications for the future design of the Program.

Another two tasks were also set for the extension phase. One was the compiling of a book based on the research findings of the preceding project. Another task was to scope a new research project as a continuation of the collaboration between Australia and China on land use management issues in China.

4 Objectives

The overall objective of the extension period research was to provide a deeper understanding of the flooding impacts of the CCFGP. In particular, the impact of revegetation on flooding behaviour along the Yellow River in North China was modelled and the values associated with reduced flooding risks estimated. The information so derived was used to provide more informative policy advice on the implementation and continuation of the CCFGP.

Other objectives of the extension period research included the compiling of a book based on the research reports produced alongside the implementation of the preceding project and scoping of a new research report as a continuation of the collaboration between ANU and the State Forestry Administration in China. The focus of the new research will be around land use management in China.

A final objective of the project was to enhance cooperation between resource management agencies and to continue capacity building in China. Some initial cooperation had been established between the State Forestry Administration and the Ministry of Water Resources during the preceding project through work on runoff reductions and the impact on agricultural production. Bio-economic modelling work was jointly conducted by researchers at ANU, the China National Forestry Economics and Development Research Center (FEDRC) and the China Institute of Water Resources and Hydropower Research (IWHR). The review report emphasised the importance to maintain such close cooperation in conducting policy research of the CCFGP. This also has important implications in resource management as good coordination among related government agencies is crucial.

5 Methodology

This research was designed to estimate the flood mitigation effect of the CCFGP in the Yellow River Basin. Flooding and its socio-economic consequences have remained key issues in the management of the Yellow River. To enhance flood control capacity and to manage areas with soil erosion problems, a number of watershed management programs have been developed by the Chinese Government. Among these is the CCFGP, designed specifically to reduce soil erosion and lessen flooding frequency in the Yellow River and Yangtze River.

Ideally, a three-stage model should be used to examine the relationship between the economic concept of value and the biophysical dimensions of the resource system being valued (Freeman 1993). As shown in the following chart, the first set of functional relationships, $F = f(d)$, relates some measure of environmental quality (extent of flooding, F) to human interventions (land use practices, particularly revegetation, d) that affect it. The second set of relationships, $Y = y(F)$, involves the human uses of the environment (economic production such as agricultural production, Y) and their dependence on environmental quality (extent of flooding, F). The third set, $V = v(Y)$, measures the change in economic welfare (V) caused by a change in economic production, Y.

Increase in vegetation cover (CCFGP)

Stage 1 ↓

$F=f(d)$

Changes in flooding patterns

Stage 2 ↓

$Y=y(F)$

Economic production change

Stage 3

$V=v(Y)$ ↓

Changes in economic welfare (utility)

For Stage 1, the natural processes of flood occurrences that are affected directly by the increase in vegetation cover under the CCFGP were simulated using a distributed hydrological model. Land use change (increase in vegetation cover) arising from the CCFGP was projected up until 2020 based on information processed using a geographical information system (GIS) platform. The physically-based distributed hydrological model, WEP-L model was applied to simulate the natural hydrological processes from 1956 to 2000 in the Yellow River Basin. Frequency analysis was conducted using historical data to derive maximum daily runoff discharges for floods of various sizes “with” and “without” the CCFGP in place. The marginal change in flood flows arising from the CCFGP during 2010-2020 was so derived, and reductions in the probability of flood occurrences were then estimated.

For this research, the three-stage framework was reduced to a two-stage model by combining stages two and three in the analysis. This was mainly due to a lack of sufficiently detailed data necessary to link changes in flood occurrences to changes in economic activities. Hence the relationship in Stage two denoted as $Y = y(F)$ could not be established empirically. Rather, a literature review of the recorded historical floods in the Yellow River Basin was carried out demonstrating that the monetary value of economic losses caused by those flood events has been recorded since the 1970s by statistical offices at both the national and local levels. This enables the relationship between changes in flood patterns and changes in economic welfare (utility) to be established directly.

Throughout the research process, close cooperation among the research team members at ANU, FEDRC and IWHR was achieved. Besides the project initiation meeting held in January 2007, both sides maintained day-to-day correspondence throughout the extension period. Professor Jeff Bennett provided overall guidance and leadership for project implementation.

6 Achievements against activities and outputs/milestones

Objective 1: To estimate flood mitigation impacts of the CCFGP, to compile a book and to scope a new research project.

no.	activity	outputs/ milestones	completion date	comments
1.1	Modelling flood behaviour	The change in probability of flood occurrences under CCFGP has been estimated.	May 2007	The hydrological modelling conducted in this research further develops the WEP-L model currently used in water management of the Yellow River Basin.
1.2	Valuing economic benefits	The economic benefits from flood reductions under CCFGO have been valuated.	Sept 2007	The estimates form an integrated component of the benefit cost analysis of CCFGP. It provides policy guidance as to the future implementation of the Program and also has implications for management options in the Yellow River Basin to mitigate flooding.
1.3	Integrating bio-economic modelling	Research report and journal article completed.	Oct 2007	The journal article will be submitted to Water Resources Research later in 2007.

1.4	Compiling of the book entitled “Environmental Protection in China: land use management”	The book scheduled to be published in April 2008 by Edward Elgar.	Sept 2007 (copy-editing finished)	The camera-ready-copy of the book is now being prepared. The camera-ready-copy will be proof read and printed in early 2008.
1.5	Site visits, meetings, and regular consultations via email and phone	New project proposal being reviewed by ACIAR.	Jan 2007	Priority area for future cooperation has been identified that will be of mutual benefits to both Australia and China.

PC = partner country, A = Australia

Objective 2: To enhance cooperation between resource management agencies in China and to scope a new project for future collaboration.

no.	activity	outputs/ milestones	completion date	comments
2.1	Project inception meeting	A work plan was developed and tasks and responsibilities allocated.	Jan 2007	Capacity building and working relationship between resource management agencies (especially for FEDRC and IWHR) has been strengthened.
2.2	Day-to-day correspondence	The development of the hydrological model and economic model.	Jan – Oct 2007	Same as above

PC = partner country, A = Australia

7 Key results and discussion

7.1 A Regional Approach

In valuing the flood mitigation effects of the CCFGP, the Yellow River Basin was divided into ten regions (see Figure 1). The area revegetated under the CCFGP in each of these regions was geographically defined and processed on the GIS platform. This region-based approach can be justified as follows. Forested areas usually register a lower frequency and rate of peak flow for small and medium size storms. For large river basins and big storms, however, other geological and climatic factors are more important than the presence of forest cover (Pattanayak 2004). Because of this, the impact of revegetation on flood occurrences can be more accurately modeled at a regional rather than a catchment wide scale.

Figure 1 Map of ten regions in the Yellow River Basin

Source: AARES 2005 and World Bank 1993.

The development of the hydrological model and further bio-economic analyses of flood reductions were based on data collected at a sub-catchment level. There are two main reasons for this. First, hydrological data can be collected mainly from the hydrological gauging stations at a sub-catchment level. In this research, a number of main hydrological gauging stations in each of the ten regions in the Yellow River Basin were selected and data from these stations were used to calibrate the hydrological model. Changes in probabilities of flood occurrences due to the CCFGP in the controlled area of these hydrological gauging stations were then estimated using the hydrological model. Second, within the same geographical region, there is normally significant variation in the magnitude of the economic losses caused by flood events across different river branches and even in different sections of the same river branch. Because of this, it is difficult to establish the link between flood occurrences and economic losses at the region level. Hence, the economic analysis was conducted for each sub-catchment with the boundary being delineated by the main hydrological gauging stations along the Yellow River.

7.2 Hydrological Model Applications and Calibration

In order to study the impact of the CCFGP on flood flow, the Water and Energy Transfer Processes in Large River Basins (WEP-L) Model (Jia et al 2006; Jia et al 2005a; Jia et al 2005b; IWHR 2004) was applied to simulate the hydrological processes in the river basin. This model was developed by combining the merits of a distributed hydrological model (e.g. the SHE model), a land process model (e.g. the Soil-Vegetation-Atmosphere Transfer model), and the results of a traditional water resources assessment (MWR 1986). The simulated hydrological processes include snow melting, evapotranspiration, infiltration, surface runoff, subsurface runoff, groundwater flow, overland flow and river flow. It also takes into consideration the specific features of the Yellow River. The distributed hydrological model has been validated in and applied to the key national fundamental research project entitled “Evolvement Law and Renewable Sustainability Mechanism of Water Resources in the Yellow River Basin” (IWHR 2004).

In principle, distributed physical models should be able to use direct measurements of parameters at the grid level so that there is no need for model calibration and validation.

However, due to the heterogeneity of basin features and the lack of measured data at the same grid level, parameters of distributed models are commonly derived from other available data sources (Moreda et al 2005). Calibration and validation is therefore needed to adjust the parameters calculated on the basis of these observed data. After model calibration, all parameters in the model are kept the same and the model is further validated.

In this research, the WEP-L model was adopted and further improved in the CCFGP context to simulate and predict flood flow with and without the Program. The natural hydrological processes from 1956 to 2000 in the Yellow River Basin were simulated using the model. The main hydrological gauging stations in the Yellow River Basin (see Figure 2) were selected for model calibration. As the flood carrying capacity of river course has an impact on flood occurrences, the selection of hydrological gauging stations took this into consideration and those stations that are located at the confluence of major rivers were selected for each of the ten regions in the Yellow River Basin. A number of hydrological gauging stations at branches of the Yellow River were also selected, such as Guide and Xiangtang. In addition, for regions that have larger areas under the CCFGP, more stations were selected.

Figure 2 Map of hydrological gauging stations in the Yellow River Basin

For model calibration, the simulated monthly runoff was compared with observed data. The 21-year timeframe from 1980 to 2000 is the model calibration period, with the parameters being corrected including hydraulic conductivity coefficient of saturated soil, permeability coefficient of riverbed material, Manning roughness coefficient, maximum water storage of billabongs under different land use regimes, and conduction and supply coefficients of the groundwater aquifer. The principle of model calibration is that the difference between simulated and observed average annual runoff discharge should be as small as possible. This is reflected by the Nash-Sutcliffe model efficiency coefficient, which should be maximised. The Nash-Sutcliffe efficiency coefficient (η) is defined as:

$$\eta = 1 - \Sigma\left(Q_{sim} - Q_{obs}\right)^2 / \Sigma\left(Q_{obs} - \overline{Q}_{obs}\right)^2 \quad (1)$$

where Q_{obs} is the observed runoff discharge, Q_{sim} is the simulated runoff discharge, and $\overline{Q}_{obs}$ is the average annual runoff discharge observed over the years. In addition, the correlation coefficient between simulated runoff discharge and observed runoff discharge should be maximised. After model calibration, all the parameters in the model are kept the same to verify the simulated results for the 45-year verification period from 1956 to 2000.

The verification results (Table 1) show that the relative errors of the average annual natural runoff discharge at the main hydrological stations are mostly less than ten per cent except for the Xiangtang Gauging Station at the confluence of the Datong River. The smallest relative error occurs for the Xiaheyan Gauging Station in the mainstream of the Yellow River (1.4 per cent). The overall Nash efficiency coefficient is 0.65, with the maximum being 0.85 (Heishiguan Gauging Station at the Yiluo River confluence). There is no standard rule for the threshold value of the Nash efficiency coefficient that can be used to justify the efficiency of models. However, based on previous research carried out in the Yellow River Basin, a Nash efficiency coefficient that is greater than 0.6 with a relative error that is less than ten per cent is usually considered satisfactory (IWHR 2004). Judged from these criteria, the model is efficient for the prediction of flood reductions in the Yellow River Basin brought about by the CCFGP.

Table 1 Verification results of monthly runoff

Hydrological gauging station	Observed average annual runoff discharge (10^8 m^3)	Simulated average annual runoff discharge (10^8 m^3)	Relative error (%)	Nash efficiency coefficient of monthly runoff discharge series
Guide	210.8	217.5	3.2%	0.72
Lanzhou	331.1	326.2	-1.5%	0.79
Tangnaihai	204.2	199.0	-2.5%	0.74
Toudaoguai	333.5	326.0	-2.3%	0.68
Longmen	386.8	365.7	-5.5%	0.67
Sanmenxia	500.8	477.7	-4.6%	0.73
Huayuankou	560.4	524.3	-6.4%	0.77
Gaocun	554.7	525.4	-5.3%	0.77
Lijin	565.0	542.1	-4.1%	0.75
Minhe	20.4	18.6	-9.1%	0.40
Xiangtang	28.8	25.4	-11.6%	0.64
Hejin	22.0	20.0	-9.2%	0.61
Huaxian	84.9	77.5	-8.7%	0.75
Heishiguan	31.3	28.7	-8.2%	0.85
Wuzhi	14.3	13.2	-7.6%	0.68
Houdacheng	2.6	2.3	-7.9%	0.62
Xiaheyan	332.9	328.3	-1.4%	0.79
Shizuishan	334.5	328.4	-1.8%	0.76
Xiaolangdi	505.4	482.9	-4.4%	0.73

7.3 Revegetation Area under CCFGP

Information on the revegetation area under the CCFGP is the key to any simulation of the hydrological processes in the river basin and its accuracy will determine the quality of simulation results. Information on the revegetation area under the CCFGP in the ten regions in the Yellow River Basin is drawn from Bennett et al (2006) who estimate runoff reductions arising from the CCFGP. The ten regions are further divided into a number of basic calculation units taking into consideration the temporal and spatial variation of the revegetation measures under the CCFGP and the runoff reduction indicators.

Data on area revegetated (conversion area) during 2000-2010 have been generated for each province and autonomous region within the Yellow River Basin. The conversion area for 2000-2004 is obtained from observations (SFA 2000-2004), while for 2005-2010, the implementation plan for the CCFGP is referred to. Based on the CCFGP plan, all the area suitable for conversion should be converted by 2010. For food security reasons, no land will be converted after 2010. The accumulated conversion area between 2000 and 2020 is predicted to total 4.87 million hectares (Table 2).

Table 2 Accumulated conversion area under CCFGP in the Yellow River Basin during 2000 – 2020 (10,000 hm^2)

Province	Qinghai	Gansu	Ningxia	Inner Mongolia	Shannxi	Shanxi	Henan	Total
Province-wide Area	34.19	96.94	37.04	81.37	135.20	48.66	53.28	486.68
Area in the Yellow River Basin	26.98	68.91	37.04	14.43	127.52	27.50	9.60	311.98
Ratio (%)	78.9	71.1	100.0	17.7	94.3	56.5	18.0	64.1

Note that the conversion area data displayed in Table 2 are province-based, and the boundaries of the basic calculation units do not correspond exactly to the boundaries of the provinces and autonomous regions. Hence these province-based data need to be further processed so that the conversion areas falling within each of the ten regions can be derived and projected. This was done through data processing on a GIS platform. First, the land area that is suitable for conversion was defined. Based on the national survey of land utilisation using remote sensing data, land in China can be classified into six main categories and further divided into 31 sub-categories (IWHR 2004). Cultivated land is one of the main categories, with seven sub-categories including highland paddy field, highland dry field, tableland paddy field, tableland dry field, lowland paddy field, lowland dry field, and sloped dry field over 25 degrees. According to the principles of conversion set by the Government, sloped dry field over 25 degrees is prone to water-induced soil erosion and should be the top priority for conversion (SFA and SDPC 2000). Highland and tableland dry field should be converted next. Soil erosion is not severe in lowland areas, and therefore lowland dry field should be converted last.

Next, based on these principles, the land use map in the Yellow River Basin in 2000 when the CCFGP started was used to define the land area which is suitable for conversion in each province and autonomous region (see Figure 3). The proportions of the potential conversion area both within and out of the Yellow River Basin were calculated based on which, the conversion area within each of the ten regions in the Yellow River Basin was derived (see Table 2).

Finally, based on the spatial distribution of the potential conversion area (2005-2010) within the Yellow River Basin, the conversion area in each basic calculation unit was estimated and aggregated to match the geographical boundaries of the ten regions. The conversion area in each of the ten regions is shown in Table 3. Because inland water areas are not included, the accumulated conversion area in the ten regions during the 20 years amounts to 3.05 million hectares, a little smaller than the accumulated conversion area in the Yellow River Basin which is about 3.12 million hectares. With this information, changes in flood events with and without the CCFGP in each of the ten regions during 2010 to 2020 were assessed and projected. The results from this process are presented in the following sections.

Figure 3 Geographical distribution of areas suitable for conversion

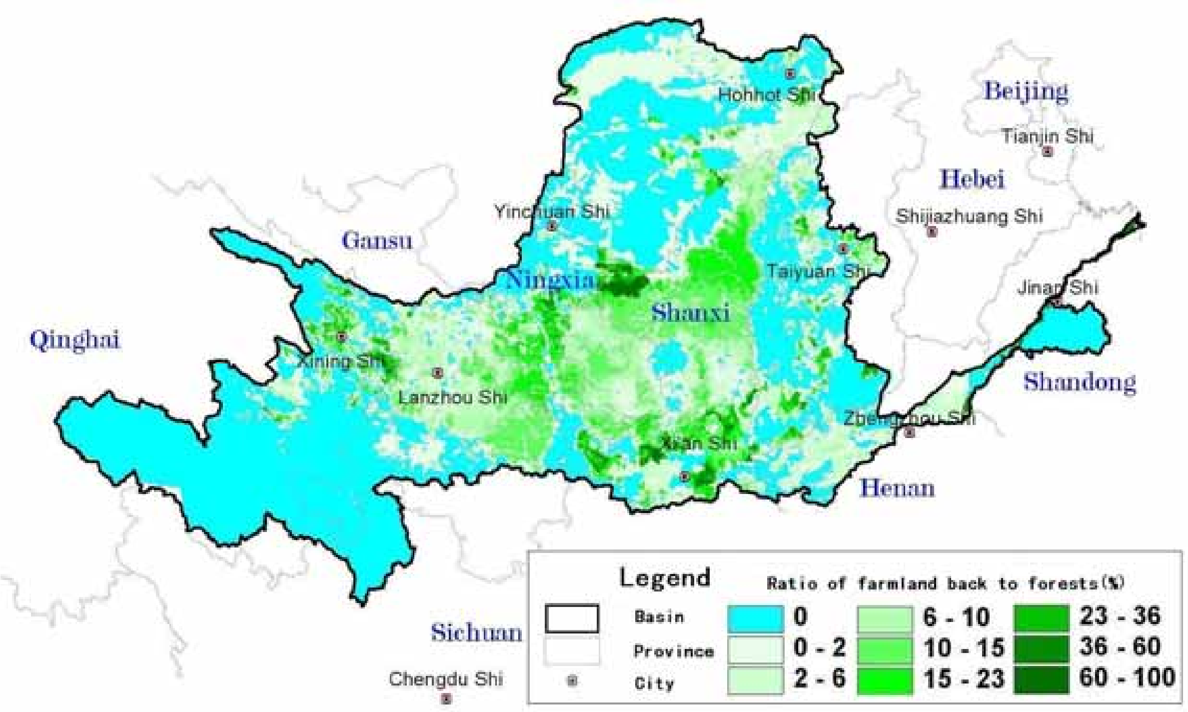


Table 3 Accumulated CCFGP areas in the ten regions in the Yellow River Basin during 2000 - 2010 (10,000 hm^2)

Year	1	2	3－A	3－B	4	5－A	5－B	6	7－A	7－B	Total
2000	0.07	0.85	1.30	0.12	0.62	0.63	2.93	0.16	0.09	0.00	6.77
2001	0.21	1.83	2.66	0.27	3.22	1.56	6.83	0.42	0.18	0.00	17.18
2002	0.89	6.20	7.81	0.84	15.97	10.38	25.21	2.36	0.66	0.00	70.32
2003	1.77	13.20	20.71	2.32	33.11	17.75	54.50	4.46	1.36	0.01	149.19
2004	1.96	14.47	25.16	3.01	42.80	19.66	67.94	4.88	1.45	0.01	181.34
2005	3.64	25.28	32.00	3.34	54.12	22.97	92.78	6.88	2.46	0.02	243.49
2006	4.15	28.56	34.81	3.58	59.56	23.71	103.07	7.63	2.88	0.02	267.97
2007	4.54	31.01	36.92	3.76	63.64	24.26	110.78	8.20	3.20	0.02	286.33
2008	4.67	31.83	37.62	3.82	65.00	24.45	113.35	8.39	3.31	0.02	292.46
2009	4.80	32.65	38.32	3.88	66.36	24.63	115.92	8.57	3.41	0.03	298.57
2010-2020	4.92	33.47	39.02	3.94	67.72	24.82	118.49	8.76	3.52	0.03	304.69

7.4 Flood Frequency Analysis

7.4.1 Concepts and Methodology

Flood frequency analysis is a method of providing information on flood probabilities. It is used to estimate the probability of the occurrence of a given flood event (USGS 2005). In hydrology, cumulative frequency is often used to describe and predict the cumulative probability of hydrological characteristics. The longer the observation period and the larger the sample size, the more reliable is the prediction. In general, frequency analysis thus refers to the calculation of the cumulative frequency of hydrological phenomena.

Because the concept of cumulative frequency is abstract, the recurrence interval is commonly used instead to indicate the probability of occurrence of various hydrological phenomena. The recurrence interval is based on the probability that the given event will be equaled or exceeded in any given year (USGS 2005). Put simply, the recurrence interval is the time that is needed for the event to occur. The relationship between flood occurrence interval (T) and cumulative frequency (P) is as follows:

$$T=1/P \quad (2)$$

Based on this formula, if the return period of a flood is 100 years, the probability of its occurrence is one per cent. Indeed, the 100-year return period does not mean that the flood occurs just every 100 years. It only implies that over a longer period the average probability of the flood occurrence is one per cent, and every year there are equal opportunities. Hence, the 50 per cent, 20 per cent, ten per cent, four per cent, two per cent and 0.5 per cent floods refer to floods with return period being two, five, ten, 25, 50, and 200 years respectively. These concepts are summarised in Table 4.

Table 4 Recurrence intervals and probabilities of occurrence

Recurrence interval (years)	Probability of occurrence in any given year	% chance of occurrence in any given year
100	1 in 100	1
50	1 in 50	2
25	1 in 25	4
10	1 in 10	10
5	1 in 5	20
2	1 in 2	50

Source: USGS 2005.

The use of annual flood series or partial series of selected flood variables (peak discharge, peak level, maximum volume) enables computation of flood frequency distributions (Rossi et al 1994). Statistical parameters such as mean values, standard deviations, skewness, and recurrence intervals are calculated. These parameters are then used to construct frequency distributions that depict the likelihood of various runoff discharges as a function of recurrence interval (also known as exceedence probability). Only three statistical parameters are introduced in frequency analysis. These are the mean value, dispersion coefficient, and skew coefficient of a series. The arithmetic average is commonly used as the mean value, which is a characteristic parameter reflecting the level of a series. The dispersion coefficient, which is the ratio of standard deviation to the mean value, is a parameter reflecting the degree of spread displayed by a series. The skew coefficient reflects if the distribution of the series is symmetrical.

The Weibull formula is used extensively in frequency analysis in the hydrological field to describe the distribution of probability. It can be expressed as:

$$P = m / (n+1) * 100\% \quad (3)$$

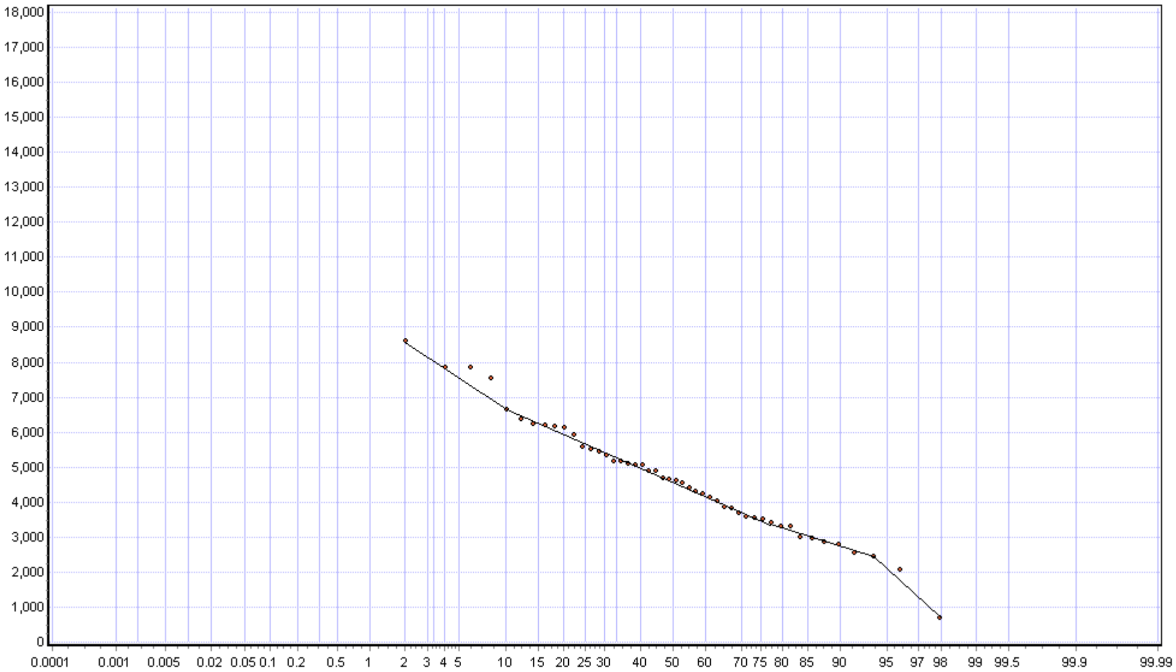
Where *p* denotes the probability (cumulative frequency) of a flow being greater or equal to a specific value, *m* denotes the rank of an individual flood events within the data series, and *n* denotes the total number of observations (Davie 2003). Specifically, a frequency curve is calculated and drawn with the following steps:

1. Ranking the sample data series from large to small, regardless of record year. In this study, the time series for the observed maximum daily runoff was used. The ranking assumes that each data point (maximum daily runoff for a particular year) is independent of any others;
2. Calculating the total number of observations in the sample, *n*;
3. Calculating the probability of a flow being greater or equal to a specific value (defined by the maximum daily runoff for a particular year) using formula (3);
4. Plotting the points (P1, X1), (P2, X2),…, (Pn, Xn) with observed maximum daily runoff (X) as the ordinate and cumulative frequency (P) as the abscissa, and then fitting a

curve to these points. An example of an empirical frequency curve at Sanmenxia Station is given in Figure 4.

Figure 4 Cumulative frequency curve of flood occurrence at Sanmenxia Station

Maximum daily runoff (m^3/s)



Frequency (%)

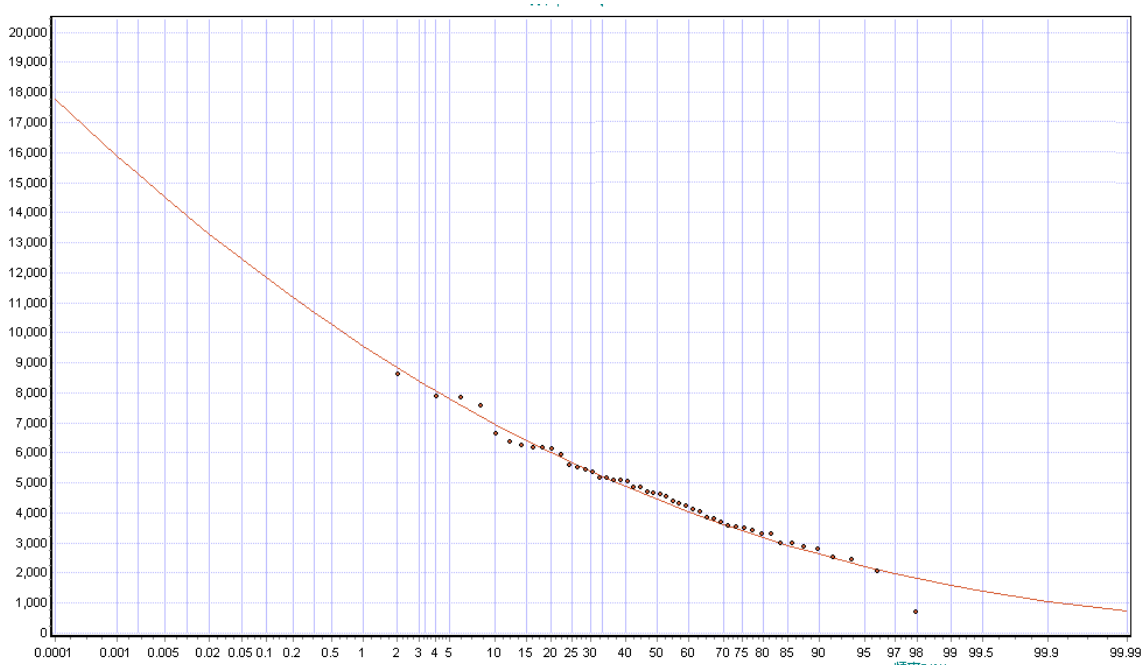
Figure 4 shows that due to data limitation, the range of the cumulative frequency curve is limited. Hence the cumulative frequency curve needs to be extrapolated to cover the range outside the observed relationship in order to meet the needs of the research. In order to reduce error due to arbitrary extrapolation, a mathematical model, or the theoretical frequency curve, is developed on the basis of the parameters that characterise the distribution observed for the sample. These statistical parameters are estimated using the observed hydrological data (IWHR 1984; Wu et al. 1998).

In general, due to the complexity of the hydrological processes and data limitations, there is no well established distribution for the hydrological random variables. It is also difficult to infer the type of distribution from theory. In this research, a P-III curve is applied to extrapolate the cumulative frequency curve. The P-III method, developed over the last three decades, is widely used for flood frequency analysis because it estimates probabilities of floods with much greater accuracy than conventional log-normal methods (Haan 1977; Bedient and Humber 1992). Using the P-III distribution, extrapolation can be carried out for the values of events with return periods beyond the observed flood events.

To derive the P-III curve, the mean value and the dispersion coefficient of the data series were calculated. Assumptions were made in relation to the ratio of the dispersion coefficient to the skew coefficient because of the large sampling error of the skew coefficient. The skew coefficients were estimated using tables found in Ma and Ye (1996). The corresponding theoretical frequency curve with the value and the dispersion coefficient was then plotted to compare against the empirical frequency points (see Figure 5 for an example). Similarly, further frequency curves can be drawn by adjusting the dispersion coefficient. The extrapolated frequency curve that has the best model fit was selected.

Figure 5 Cumulative frequency curve of flood occurrence at Sanmenxia Station

Maximum daily runoff (m^3/s)



Frequency (%)

7.4.2 Frequency analysis results

Historical data series of the observed maximum annual average daily runoff (hereinafter referred to as the “maximum daily runoff”) at the main hydrological stations in the ten regions were used in the frequency analysis. This ensures data consistency in the valuation of flood reductions as data on flood-related economic losses are mostly historical data. Among the hydrological stations in the Yellow River Basin, the Maqu Station has the shortest time series of data (42 years) while the Lanzhou Station has the longest (57 years).

Using the frequency analysis, the maximum daily average runoffs at different frequency levels for each of the main stations in the Yellow River Basin were calculated. Results are displayed in Table 5. Compared to the mean annual maximum daily runoff over a number of years, the maximum daily runoffs at the main hydrological stations at frequency levels other than 50 per cent are all larger yet to varying degrees. For instance, while the mean annual maximum daily runoff at Lanzhou Station is 3015 M^3/s over the 57-year time period, the maximum daily runoff for a 200-year flood (at 0.5 per cent frequency level) amounts to 3304.5 M^3/s. The maximum daily runoff for a 2-year flood (at 50 per cent frequency level) is 2858.2 M^3/s, more than 13 per cent lower than the mean annual.

Across all the main hydrological gauging stations in the Yellow River Basin, the maximum daily runoff discharge for a 200-year flood is about 100 – 700 per cent more than that of the mean annual. The maximum daily runoff discharge for a 100-year flood is 100 – 550 per cent of the mean annual, and for a five-year flood, the exceedance ranges from 30 to 60 per cent. The variations of the maximum daily runoff discharge at various frequency levels become more distinctive at the local level. For instance, the maximum daily runoff discharge for a 200-year flood is greater by 597 per cent, 693 per cent, 697 per cent and 714 per cent respectively for Heishiguan, Houdacheng, Hejin and Wuzhi as compared to their annual means.

Table 5 Maximum daily runoff of floods at different frequency levels

Region	Hydrological station	Mean annual maximum daily runoff (m^3/s)	Maximum daily runoff at different frequency levels (m^3/s)						
			0.5%	1%	2%	4%	10%	20%	50%
1	Tangnaihai at main river	2282	5302.7	4919.3	4517.8	4116.2	3504.7	2993.6	2163.0
	Guide at main river	2027	5212.9	4797.2	4364.6	3933.0	3275.8	2742.5	1884.9
2	Minhe at Huangshui river	277	621.0	577.7	532.3	487.0	417.2	359.2	263.5
	Xiangtang at Datonghe river	556	1361.0	1257.6	1149.5	1041.4	876.8	741.4	522.3
	Lanzhou at main river	3015	7006.7	6500.2	5969.6	5438.9	4630.9	3955.6	2858.2
3-A	Xiaheyan at main river	2713	6617.4	6135.1	5628.4	5129.3	4337.2	3680.9	2572.9
	Shizuishan at main river	2950	7840.7	7192.2	6523.9	5859.8	4847.4	4031.8	2729.1
3-B	Toudaoguai at main rive	2750	5954.8	5554.9	5135.2	4719.4	4068.1	3529.6	2628.9
4	Houdacheng at Sanchuanhe river	186	1374.2	1163.4	954.5	761.4	490.5	306.6	93.8
	Longmen at main river	3294	8897.9	8149.0	7380.7	6618.9	5456.8	4523.8	3038.9
5-A	Hejin at Fenhe river	414	3304.5	2781.8	2264.9	1788.4	1128.1	680.0	185.7
	Sanmenxia at main river	4656	10083.5	9406.3	8695.6	7991.6	6888.7	5976.9	4451.5
5-B	Huaxian at Weihe river	2668	7234.1	6657.0	6052.2	5448.8	4523.6	3752.3	2490.0
	Lintong at Weihe river	2632	10756.8	9541.5	8305.7	7111.0	5362.0	4035.9	2126.8
	Weijiabu at Weihe river	1147	4749.6	4209.4	3660.1	3128.9	2353.0	1765.6	922.6
	Tongguan at Weihe river	2944	13750.5	11994.7	10189.5	8545.0	6134.0	4402.9	2152.6
	Jiaokouhe at Weihe river	254	1619.8	1391.2	1156.6	940.0	633.4	417.4	150.4
	Xianyang at Weihe river	1671	7180.4	6342.0	5500.9	4679.0	3487.1	2591.2	1317.2
6	Heishiguan at Yiluohe river	1526	9112.7	7774.8	6440.9	5221.2	3492.8	2319.1	933.1
	Baimasi at Yiluohe river	911	6060.5	5068.6	4126.9	3235.2	2032.9	1271.5	510.1
	Wuzhi at Qinhe river	387	3152.4	2610.0	2096.7	1614.6	973.4	564.9	169.7
	Xiaolangdi at main river	4809	10601.8	9875.9	9114.4	8358.2	7182.2	6207.2	4588.1

7-A	Huayuankou at main river	6170	22740.8	19966.9	17120.1	14491.8	10771.4	8150.4	4910.5
7-B	Gaocun at main river	5875	17361.5	15657.6	13924.4	12250.0	9782.3	7902.3	5170.2
	Lijin at main river	4696	11684.8	10783.9	9841.6	8899.3	7465.3	6291.6	4394.6

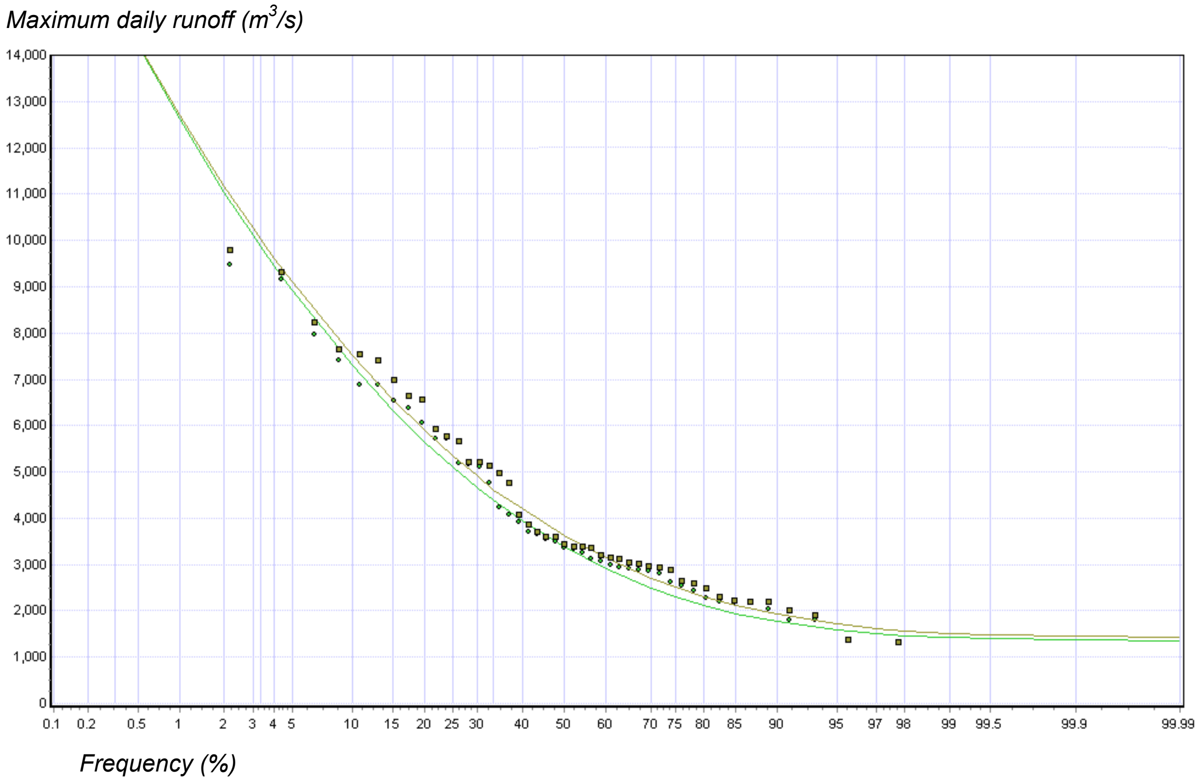
7.5 Flood Reductions Caused by CCFGP

7.5.1 Reductions in runoff discharge

In order to analyse and predict the impact of the CCFGP on flood flows in the Yellow River Basin, the WEP-L distributed hydrological model is applied to simulate the hydrological processes. Two underlying surface conditions - “with” and “without CCFGP” scenarios - are simulated to assess the marginal change in the maximum daily runoff brought about by the Program, with other input factors (such as precipitation and air temperature) being held constant. A simulation period from 1956 to 2000 is used in the model, taking into account the availability and representation of the hydrological data series.

The simulated maximum daily average runoffs from 1956 to 2000 under the two underlying surface conditions give two data series. Frequency analysis is conducted with these two 45-year time series, and two frequency curves are thus derived. By comparing the difference of flood flows at different frequency levels, the reductions in flood flows caused by the CCFGP are calculated. Figure 6 uses the Sanmenxia Station as an example to demonstrate the results of flood reductions. In Figure 6, the two frequency curves depict the maximum daily runoff at different frequency levels, or the probabilities for floods at different flow levels to occur under both the “with CCFGP” and “without CCFGP” scenarios. Changes in the maximum daily runoff arising from the CCFGP as well as changes in probabilities of floods at various sizes can thus be derived. For instance, for a two-year flood (at 50 per cent frequency level), the reductions in the maximum daily runoff at Sanmenxia Station is around 200 M^3/S.

Figure 6 Flood reductions caused by the CCFGP at Sanmenxia Station



Results of the runoff reduction simulations at the main hydrological gauging stations along the Yellow River under the CCFGP are displayed in Table 6. It can be seen that revegetation under the CCFGP results in relatively small flood flow reductions in the upper reaches of the Yellow River, specifically in regions 1, 2, 3-A and 3-B. For instance, the mean annual maximum daily runoffs at the Toudaoguai and Xiangtang hydrological stations decrease by only around one per cent. Reductions in flood flows concentrate in the middle reaches of the Yellow River, specifically in regions 5-A, 5-B, 6 and 7-A. In particular, the Weihe River Basin has the largest flood flow reductions, with the mean annual maximum daily runoff decreasing by around ten per cent. In the lower reaches of the Yellow River Basin, specifically for Region 7-B, flood flow reductions range from two to three per cent. The runoff reductions in this region are largely due to the relatively large runoff reductions in the middle reaches of the Yellow River. At the basin level, the extent of runoff reductions decreases as the frequency level of floods increases from 0.5 per cent to 50 per cent. Overall, flood flow reductions caused by the CCFGP in the Yellow River Basin are relatively small, ranging from 0.01 per cent to ten per cent.

Table 6 Reductions in flood runoff in the Yellow River Basin caused by CCFGP

Region	Hydrological gauging station	Reductions in mean annual maximum daily runoff (m^3/s)	Reductions in maximum daily runoff at different frequency level (m^3/s)						
			0.5%	1%	2%	4%	10%	20%	50%
1	Tangnaihai（at main river）	0.3	0.7	0.6	0.6	0.5	0.4	0.4	0.3
	Guide（at main river）	0.7	1.7	1.6	1.4	1.3	1.1	0.9	0.6
2	Minhe at Huangshui river	9.6	17.5	17.9	17.3	15.9	15.4	12.9	9.5
	Xiangtang at Datonghe river	1.2	3.6	3.2	2.9	2.5	2.0	1.6	1.1
	Lanzhou（at main river）	20.5	58.9	53.7	48.3	43.0	35.0	28.6	18.6
3-A	Xiaheyan（at main river）	32.4	97.1	87.8	78.5	69.1	55.4	44.8	28.8
	Shizuishan（at main river）	34.6	102.0	92.4	82.7	73.0	58.8	47.6	30.9
3-B	Toudaoguai（at main river）	29.9	89.5	81.0	72.3	63.7	51.1	41.3	26.5
4	Houdacheng at Sanchuanhe river	0.2	1.9	1.6	1.2	0.9	0.6	0.3	0.1
	Longmen（at main river）	55.4	171.3	154.5	137.6	120.8	95.9	77.1	48.7
5-A	Hejin at Fenhe river	6.4	38.0	32.5	26.9	21.9	14.7	9.8	4.0
	Sanmenxia（at main river）	209.1	233.2	239.5	245.5	252.2	250.4	242.7	213.9
5-B	Huaxian（at main river）	181.8	255.1	261.6	277.9	275.9	268.9	254.6	186.9
	Lintong at Weihe river	194.1	422.4	401.3	371.7	349.4	305.3	264.6	189.4
	Weijiabu at Weihe river	72.8	140.2	137.4	127.7	123.5	112.1	99.6	74.4
	Tongguan at Weihe river	206.7	184.9	213.7	241.7	275.4	290.2	290.1	222.6
	Jiaokouhe at Weihe river	30.7	129.7	115.0	99.8	86.4	64.8	48.8	24.3
	Xianyang at Weihe river	68.0	125.8	126.3	116.3	114.5	106.0	95.0	72.0
6	Heishiguan at Yiluohe river	28.9	28.4	35.3	42.3	49.9	54.7	47.8	25.4
	Baimasi at Yiluohe river	21.3	51.7	49.8	48.1	47.2	42.8	34.3	16.9
	Wuzhi at Qinhe river	2.5	1.9	2.6	3.2	3.7	3.9	4.0	2.9
	Xiaolangdi（at main river）	197.5	237.1	240.7	255.6	253.8	242.7	244.3	212.7
7-A	Huayuankou（at main river）	207.5	642.0	578.9	515.6	452.7	359.5	288.8	182.7
7-B	Gaocun（at main river）	197.2	576.4	524.7	471.0	418.7	339.8	276.4	178.4
	Lijin（at main river）	227.7	274.9	286.6	287.2	282.5	289.5	265.8	230.3

7.5.2 Probability of flood occurrence changes

The simulation of flood occurrences “with” and “without CCFGP”, and the information on runoff reductions arising from the CCFGP were used to derive changes in the probability of occurrence of floods of various sizes in the Yellow River Basin. Details of the calculation are as follows. Through frequency analysis of the simulated flood occurrences without the CCFGP in place, the maximum daily runoff at a certain frequency level can be derived. In other words, the probability for a flood with this level of maximum daily runoff can be derived. Relating this same amount of maximum daily runoff to the frequency curve drawn for the “with CCFGP” scenario, a corresponding frequency level (also the probability of flood occurrence) can be derived. Hence, the changes in the probability of flood occurrence arising from the CCFGP can be calculated.

Results are shown in Table 7. Due to the revegetation carried out under the CCFGP, the probability of flood occurrence at different frequency levels in the Yellow River Basin decreases to various extents. In general, the CCFGP has greater impact on small and medium sized floods than on big floods. For instance, for the Jiaokouhe Station at the Weihe River confluence, the probability of the occurrence of a two-year flood (at 50 per cent frequency level) decreases by 3.8 per cent, whereas the probability decreases by only 0.14 per cent for a 200-year flood (at 0.5 per cent frequency level). At the Basin level, the probability change in flood occurrences is more distinctive in the middle and lower reaches of the Yellow River as compared to in the upper reaches.

Table 7 Probability reductions of floods in the Yellow River Basin

Region	Hydrological Station	Probability reductions of floods at different frequency levels						
		0.5%	1%	2%	4%	10%	20%	50%
1	Tangnaihai（at main river）	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	Guide（at main river）	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%	0.01%
2	Minhe at Huangshui river	0.01%	0.03%	0.05%	0.11%	0.21%	0.40%	0.65%
	Xiangtang at Datonghe river	0.00%	0.01%	0.01%	0.02%	0.03%	0.06%	0.07%
	Lanzhou（at main river）	0.01%	0.02%	0.03%	0.05%	0.08%	0.14%	0.17%
3-A	Xiaheyan（at main river）	0.01%	0.02%	0.04%	0.07%	0.12%	0.21%	0.27%
	Shizuishan（at main river）	0.01%	0.03%	0.05%	0.08%	0.14%	0.23%	0.30%
3-B	Toudaoguai（at main river）	0.01%	0.02%	0.04%	0.08%	0.12%	0.22%	0.28%
4	Houdacheng at Sanchuanhe river	0.00%	0.01%	0.01%	0.02%	0.02%	0.03%	0.00%
	Longmen（at main river）	0.02%	0.04%	0.07%	0.13%	0.21%	0.37%	0.47%
5-A	Hejin at Fenhe river	0.02%	0.05%	0.09%	0.16%	0.23%	0.37%	0.37%
	Sanmenxia（at main river）	0.02%	0.05%	0.10%	0.21%	0.43%	0.91%	1.68%
5-B	Huaxian（at main river）	0.03%	0.09%	0.18%	0.39%	0.78%	1.71%	2.94%
	Lintong at Weihe river	0.06%	0.17%	0.32%	0.62%	1.11%	2.13%	3.21%
	Weijiabu at Weihe river	0.05%	0.13%	0.25%	0.49%	0.93%	1.83%	2.88%
	Tongguan at Weihe river	0.02%	0.06%	0.14%	0.34%	0.74%	1.74%	3.17%
	Jiaokouhe at Weihe river	0.14%	0.37%	0.62%	1.18%	1.83%	3.22%	3.80%
	Xianyang at Weihe river	0.03%	0.08%	0.14%	0.29%	0.55%	1.11%	1.78%
6	Heishiguan at Yiluohe river	0.00%	0.01%	0.03%	0.08%	0.19%	0.42%	0.62%
	Baimasi at Yiluohe river	0.01%	0.03%	0.07%	0.14%	0.28%	0.55%	0.76%
	Wuzhi at Qinhe river	0.00%	0.01%	0.01%	0.04%	0.08%	0.21%	0.40%
	Xiaolangdi（at main river）	0.02%	0.05%	0.10%	0.20%	0.38%	0.85%	1.50%

7-A	Huayuankou（at main river）	0.04%	0.11%	0.20%	0.36%	0.58%	1.02%	1.29%
7-B	Gaocun（at main river）	0.05%	0.13%	0.22%	0.40%	0.64%	1.08%	1.36%
	Lijin（at main river）	0.02%	0.06%	0.12%	0.24%	0.51%	1.01%	1.75%

7.6 Economic Valuation of Flood Reductions

7.6.1 The Approach

To account for the random nature of flooding, the expected value of flood reductions (E(V)) arising from the CCFGP was estimated. The expected value of flood reductions is the avoided flood damage potential due to the implementation of the Program. The flood damage potential can be approximated by adjusting realized flood damage by the probability of the event occurring. The annual expected value of flood reductions in each region ($E(V_R)$) can be expressed as:

$$E(V_R) = \sum_{i=1}^{k} D_{Rk} \times P_{Rk} \times \Delta P_{Rk} \qquad (4)$$

where *R* denotes the region in the Yellow River Basin, *k* denotes the type of floods (also the frequency level), D_{Rk} denotes the economic losses brought about by type *k* flood in Region *R* being adjusted for inflation, P_{Rk} denotes the probability of flood occurrences for type *k* flood in region *R*, and ΔP_{Rk} denotes the change in probability of type *k* flood in region *R* brought about because of the CCFGP. Equation (4) shows that ΔP_{Rk} is used to derive the expected economic value of flood reductions. The total expected economic value of flood reductions across the Yellow River Basin during 2010-2020 can be expressed as a summation of the annual expected economic value in each region for a 10-year period. This is illustrated as follows:

$$E(V) = \sum_{t=1}^{n} \sum_{i=1}^{R} E(V_R)/(1+r)^n \qquad (5)$$

where *R* denotes the region in the Yellow River Basin, *r* denotes the discount rate, and *n* denotes the time period which is 10 years in this case.

To estimate the expected economic value of flood reductions, both hydrological data on the flood events and economic loss information are required. Specifically, the maximum daily runoff of the flood events is required to categorise flood events into floods of various sizes (i.e. floods at different frequency levels) in the Yellow River Basin. Consequently the probability change in the occurrence of the specific type of flood can be derived. Based on a review of the available literature, a total of 131 major flood events in the Yellow River were recorded during 1949 – 2000 (Wen 2005; Guo and Zheng 1995; Fan 1999; CSDN 2007; CMA 2007; MWR 2007). A temporal distribution of major flood events in the Yellow River Basin is shown in Table 8.

Table 8 Temporal distribution of major flood events in the Yellow River Basin

Time	1950s	1960s	1970s	1980s	1990s	Total
Occurrence	27	17	27	40	20	131

Of these, 44 flood events do not have related hydrological data available for further analysis. Hence, information on the remaining 87 flood events is used in this analysis. These flooding events were concentrated in the following regions of the Yellow River Basin:

- the section from Hekouzhen to Longmen in the Middle Reach of the Yellow River;
- the section from Longmen to Sanmenxia in the Middle Reach of the Yellow River;

- the section from Sanmenxia to Huayuankou in the Middle Reach of the Yellow River; and,
- the lower reach of the Yellow River.

Referring to the map of the Yellow River Basin (Figure 2), these regions mainly relate to Regions 4-7B. In the past five decades since the founding of New China, there have been no severe flood events recorded for Regions 1-3B. There are a number of reasons for this. First, Regions 1-3B are under-developed regions which lack well-documented statistical data. Second, these regions are located in the upper reach of the Yellow River, whereas the impact of flooding is mainly experienced in the downstream area. Third, the impact on runoff reductions brought about by the CCFGP is small in these regions, and hence the benefits from flood reductions are negligible. Because of these reasons, Regions 1-3B are not included in further analysis.

7.6.2 Economic Losses from Floods

To derive the expected economic value of flood reductions under the CCFGP, information on the economic losses from floods (D_{Rk} in Equation (4)) in the Yellow River Basin is sought. Flood losses can be categorised as direct and indirect. Direct flood damage arises from physical contact of floodwater with people or property. These include the loss of human life and agricultural production, and costs to repair damaged buildings, washed out railroad beds and bridges. Indirect flood damage is caused by the disruption to physical and economic linkages, and include such categories as the interruption of traffic flows, loss of personal income and business profits, as well as the cost of alleviating hardship (Green et al 2000; Lekuthai and Vongvisessomjai 2001). Indirect damage is often calculated as a percentage of direct flood damage (Lekuthai and Vongvisessomjai 2001).

Based on the literature review of flood events in the Yellow River Basin, the direct damages being recorded mainly include inundated area, number of people being affected by floods, number of houses collapsed, decline in crop production, and damaged bridges, pumping stations and wells. These are summarised in Table 9.

Table 9 Direct flood damages in the Yellow River Basin

Region	Hydrological Station	Time of occurrence	No. of Occurrences	Direct Flood Damages				
				Inundated area (mu)	Affected population	No. of damaged houses	Crop loss (kg)	Other damages
4	Houdacheng	1970s	4	852,000	120,000	3650		
	Longmen	1950s 1960s	6	839,000	3,023,000	41436	178,000	
5-A	Hejin	1990s	3	207,000	490,000	29092	350,000	
	Sanmenxia	1980s 1990s	5	215,000	22,000	2277		
5-B	Huaxian, Lintong, Tongguan, Weijiabu, Jiaokouhe, Xianyang	1980s	39	20,531,000	5,471,000	545,816		
6	Heishiguan, Baimasi	1950s	7	238,000		1696		
7-A	Huayuankou	1980s	11	13,932,000	4,090,000	797,441		1397 bridges, 1038 pumping stations, 5027 wells
7-B	Gaocun	1950-80s	12	11,811,000	39,650,000	737,520		5 bridges, 48 pumping stations, 1461 wells

Source: Wen 2005; Guo and Zheng 1995; Fan 1999; CSDN 2007; CMA 2007; MWR 2007; Xu 1994; Zhang 1993; NCC 1995; NDRC 1991, 1994-96.

Table 9 shows that Regions 5-B, 7-A and 7-B of the Yellow River Basin suffered most severely overtime from flooding. Region 5-B is located in the catchment of the Weihe River, the biggest tributary of the Yellow River. Carrying a heavy sediment load and being located in the backwater region of the Sanmenxia Reservoir, the Weihe River has been silting up at a high rate since the construction of the reservoir in 1960. Consequently, some morphological changes have occurred in this river, such as stream channel blockage, flood drainage capacity reduction, and a rising flood stage. These have brought about an increased flood threat to the lower Weihe River (Li et al 2005). Regions 7-A and 7-B are located in the lower reach of the Yellow River. Due to a combination of factors, in particular the decreased flood conveyance capacity and the low design flood discharge, these regions also suffer severe flooding damage costs (Li 1998).

The monetary value of economic losses from flood damage in the Yellow River recorded in the literature involves both direct flood damage and indirect damage to the national economy. Where the documentation of the monetary value of economic losses caused by a specific flood event is incomplete, estimates were made with reference to the historical data displayed in Table 10. With information on the total area impacted by the flood event and the type of the flood event (also the frequency level of the flood), its economic losses can be calculated with reference to the unit price displayed in Table 10. As damages are reported in the year of occurrence, values were adjusted for inflation. The general purchasing price index of farm products was used to adjust flood damage estimates to year 2000 level (SSB 1999).

Table 10 Unit price for economic losses from floods   Unit: CNY/ ha

	1950s	**1960s**	**1970s**	**1980s**
Big Floods*	1500	3600	6000	9000
Medium-scale Floods**	750	1350	2250	3000
Small Floods***	525	900	1575	2100

*Note: *Big floods are defined as 200-year, 100-year and 50-year floods; **Medium-scale floods are defined as 25-year and 10-year floods; ***Small floods are defined as 5-year and 2-year floods.*

Source: HDWR 1992.

The economic losses (adjusted to 2000 level) from flood events at a number of hydrological gauging stations in Regions 4-7B are displayed in Table 11. It can be seen that some catchments, such as Longmen in Region 4, Huayuankou in Region 7-A and Gaocun in Region 7-B, recorded more types of floods (i.e. floods of various sizes) during 1949 – 2000 as compared to other catchments. For most catchments, floods of the same size were recorded more than once. For instance, among the 11 flood events recorded for Huayuankou catchment in Region 7-A at the lower reach of the Yellow River, four were the two-year floods. In addition, there were two each of the five-year and ten-year floods, and one each of the 25-year and 50-year floods at Huayuankou. In these circumstances, a weighted average was calculated for the economic losses brought about by that specific type of flood for the catchment. There were no floods recorded in the literature for Wuzhi and Xiaolangdi catchments in Region 6 and Lijin catchment in Region 7-B.

Table 11 Economic losses from floods in the Yellow River Basin   Unit: CNY 10,000

Region	Hydrological Station	Economic losses from floods at different frequency levels						
		0.5%	1%	2%	4%	10%	20%	50%
4	Houdacheng						94029 (1)	3639 (3)
	Longmen	26903(1)	18501(1)	12599(1)	8609(1)	4815(1)	3020(1)	
5-A	Hejin					38023(1)	12971(1)	3961(1)
	Sanmenxia				4724(2)	3393(1)	2581(1)	1633(1)
5-B	Huaxian				27983(1)	9220(2)	3654(1)	803(1)
	Lintong				900340(1)	156614(1)	41582(2)	6163(1)
	Weijiabu		268967(1)			110037(2)	72670(1)	29893(6)
	Tongguan			110344(1)		49033(1)	34684(3)	22114(1)
	Jiaokouhe					69733(1)	34301(2)	7421(5)
	Xianyang			38509(1)			14869(1)	6649(3)
6	Heishiguan		83336(1)			8968(2)	3311(1)	
	Baimasi					8869(1)	7109(1)	4621(1)
	Wuzhi							
	Xiaolangdi							
7-A	Huayuankou		263303(1)	119528(1)	75183(1)	32938(2)	15165(2)	3704(4)
7-B	Gaocun		190972(1)	109427(1)	78261(1)	42550(2)	23518(4)	8461(3)
	Lijin							

Note: Numbers in brackets denote the number of occurrences of flood events.

Source: Wen 2005; Guo and Zheng 1995; Fan 1999; CSDN 2007; CMA 2007; MWR 2007; Xu 1994; Zhang 1993; NCC 1995; NDRC 1991, 1994-96.

7.7 Economic Value from Flood Probability Reductions

With information on the economic losses caused by floods of various sizes (D_{Rk}) and reductions in the probability of the occurrences of these floods (ΔP_{Rk}) under the CCFGP, the economic losses that can be avoided, or in other words, the economic value from flood probability reductions can be calculated. Results are shown in Table 12. These annual value estimates were derived by using Equation (4).

Table 12 Annual economic value from flood reductions in the Yellow River Basin Unit: CNY 10,000

Region	Hydrological Station	Economic losses from floods at different frequency levels						
		0.5%	1%	2%	4%	10%	20%	50%
4	Houdacheng at Sanchuanhe river						5.64	0
	Longmen（at main river）	0.027	0.074	0.176	0.448	1.01	2.24	
5-A	Hejin at Fenhe river					8.75	9.6	7.35
	Sanmenxia（at main river）				0.396	1.46	4.7	13.7
5-B	Huaxian（at main river）				4.364	7.19	12.5	11.8
	Lintong at Weihe river				223.284	173.84	177.14	98.9
	Weijiabu at Weihe river		3.497			102.33	265.98	430.45
	Tongguan at Weihe river			3.09		36.28	120.7	350.5
	Jiaokouhe at Weihe river					127.61	220.9	141
	Xianyang at Weihe river			1.078			33	59.2
6	Heishiguan at Yiluohe river		0.083			1.7	2.78	
	Baimasi at Yiluohe river					2.48	7.82	17.55
	Wuzhi at Qinhe river							
	Xiaolangdi（at main river）							
7-A	Huayuankou（at main river）		2.896	4.782	10.828	19.1	30.94	23.9
7-B	Gaocun（at main river）		2.483	4.814	12.52	27.23	50.8	57.55
	Lijin（at main river）							

Based on the above results, the annual economic benefits from flood reductions in the Yellow River Basin due to the CCFGP total CNY 29.4 million in year 2000 prices. As the general purchasing price index of farm products is not available in China since 2000, a discount rate of three per cent was used to adjust the value estimates to the current level. This is consistent with the previous studies of the CCFGP. The present value of the annual economic benefits from flood reductions hence totals CNY 36.2 million. Flood disasters in the Yellow River Basin during 1950-1990 brought about an economic loss of CNY 52.05 billion (HDWR 1992). This is equivalent to CNY 102.3 at 2007 level. Annual economic losses due to flood events totalled CNY 2.6 billion, of which 1.4 per cent could potentially be offset by flood reductions due to the CCFGP.

For a 10-year period from 2010 to 2020, the net present value of the total economic benefits from flood reductions amounts to CNY 362 million. The regional distribution of the CCFGP impacts on flood reductions in the Yellow River Basin are shown in Table 13. From a regional perspective, the CCFGP has greater impact on the flood frequency and hence losses in Regions 5-A, 5-B, 7-A and 7-B while the impact in Region 4 is insignificant. This is partly due to the fact that the Fenhe River Basin and Weihe River Basin (Regions 5-A and 5-B) and the lower reach of the Yellow River (Regions 7-A and 7-B) are the main agricultural areas in North China and these regions also suffer from frequent flood events. Hence the impacts of water and soil conservation measures on flood reductions in these regions are more significant than on the other regions in the Yellow River Basin.

Table 13 Economic benefits of flood reductions in the Yellow River Basin Unit: CNY 10,000

	Region 4	Region 5-A	Region 5-B	Region 6	Region 7-A	Region 7-B	Basin level
Annual benefits	11.81	56.57	3203.33	39.84	113.64	191.12	3616.32
10-year benefits at 3% discount rate	118.1	565.7	32033.3	398.5	1136.4	1911.2	36163.2

The flood reduction impact in different regions suggests that future implementation of the CCFGP should be strengthened in Region 5-B. The implementation of the Program will not only reduce the economic losses caused by flood events in this region, but will also have far-reaching effects on the main crop production area in the downstream Henan and Shandong provinces.

Table 14 shows that the CCFGP has different impacts on floods of various magnitudes. The economic benefits from flood reductions under the CCFGP increase as the magnitude of floods decreases. The impact of the CCFGP on large-scale floods, specifically, the 200-year, 100-year and 50-year floods, is negligible. In contrast, the CCFGP has significant impact on floods of small and medium scale. The economic benefits from flood reductions arising from the CCFGP are the greatest for the two-year floods, which are more than four times as much as those from the 25-year floods.

Table 14 Economic benefits from flood reductions at different frequency levels Unit: CNY 10,000

Frequency Level	0.005	0.01	0.02	0.04	0.1	0.2	0.5	All floods
Annual benefits	0.033	11.11	17.14	309.73	625.98	1161.91	1490.48	3616.32
10-year benefits at 3% discount rate	0.332	111.10	171.44	3097.31	6259.81	11619.1	14904.8	36163.2

It should be noted, however, that due to data limitations, the impact of the CCFGP on floods of certain magnitudes in some of the regions has not been included in the analysis. In addition, the intangible impacts of flooding on households – the stress, disruption and loss of items of sentimental value – can potentially be significant yet are not included in this analysis. This might lead to an under-estimation of the overall flood reduction impact of the Program and the expected economic benefits thus derived.

8 Impacts

8.1 Scientific impacts – now and in 5 years

In this research, the physically-based distributed hydrological model, the Water and Energy Transfer Processes in Large River Basins (WEP-L) Model was applied to simulate the natural hydrological processes from 1956 to 2000 in the Yellow River Basin. This model has been further developed through this research. This will contribute to improved hydrological modelling in the Yellow River Basin and consequently better water management along the Yellow River.

8.2 Capacity impacts – now and in 5 years

Through this research, the capacity for interdisciplinary research among the Chinese researchers has been improved through closer cooperation between the hydrologists and economists. The potential of using the spatial scenario modelling tools in the Chinese policy context has been explored and the research outcome will be extended. The hydrological model developed through this research can be used to evaluate other ecological restoration programs in China.

8.3 Community impacts – now and in 5 years

Community impacts of the research project can be seen from the following three aspects, namely economic impacts, social impacts and environmental impacts not only in the project area (in this case the Yellow River Basin) but across China.

8.3.1 Economic impacts

The research findings will contribute to the knowledge base of current research work on the CCFGP and address the priority issue around the implementation of CCFGP which is the quantification of its ecological impacts. The more comprehensive cost benefit analysis of the Program produced in this research will assist in better decision-making in the CCFGP policy context. An improved policy design thus derived will have economic impacts on the Chinese community both on-site and off-site of the program area.

8.3.2 Social impacts

Both the decision-making agencies in natural resource management and the public have been better informed of the impacts of the CCFGP. This will bring further changes to the policy-making process for the implementation of the land use change programs in China. Through this project, the social awareness of the importance of environmental improvements was also raised. This is a key component to ensure the successful implementation of land use change programs at the grass-roots level.

8.3.3 Environmental impacts

The flood mitigation impact of the CCFGP presented in this research contributes to a more comprehensive environmental assessment of the Program. The economic benefits from potential flood reductions under the CCFGP can be compared to the economic losses from agricultural productions due to reduced runoff. This has implications for having revegetation activities as one of the water management options in the Yellow River Basin. The research findings will contribute to an improved environmental performance within the government budget constraints.

8.4 Communication and dissemination activities

The project extension outputs have been incorporated into the preceding project's web site. The research report will be translated and printed. Copies of the report will be sent to all interested parties, including related government agencies in China, research institutes both in China (e.g. CCAP), and Australia (e.g. CSIRO, ABARE), foreign embassies in China as well as international organisations (e.g. FAO, UNDP and World Bank China Office). The report will be converted into a journal article and submitted to the Water Resources Research later in 2007.

Findings from the research will also be briefed to the high-level officials at the State Forestry Administration during Professor Bennett's next travel to China scheduled in early 2008 during the inception meeting of the new project. The updated version of the WEP-L hydrological model as an output of this project will be applied in future hydrological modelling of the Yellow River for better water management decision-making in China.

9 Conclusions and recommendations

9.1 Conclusions

Even though the increase in forest cover provided under the CCFGP mitigates only small and medium size floods, the benefits to the local economies and to the poor and resource dependent farming households is shown to be significant. This warrants the inclusion of the economic benefits from flood reductions into the benefit cost analysis of the CCFGP.

In this research, the relationship between changes in land use practices and the probability of different flood events occurring is initially established. Hydrological modelling is conducted to analyse and predict changes in the probability of flood occurrences in the Yellow River Basin due to revegetation activities under the CCFGP. The physically-based distributed hydrological model, WEP-L model is applied and developed in this case study. The natural hydrological processes from 1956 to 2000 in the Yellow River Basin are simulated using the model. With this model, the flood reduction impact of the CCFGP can be delineated from other flood control programs in the region such as the strengthening of dykes and the managing of sediment in strategically located reservoirs.

In this study, the Yellow River Basin is divided into ten regions and revegetation information in each of the ten regions is processed using a GIS platform. Hydrological data from the main hydrological gauging stations along the Yellow River in these regions are used for hydrological analysis. Frequency analysis is conducted using historical data to derive maximum daily runoff discharges for floods of various sizes "with" and "without" the CCFGP in place. The marginal change in flood flows arising from the CCFGP during 2010-2020 is hence derived, and reductions in the probability of flood occurrences are estimated.

The prediction of changes in flood frequency is crucial to the economic analysis of the impact of the CCFGP in terms of flood reductions in the Yellow River Basin. The estimates can be integrated into the cost benefit analysis framework of the implementation of the Program. This will enable a more comprehensive policy analysis and will further provide better indicators of the appropriate direction for the land use change policy. Compared to the total investment of around CNY 65.5 billion in the region under the CCFGP (Wang 2007), the economic benefits from flood reductions (CNY 362 million) are small. This is mainly due to the relatively small potential impacts of the CCFGP on flood probability reductions in the Yellow River Basin. Previous studies found the net environmental benefits arising from the CCFGP in the region will total CNY 42.8 billion (Wang et al 2007). Hence the economic benefits of flood reductions under the CCFGP will be less than one per cent of the total environmental benefits generated by the Program. Further, the potential economic benefits from flood reductions will be offset by the potential economic losses from agricultural production (CNY 667 million) with reduced runoff under the Program (Wang et al 2007). This has implications for the ranking of the management options (either structural or non-structural) to mitigate flood disasters in the Yellow River Basin.

9.2 Recommendations

The accuracy of the methods used to estimate flood flow reductions is constrained to some degree by the simplification of the hydrological processes in the distributed hydrological model. The simplification was due to a lack of information on the mechanism of the hydrological cycle as well as limitations on data collection and computational capacity. For instance, the spatial variability of hydrological variables and parameters as well as the water intake process of different types of vegetation at various stages of growth under different meteorological conditions were not taken into full account in the model. In addition, the minimum time interval of the flood data used in the distributed hydrological model in this research was one hour, whereas ideally, a time interval less than one hour should be used in calculating flood occurrences. The accuracy of the research results is also constrained by the limited data on flood losses recorded in the literature as well as the lack of consistency in damage estimation procedures across different sub-catchments in the Yellow River Basin. Hence, further policy analysis using the estimates generated in this study should take into account these constraints and the potential bias thus generated.

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