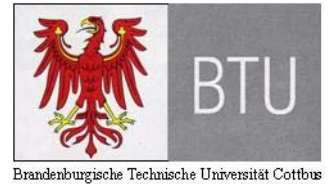


Brandenburg University of Technology in Cottbus
Faculty of Environmental Sciences and Process Engineering
Department of Ecosystem and Environmental Informatics



On the Use of Game Theoretic Models for Water Resources Management

A thesis approved by the Faculty of Environmental Sciences and Process Engineering at the Brandenburg University of Technology in Cottbus in partial fulfillment of the requirement for the award of the academic Degree of Doctor of Philosophy (Ph.D.) in Environmental and Resource Management

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Brandenburgische Technische Universität Cottbus
Fakultät Umweltwissenschaften und Verfahrenstechnik
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Über die Anwendung spieltheoretischer Modelle zur Wasserbewirtschaftung

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Dissertation in Umwelt-und Ressourcen Management

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Declaration

I, Shouke Wei, hereby declare that this submission is my own work, which was completed under the supervision of Prof. Dr. rer. nat. habil. Albrecht Gnauck, Priv. - Doz. Dr. - Ing. habil. Thomas Rauschenbach and Prof. Dr. - Ing. Alin Lei, and that, to the best of my knowledge and belief, it contains no material previously published or written by another person and nor material which to a substantial extent has been accepted for the award of any other degree or diploma in other universities or institutes, except where due acknowledgment has been made in the text.

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29th, January 2008

Abstract

Water quality degradation and water scarcity are two serious problems, and water resources management related to those problems usually involves conflicts. In the absence of market and exclusive property rights, those conflicts are unavoidable. Game theory is an appropriate approach to simulate and resolve such conflicts. The overall objective of this research is to develop a practical methodology and mechanism to promote the maximization of public welfare from a socio-economic and environmental perspective using game theory. There are three main goals: 1) to use game theory to illustrate and analyze phenomena of water resources management, 2) to set up non-cooperative and cooperative game theoretic simulation models of water conflicts in a river basin, and 3) to apply the game theoretic simulation approach into water conflicts involved in the Hanjiang River Basin (HRB) in China. In the case of HRB, the Municipalities of Beijing, Hanzhong, Ankang and Shangluo, Shiyang and the Cities of Xixia and Xichuan are defined as the main players. For each main player, industry, households and agriculture are defined as the sub-players. Statistical and econometric regression modeling methods are used to formulate payoff functions of the players. The models are evaluated by forecasting and scenarios analyses. Cost-benefit Analysis (CBA) and demand-supply principle (DSP) are applied to compare the game outcomes. Economic valuation methods (EVMs) are applied to the value transformation. Scenario analysis is also employed to analyze the future risks and uncertainties. The main results prove that the non-cooperative game will cost all players an overall loss, though it yields benefits to some players. However, cooperative game results show that there is an overall benefit, though some players have loss. Comparing with the results of non-cooperative and cooperative games, it finds that cooperation makes all the players better off though some players are worse off. Scenario results illustrate that player one and his sub-players have serious water deficits even in the optimistic scenario. Thus, cooperation with other players is the dominant strategy for this player. The risks of non-cooperation come from some other players and sub-players. The game theoretic simulation approach and results benefit not only different groups of water stakeholders, but also decision makers to make policies on water quantity allocation, water quality protection, water pricing as well as ecological loss compensation.

Keywords: Water resources, conflicts, game theory, simulation, scenario analysis, the Hanjiang River Basin

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Contents

Declaration	iii
Abstract	iv
Acknowledgements	v
Table of Contents	vi
List of Figures	viii
List of Tables and Matrix	xiii
List of Abbreviations	xv
Glossary of Symbols	xviii
1. Introduction	1
1.1 Objectives and principles of water resources management	2
1.2 Solving water conflicts	4
1.3 Selected literature on game theory for water resources management	8
1.4 Objectives, research methodology and structure of thesis	10
2 Game theory and water resources management	15
2.1 Theory of games	15
2.2 Game theoretical models	18
2.2.1 Cooperative and non-cooperative models	18
2.2.2 Strategic and extensive game theoretical models	19
2.2.3 Special game models	22
2.3 Game theoretical approach for water resources management	25
2.3.1 Types of games	26
2.3.2 A game theoretical approach to solve conflicts	27
2.4 Game theoretic methods to solve water conflicts in a river basin	29
2.4.1 Cooperative and non-cooperative games in a river basin	30
2.4.2 A strategy for water resources management using game theory	30
2.4.3 Cooperative and non-cooperative game theoretical models	32
2.4.3.1 A non-cooperative game model	32
2.4.3.2 A cooperative game model	34
2.5 Data used for game theoretic models	34

3	Game-theoretic approaches to river water management in China	36
3.1	The Hanjiang River Basin	38
3.1.1	Water quantity	40
3.1.2	Water quality	41
3.1.3	Sources of water pollution	46
3.2	Conflicts and games involved in the Hanjiang River Basin	48
3.2.1	Conflicts involved	48
3.2.2	Games involved	52
3.3	Game theoretical models for the Hanjiang River Basin	53
3.3.1	Formulating the game models	54
3.3.2	Game simulating process	56
3.4	Design of scenarios	84
4	Results and discussion	87
4.1	Results of the simulation	87
4.2	Results of the scenarios	95
4.2.1	Scenario results of game 1	95
4.2.2	Scenario results of game 2	100
4.2.3	Scenario results of game 3	104
4.2.4	Scenario results of game 4	109
4.2.5	Scenario results of game 5	113
4.3	Discussions	116
4.3.1	Discussion of the simulation results	116
4.3.2	Discussion of the scenario results	118
4.3.3	Evaluation of the results	120
5	Conclusions	124
	References	130

List of Figures

1.1	Instruments to solve water conflicts	5
1.2	Sketch of technical route of the research	11
2.1	A game tree used to illustrate dynamic games with three players	21
2.2	Game of prisoners' dilemma	22
2.3	Chicken game	23
2.4	Assurance game	23
2.5	Driving force game	24
2.6	The transforms among the models of prisoners' dilemma game, chicken game, assurance game and driving force game	25
2.7	Nature and human society from a game theoretical perspective	26
2.8	General flow chart of game theoretic approach to solve conflicts	28
2.9	A strategy for water resource management using game theory	31
3.1	Map of South-to-North Water Transfer Projects	37
3.2	Sketch of South-to-North Water Transfer Projects	37
3.3	Sketch of Hanjiang River Basin	39
3.4	The Danjiangkou Reservoir and the water monitoring stations	42
3.5	Water quality of the Danjiangkou Reservoir	43
3.6	Main tributaries of the Danjiangkou Reservoir	44
3.7	Comparison of the pollutant concentrations of the main tributaries of the Danjiangkou Reservoir in 1995 and 2004	45
3.8	Scatter plots of waste discharge vs. GDP and population in Hubei, He'nan and Shaanxi	47
3.9	Fertilizer consumptions by 100% effective components in Hubei, He'nan and Shaanxi	47
3.10	Per Capita GDP and Per Capita water resource of Beijing, Tianjin, Hebei, He'nan, Hubei and Shaanxi	49
3.11	Conflicts involved in the Hanjiang River Basin	50
3.12	Total amount of water resources and water demand of Beijing, Tianjin and Hebei	51
3.13	Ground water table of Beijing	51
3.14	Games involved in the Hanjiang River Basin	52

3.15	Sketch of the regions involved in Hanjiang River Basin	54
3.16	Game simulating process	57
3.17	Game tree of water seizing game	58
3.18	Water seizing game model	59
3.19	Water demand per unit added value of player 11	60
3.20	Added value of player 11	60
3.21	Water demand of player 12	61
3.22	Added value of player 12	61
3.23	Water demand per unit of added value of player 13	62
3.24	Added value of player 13	62
3.25	Ecological based water use	63
3.26	Domestic sewage discharge	64
3.27	Ecological based water demand	65
3.28	Waste water discharge of player 21	67
3.29	Waste water discharge of player 31	68
3.30	Waste water discharge of player 41	68
3.31	Urban population of player 22	69
3.32	Rural population of player 23	70
3.33	Urban population of player 32	70
3.34	Rural population of player 33	71
3.35	Urban population of player 42 and the forecast values	71
3.36	Rural population of player 43	72
3.37	Domestic sewage discharge of player 22	72
3.38	Domestic sewage discharge of player 32	73
3.39	Domestic sewage discharge of player 42	73
3.40	Pig equivalences of player 23	74
3.41	Pig equivalences of player 33	75
3.42	Pig equivalences of player 43	75
3.43	Nitrogen fertilizer consumption of player 23	76
3.44	Nitrogen fertilizer consumption of player 33	76
3.45	Nitrogen fertilizer consumption of player 43	77
3.46	Game tree of TN reduction for the Danjiangkou Reservoir	77
3.47	Benefit coefficient of player 11	78
3.48	Benefit coefficient of player 12	79

3.49	Benefit coefficient of player 13	79
3.50	Scatter plots of added value vs. time, nitrogen fertilizer consumption and labours	80
3.51	Exponential model of added value vs. time and nitrogen fertilizer consumption	81
3.52	Linear model of nitrogen fertilizer consumption vs. time	81
3.53	Controlling lines of TN concentration in the Danjiangkou Reservoir	82
3.54	Annual inflow of the Danjiangkou Reservoir	83
3.55	Consumer price index of player 1 and his sub-players	84
3.56	Sketch of influences of socio-economic and hydro-climatological factors to game modeling structure	85
4.1	Scenarios of added value and water demand of player 11	95
4.2	Scenarios of added value and water demand of player 12	96
4.3	Scenarios of population and water demand of player 12	96
4.4	Scenarios of added value and water demand of player 13	97
4.5	Scenarios of urban sewage discharge and reclaim water of player 1	97
4.6	Scenarios of ecological based water use and water demand of player 1	98
4.7	Scenarios of total water demand and water supply of player 1	98
4.8	Scenarios of water shares and water deficit of player 11 in a cooperative game	99
4.9	Scenarios of water shares and water deficit of player 12 in a cooperative game	99
4.10	Scenarios of water shares and water deficit of player 13 in a cooperative game	100
4.11	Scenarios of rural population and nitrogen discharged into the reservoir by player 23	100
4.12	Scenarios of urban population and nitrogen discharged into the reservoir by player 22	101
4.13	Scenarios of soil erosion and nitrogen discharged into the reservoir by player 23	101
4.14	Scenarios of nitrogen fertilizer consumption and nitrogen discharged into the reservoir by player 23	102
4.15	Scenarios of pig equivalences and nitrogen discharged into the reservoir by player 23	102

4.16	Scenarios of nitrogen discharged into the reservoir from rural domestic life and animal husbandry by player 23 in four treatment scenarios	103
4.17	Scenarios of nitrogen discharged into the reservoir from urban domestic life by player 22 and industry waste water by player 21 in four treatment scenarios	103
4.18	Nitrogen discharged into the reservoir by the players 21, 22 and 23 in scenarios 1, 2, 3 and 4	104
4.19	Scenarios of rural population and nitrogen discharged into the reservoir by player 33	105
4.20	Scenarios of urban population and nitrogen discharged into the reservoir by player 32	105
4.21	Scenarios of soil erosion and nitrogen discharged into the reservoir by player 33	106
4.22	Scenarios of nitrogen fertilizer consumption and nitrogen discharged into the reservoir by player 33	106
4.23	Scenarios of pig equivalences and nitrogen discharged into the reservoir by player 33	107
4.24	Scenarios of nitrogen discharged into the reservoir from rural domestic life and animal husbandry by player 33 in four treatment scenarios	107
4.25	Scenarios of nitrogen discharged into reservoir from urban domestic life by player 32 and industry waste water by player 31 in four treatment scenarios	108
4.26	Nitrogen discharged into the reservoir by players 31, 32 and 33 in scenarios 1, 2, 3 and 4	108
4.27	Scenarios of rural population and nitrogen discharged into the reservoir by player 43	109
4.28	Scenarios of urban population and nitrogen discharged into the reservoir by player 42	110
4.29	Scenarios of soil erosion and nitrogen discharged into the reservoir by player 43	110
4.30	Scenarios of nitrogen fertilizer consumption and nitrogen discharged into the reservoir by player 43	111
4.31	Scenarios of pig equivalences and nitrogen discharged into the reservoir by player 4	111
4.32	Scenarios of nitrogen discharged into the reservoir from rural domestic life and animal husbandry by player 43 in four treatment scenarios	112

4.33	Scenarios of nitrogen discharged into the reservoir from urban domestic life by player 42 and industry waste water by 41 in four treatment scenarios	112
4.34	Nitrogen discharged into the reservoir by players 21, 22 and 23 in scenarios 1, 2, 3, 4 in game 4	113
4.35	Scenarios of water deficit of player 1	114
4.36	Scenarios of nitrogen discharged into the reservoir by players 2, 3 and 4	114
4.37	Scenarios of nitrogen reduction of players 2, 3 and 4	115

List of Tables and Matrices

Tables:

1.1	Objectives and principles of water resources management	2
1.2	Policy instruments to solve water conflicts	7
2.1	Data used for game theoretic models	35
3.1	Flow division and characteristics of the Hanjiang River	39
3.2	Water resources in the upper basin of Hanjiang River	40
3.3	Water resources of different zones in middle-low reaches of the Hanjiang River	41
3.4	Monitoring results of water quality in the Hanjiang River	41
3.5	Comparison of four algae blooms in middle and low reaches of the Hanjiang River	46
3.6	Soil erosion in different provinces in the upstream river basin	48
3.7	Number of domestic animals and poultry in the upstream river basin in 2005	48
3.8	Water resources in different hydrological years in Beijing (1986-2005)	51
3.9	The regions included in the game models	53
3.10	Different transportation rates of nitrogen	67
3.11	Average N amount produced by one person and a pig per year	69
3.12	Descriptions of main scenarios for all games	86
3.13	Assumption of main scenarios for all players and sub-players	86
4.1	Water demand equilibrium of players 11, 12 and 13 in the non-cooperative game	87
4.2	Water Shares of different players in the cooperative game	88
4.3	Water deficit of players 11, 12 and 13 in the cooperative game	88
4.4	Nitrogen produced by players 21, 22 and 23 in the non-cooperative game	88
4.5	Nitrogen reduced by players 21, 22 and 23 in the cooperative game	89
4.6	Nitrogen produced by players 31, 32 and 33 in the non-cooperative game	89
4.7	Nitrogen reduced by players 31, 32 and 33 in the cooperative game	90
4.8	Nitrogen produced by players 41, 42 and 43 in a non-cooperative game	90
4.9	Nitrogen reduced by player 31, 32 and 33 in the cooperative game	90
4.10	Losses of sub-players of 11, 12, and 13 in the non-cooperative game	

	at current prices	92
4.11	Losses of sub-players 21, 22 and 23 in the cooperative game	92
4.12	Losses of sub-players 31, 32 and 33 in the cooperative game	92
4.13	Losses of sub-players 41, 42 and 43 in the cooperative game	93
4.14	Consumer Price Index of player 1 and his sub-players from 2005 to 2016	93
4.15	Losses of sub-players of 11, 12, and 13 in the non-cooperative game at comparable prices	94
4.16	Comparisons of observations and forecasts in game 1 and its sub-games	121
4.17	Comparisons of observations and forecasts in games 2, 3 and 4 and their sub-games	122
4.18	Error classification and analyses	122

Matrices:

3.1	Games of pollutant reduction	65
4.1	Payoff matrix of players 1, 2, 3 and 4 in the non-cooperative and cooperative game at current prices	91
4.2	Payoff matrix of players 1, 2, 3 and 4 in the non-cooperative and cooperative game at comparable prices	94

List of Abbreviations

AK	Ankang
ANZECC	the Australian and New Zealand Environment and Conservation Council
AQSIQC	Administration of Quality Supervision, Inspection and Quarantine of China
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
AusAID	Australian Agency for International Development
BJ	Beijing Municipality
BJSB	Beijing Statistic Bureau
BJWB	Beijing Water Resources Bureau
BOD ₅	Biochemical Oxygen Demand after five days
BTU	Brandenburg University of Technology
CBA	Cost-benefit Analysis
CCICED	China Council for International Cooperation on Environment and Development
CESY	China Environmental Statistic Yearbooks
CODMn	Permanganate Index
CPI	Consumer Price Index
CEQSSW	Chinese Environmental Quality Standards for Surface Water
CWRA	China Water Resource Administration
CWRC	Changjiang Water Resources Commission
CWRPI	Changjiang Water Resources Protection Institute
DB-CWRPI	Database of the Changjiang Water Resources Protection Institute
DB-NBSC	Database of the National Bureau of Statistics of China
DO	Dissolved Oxygen
DSP	Demand-supply Principle
EEA	European Environment Agency.
EPAC	Environment Protection Administration of China
ERP	Eastern Route Project
EVM	Economic Valuation Method

HRB	Hanjiang River Basin
HEB	Hebei Province
HBEPB	Hubei Environmental Protection Bureau
HH-G	Games played among human beings, including different countries, world regions, or areas within regions
HN-G	Games played between man and the nature
HNSB	Henan Statistic Bureau
HRB	Hanjiang River Basin
HBSB	Hubei Statistic Bureau
HZ	Hangzhong City
HUB	Hubei Province
IIASA	International Institute for Applied Systems Analysis
ISEH	International Society for Ecosystem Health
IWRM	Integrated Water Resources Management
MLRB	Middle-Low River Basin
MRP	Middle Route Project
MRSNWTP	Middle Route of South-to-North Water Transfer Project
MVM	Market Value Method
NH ₃ -N	Ammonia Nitrogen
NN-G	Nature and nature games, i.e. the games in nature itself
NBSC	National Bureau of Statistics of China
OECD	Organisation for Economic Co-operation and Development
OBM	Opportunity Benefits Method
OCM	Opportunity Cost Method
RA	Reservoir Area
RCA	Replacement Cost Approach
SEM	Shadow Engineering Method
SNWT	South to North Water Transfer
SL	Shangluo City
SX	Shaanxi Province
SXSB	Shaanxi Statistic Bureau
SY	Shiyan City
TCA	Taocha Monitoring Station
TJ	Tianjin Municipality

TN	Total Nitrogen
TP	Total Phosphorus
TZS	Taizishan Monitoring Station
UNCED	United Nations Conference on Environment and Development
UN-CSD	United Nations, Commission on Sustainable Development
UNEP	United Nations Development Program
UNESCAP	United Nations, Economic and Social Commission for Asia and the Pacific
URB	Upper River Basin
VAR	Vector Auto-regression
WMO	World Meteorological Organization
WRP	Western Route Project
XC	Xichuan County
XX	Xixia County

Glossary of Symbols

A	Profile of action (or move) of the players
$A_i = \{a_i\}$	Player i 's action set, i.e. the entire set of actions available to him
a_i	An action combination for each of the n players in a game
$[a_{ij}]$	A matrix
$B(Q)$	Benefit function of water consumption in a cooperative game
$B_i(Q)$	Benefit function of water consumption of player i in a non-cooperative game
B_1^t	Benefit coefficients of water consumption in industry and during the period of time t (a year)
B_2^t	Benefit coefficients of water consumption in domestic life during the period of time t (a year)
B_3^t	Benefit coefficients of water consumption in agriculture during the period of time t (a year)
B_{ij}	Benefits of player ij
C	Loss resulting from water deficit
$C(P)$	Cost to abate pollutants in a cooperative game
$C_i(P)$	Cost of every player i to abate pollutants in a non-cooperative game
C_{ij}	Cost or loss imposed to player ij
$C_{ij}^{\rightarrow R}$	Annual average concentration of nitrogen reaching in the reservoir
C_{il}	Nitrogen concentration of per unit of waste water
Cl	Cycle part of annual inflow
C_S	Controlling concentration of pollutant i or the standard in the reservoir
C_n	Cities, such as C_1, C_2 and C_3 refer to Cities 1, 2 and 3, respectively
$c_{x,y-1}^t$	Concentration of pollutant x in the upstream section $y-1$
$c_{x,y}^t$	Concentration of pollutant x in the section y
$c_{x,y}^c$	Controlling concentration of pollutant x in the section y
D_g^t	Water quota for one unit of public green area

D_t	Dummy variables
D_{tr}^t	Water quota for a tree
D_w	Domestic waste water discharge
D_w^t	Domestic waste water discharge
E	Equilibrium or equilibria
E^t	Evapotranspiration
$e^{-\delta t}$	Discount factor
F	Probability distribution
F_{i3}	Nitrogen fertilizer consumptions
F_{23}	Nitrogen fertilizer consumptions of player 23 (agriculture of Hanzhong, Ankang and Shangluo)
F_{33}	Nitrogen fertilizer consumptions of player 33 (agriculture of Shiyan)
F_{33}	Nitrogen fertilizer consumptions of player 43 (agriculture of Xixia and Xichuan)
F_N	Nitrogen fertilizer consumed in every year
G_T	A game
G	Strategic (or Normal) game
G^t	Ground water amount
G_i	A set of games
G_{ij}	Sub-games
G_l	Ground water recharge
G_s	Number of goats and sheep
H	Sequence set of players' decision in different period of time (called history)
I	Information set
I_d	Consumer Price Index
I_d^k	Consumer Price Index in year k
I_d^t	Consumer Price Index in year t
I_i	Information set of player i on the player(s) in history
i	Every player
$-i$	The other $n-1$ players or i 's opponents in some senses

$i1$	Industry
$i2$	Households
$i3$	Agriculture
J_1	Mean nitrogen amount per unit of manure of a person in one year
J_2	Mean nitrogen amount per unit of liquid of a person in one year.
J_3	Nitrogen amount per year in the manure of livestock and poultry
J_4	Nitrogen amount per year in the liquid of livestock
j	Every sub-player
$1j$	Sub-player $1j$ in game 1, such as 11, 12 and 13
$2j$	Sub-player $2j$ in game 2, such as 21, 22 and 23
$3j$	Sub-player $3j$ in game 3, such as 31, 32 and 33
$4j$	Sub-player $4j$ in game 4, such as 41, 42 and 43
K	Reclaiming rate of domestic waste water
k_{ij}	Transport rate of nitrogen into the reservoir
L_{i2U}	Urban population of every player of $i2$
L_{i3R}	Rural population of every player of $i3$
L_{22U}	Urban population of player 22 (Households of Hanzhong, Ankang and Shanluo)
L_{23R}	Rural population of player 23
L_{32U}	Urban population of player 32 (Households of Shiyan)
L_{33R}	Rural population of player 33
L_{42U}	Urban population of player 42 (Households of Xixia and Xichuan)
L_{43R}	Rural population of player 43
L_a	Number of large animals
$M_{ij}^{\rightarrow R}$	Load of nitrogen discharged into the reservoir
N	A set of players, $N = \{1, 2, \dots, n\}$
N_{tr}^t	Trees in time t
NC	Non-cycle part of annual inflow
NP_{ij}	Amount of nitrogen production
NP_{i2}	Nitrogen produced by every player of $i2$
NP_{i3}	Nitrogen produced by every player of $i3$
NP_{i3A}	Nitrogen produced by the animal husbandry
NP_{i3F}	Nitrogen produced by fertilizer consumptions

NP_{i3S}	Nitrogen produced by soil erosion
O	Outcomes of a game
O_l	Overlap calculation between surface water and ground water recharge
Q_f	Natural inflow of the reservoir
P	Payoff (or Utility), or Pollutants discharged
$P(h)$	The player(s) who will move to make decision after history h
$P(a h)$	The probability of action a chosen as moving action after history h
P^t	Precipitation
$-P_{ij}^t$	Pollutants reduced by every player ij in time t
$P_{x,y-1}^t$	Load of pollutant x from the upstream controlling section $y-1$
$P_{x,y}^t$	Load of pollutant x in the controlling section y
$P_{x,y}^c$	Controlling load of pollutant x in the controlling section y
P_g	Number of pigs
P_o	Number of poultry
P_{ij}^-, NP_{ij}^-	Nitrogen reduced by every player ij
P^-	Total reduction of nitrogen
$P^{\rightarrow R}$	Total nitrogen reached into reservoir
P_s	Controlling amount of nitrogen entering into the reservoir
P1	Player 1 (Beijing Municipality)
P2	Player 2 (Municipalities of Hanzhong, Ankang and Shangluo)
P3	Player 3 (Shiyan Municipality)
P4	Player 4 (Cities of Xixia and Xichuan)
P_{i2}	Nitrogen productions from domestic life
Q	Water consumption
Q_i	Water consumption of every player i
Q_i^t	Water consumption of different players in time t (a year)
Q_{ij}^t	Water that every player ij can get in time t
$+Q_{ij}^t$	Water obtained by every player ij in time t ,
$-Q_{ij}^t$:	Water lost by every player ij in time t
$Q_{l_jz}^t, Q_{l_jx}^t, Q_{l_jk}^t$	Different water amounts that players can get in different

$Q_{l_{jm},}^t$ and $Q_{l_{jn}}^t$	combined strategies
Q_{Ri}^t	Real water demand of each player
Q_e^t	Ecological water demand
Q_{ik}^t	Water consumption of every player in a cooperative game
Q_{11}	Water demand of player 11 (Industry of Beijing)
Q_{12}	Water demand of player 12 (Households of Beijing)
Q_{13}	Water demand of player 13 (Agriculture of Beijing)
$Q_{1,jk}^t$	Water quartos that different players should consume if they do not seize water
Q_{1e}^t	Ecological based water consumption
Q_{1eR}^t	Real minimum ecological water demand
Q_1^t	Water consumption of industry during the period of time t (a year)
Q_2^t	Water consumption of domestic life during the period of time t (a year)
Q_3^t	Water consumption of agriculture during the period of time t (a year)
Q_4^t	Water demand for soil conservation during the period of time t (a year)
Q_5^t	Ecological water demand during the period of time t (a year)
Q_0^t	Water demand in other sectors
Q_{y-1}^t	Water inflow from the upstream section $y-1$
$Q_{(y-1,y)}^t$	Water inflow in the section y ;
\underline{Q}_i^t	The minimum of water demand
\bar{Q}_i^t	The maximum of water demand
Q_{1e}	Ecological water use
Q_s^t	Water demand of water surface
Q_g^t	Water demand of public green area
Q_{tr}^t	Water demand of trees
Q_{1j}	Water consumed by every player $1j$
Q_f	Natural inflow of the reservoir

\bar{O}_{i3}	Number of pig equivalences, i.e. all the livestock and poultry weighted by pig unit
\bar{O}_{23}	Number of pig equivalences of player 23
\bar{O}_{23}	Number of pig equivalences of player 33
\bar{O}_{43}	Number of pig equivalences of player 43
R_1	Region 1 (Beijing)
R_1^t	Reclaimed water from urban waste water
R^t	Waste water discharged into the river or the reused waste water
R_m	The regions
R_A	Nitrogen loss rate of the manure of livestock and poultry
R_F	Loss rate of N fertilizer,
R_S	Loss rate of N per unit of soil erosion
S	Strategy set (called <i>strategies space</i>) of the players
S_i	Player i 's strategy space, the set of all the strategies which player i can choose
S^t	Surface water amount
S_1^t	Surface water resources of player 1
S_E	Areas of soil erosion
S_w	Areas of water surface
S_g^t	Public green areas
S_R	Reduction of soil erosion areas
S1	Scenario 1
S2	Scenario 2
S3	Scenario 3
S4	Scenario 4
S_i^*	Player i 's best response to the strategies specified for the n-1 other players
$s^* = \{s_1^*, s_2^*, \dots, s_n^*\}$	A best strategy combination of the n players
T, t	Time (year)
U	Total benefit obtained from a cooperative game
U_i	Payoff of each player i in a cooperative game
U_B	Total net benefit obtained from a cooperative game

U_i	Profile of players' utility (payoff) functions on history H
U_1	Payoff of player 1 at current prices in a cooperative game
U_2	Payoff of player 2 at current prices in a cooperative game
U_3	Payoff of player 3 at current prices in a cooperative game
U_{11}	Payoff of player 11 at current prices in a cooperative game
U_{12}	Payoff of player 12 at current prices in a cooperative game
U_{13}	Payoff of player 13 at current prices in a cooperative game
U'_1	Payoff of player 1 at comparable prices in a cooperative game
U'_2	Payoff of player 2 at comparable prices in a cooperative game
U'_3	Payoff of player 1 at comparable prices in a cooperative game
U'_{11}	Payoff of player 11 at comparable prices in a cooperative game
U'_{12}	Payoff of player 12 at comparable prices in cooperative game
U'_{13}	Payoff of player 13 at comparable prices in a cooperative game
$u_i(s_i, s_{-i})$	Player i 's payoff function when he choose strategy s_i
V_i	Payoff of every player i ,
V_1	Payoff of player 1, i.e. added value produced by player 1
V_{11}	Payoff of player 11, i.e. added value produced by player 11
V_{12}	Payoff of player 12, i.e. added values produced by player 12
V_{13}	Payoff of player 13, i.e. added value produced by player 13
V_{1j}	Payoff of sub-player $1j$, i.e. added values produced by sub-player $1j$
V_{i3}	Payoff of sub-players $i3$, i.e. added values produced by sub-player $i3$
V'_{ij}	Payoff of every player ij in time t
V'_1	Payoff of player 1 at comparable prices in a non-cooperative game
V'_2	Payoff of player 2 at comparable prices in a non-cooperative game
V'_3	Payoff of player 1 at comparable prices in a non-cooperative game
V'_{11}	Payoff of player 11 at comparable prices in a non-cooperative game
V'_{12}	Payoff of player 12 at comparable prices in a non-cooperative game
V'_{13}	Payoffs of player 13 at comparable prices in a non-cooperative game
V_R^K	Comparable or real value of V at the price of year k

V_N^t	Normal value of V at the price of year t
W_1^t	Total water resources
\ddot{W}_{i1}	Waste water discharge of player $i1$
\ddot{W}_{21}	Waste water discharge of player 21
\ddot{W}_{31}	Waste water discharge of player 21
\ddot{W}_{41}	Waste water discharge of player 41
\ddot{W}_{22}	Urban domestic sewage discharge of player 22
\ddot{W}_{32}	Domestic waste water discharge of player 32
\ddot{W}_{42}	Domestic waste water discharge of player 42

Greek symbols:

α	Coefficient of agriculture water consumption
β	Benefit coefficients, i.e. the values produced by consuming per unit of water
β_{11}	Benefit coefficient of player 11
β_{12}	Benefit coefficient of player 11
β_{13}	Benefit coefficient of player 13
γ_x	Cost coefficient of pollutant x
ℓ_{ij}	Loss rate of nitrogen
λ_{ij}	Transport rate of nitrogen into the river
μ	Coefficient of industrial and domestic waste water discharged into river
$\sum_{i=1}^2 u_i(s) = 0$	Two-person zero sum game
φ_{ij}	Maintaining rate of nitrogen finally in the reservoir
Ψ	Distribution factor of cooperative benefit
ψ_{1j}	Water distribution factor
Γ	Extensive game

Logical symbols:

\forall_i	For every player i
\equiv	Be defined as
\triangleq	Equal by definition

1. Introduction

Water resources are essential for the existence of human and all other species. From an economic point of view, water resources are composite assets which provide a variety of services for consumptive and productive activities. However, water quality degradation and water scarcity are two serious problems in developing countries. Due to temporally and spatially uneven distributed precipitation (Wetzel, 1983; Al Radif, 1999), exponentially increasing water consumption with increased population growth rate, degradation of water quality (UN-CSD, 1994), the loss of potential sources of freshwater resulting from unsustainable water resources management practices (Wang, 2005) as well as increasing temperature (Westmacott and Burn, 1997), water supply has been increasing scarcities in countries. It is estimated that in 2025, 5 billion out of the world's 7.9 billion people will be difficult or even impossible to meet basic water demand for drinking, cooking and sanitation (Leete et al., 2003; Wei and Gnauck, 2007c). Water resources management related to these problems usually involves multi-stakeholders with contradictory or conflicting interests (Wang et al., 2003; Fang et al., 1998, 2002; Hipel et al., 1997; van der Veeren and Tol, 2003), goals and strategies (Wei and Gnauck, 2007b).

Water property rights are difficult to define, and thus water market is not easy to establish in most countries. In the absence of exclusive property rights and market, conflicts between multi-stakeholders competing for water uses are unavoidable (Pethig, 1992). In this sense, the models of water resources management should resolve the conflicts involved. Game theory is a useful approach to model such conflicts, since it studies the strategies and equilibrium of multi-actors in interactive and interdependent situations.

This introduction chapter starts with presenting the principles and objectives of water resources management. It turns on interpreting some instruments used to solve water conflicts. The third part reviews literature on application of game theory in environmental and water resources management. The last part interprets the research objectives, methodology and structure of the thesis.

1.1 Objectives and principles of water resources management

In general, the main task of water resources management is to promote the coordinated water use in order to maximize economic, social and environmental welfares in equitable, efficient and sustainable manners. This task involves the objectives and principles of water resources management, which are summarized in table 1.1.

Table 1.1: Objectives and principles of water resources management (adapted from UNESCAP, 2000; Wang, 2005)

Objective	Principle	Outcome
Society	Equity	Provide for essential social needs: <ul style="list-style-type: none"> • Sufficient water for different users • Safe and affordable drinking water • Water for sanitation • Food security
Economics	Efficiency	Maximize economic value of water use: <ul style="list-style-type: none"> • Agricultural and industrial development • Power generation • Regional development • Local economies • Less pollutants discharge
Environment	Sustainability	Maintain environmental quality: <ul style="list-style-type: none"> • Maintain water quality • Support instream habitat and life • Aesthetic and natural values • Maintain hydrological cycle and environmental flow

Equity means fair distribution of water resources among different existing and potential water consumers within river basins, at the regional, national, and international levels. The water consumers include both human being and natural elements. Equity is not so easy to reach, because different people may have different perceptions. Notion of equity should be based on different cultures and norms. Equity usually includes interbasin water diversion, in which water policy makers usually transfer water from water-rich areas to water-scarce

areas. In this situation, the source areas of water transfers should be compensated for their water reduction or bad impacts resulting from water reduction.

Efficiency refers to economic use of water resources. It usually means to use less amount of water to produce higher value with less pollutants discharge. In order to achieve efficient water use, water might be diverted from the fields or areas with inefficient water use to efficient ones. For example, due to the low profit use of agriculture, policy makers usually decide to transfer water from agricultural irrigation to some industries in order to produce higher economic values. Due to the spatially uneven distribution of water resources, interbasin water transfer projects are usually undertaken in many countries in order to transfer water from water rich regions to the indigent regions, such as inter-basin water transfer projects in the United States, Canada, China and India. However, efficiency is not so easy to achieve, because water allocation to different users relates to the physical delivery or transport of water to the demanding points of use (Wang, 2005).

At the United Nations Conference on Environment and Development (UNCED) in 1992, the 'sustainable development' concept was endorsed as the guiding principle for economic development and environmental management. For water resources management, the principle of sustainability prompts the environmentally sound use of water resources. It usually interpreted that today's utilization of water resources should not expand to such an extent that it may not be usable for all of the time or some of the time in the future (Savenije and Van der Zaag, 2000). It is also interpreted as a concept aimed at using water to achieve both social and economic development while maintaining water quality.

During the last four decades an increasing interest for ecosystem theory has emerged as a consequence of our increasing concern for environment. Freshwater ecosystem is one of the important parts of environment. It provides places and energies for life, and it usually works as a receptor of waste produced by productive and consumptive activities of human being. However, freshwater ecosystem is a complex, in which abiotic and biotic organisms interact with their physical and chemical water environment and climatic conditions. The physical components are such as light, temperature, mixing, flow, habitat, etc., and chemical components organic and inorganic carbon, oxygen, and nutrients, etc. The physical and chemical components can indicate the lives and the structure of the food web (ANZECC and ARMCANZ, 2000) in the ecosystem. In the field of ecological economics, the concept of ecosystem goods and services has been developed. An ecosystem good or service is de-

defined as any natural phenomenon that has a perceived societal function or value (Daily, 1997). Ecosystem goods and services enhance human welfare and promote societal development (Costanza and Folke, 1996), and provide the basis for human existence (Dasgupta et al., 1994). With degradation of earth's ecosystem, the concept of healthy ecosystem and ecosystem medicine emerge in practice (Rapport et al., 1999).

Water quality and quantity are two vital points in water resources management. Jøneh-Clausen (2004) stressed that water scarcity and deteriorating water quality had or would become critical factors limiting national economic development, expansion of food production and/or provision of basic health and hygiene services to the population in an increasing number of countries. In the past, water quality management was regarded as "chemical water quality management" (Hohls, 1996), and water resources management was primarily based on the need of human being. With the development of ecosystem theory, the concept of ecosystem management has been widely adopted by water resource managers and policy makers. Water is a resource for all forms of life and their natural environment, but not only for human being. Hohls (1996) expressed that the uses and benefits that people obtain from water resources were dependent on ecosystem health. However, the ecosystem can be enhanced or weakened by human intervention. Without water of adequate quantity and quality, it is impossible for a healthy ecosystem and healthy human being. According to UNEP (2000), approximately 20% of the world's population lacks access to safe drinking water and about 50% has inadequate sanitation. By the year 2025, as many as two-thirds of the world population may be subject to moderate to high water stress (WMO, 1997). The effect on ecosystem health mainly comes from human activities. Wetzel (1983) argued that man, his use and misuse of freshwater are influential factors in maintenance of (lake) ecosystems. Therefore, human activities of destroying freshwater ecosystem should be firstly considered in water resources management.

1.2 Solving water conflicts

The problems of water quality degradation and water scarcity usually involve multi-stakeholders with contradictory interests, goals and strategies, which often result in water conflicts, such as the disputes between Arabs and Israelis, Indians and Bangladeshes, Americans and Mexicans, and among all 10 Nile basin coriparians (Wolf, 1999). In details, water conflicts are usually created by (1) multiple use of water quantity, such as different water demand and supply, (2) multi-stakeholders competing for scarce water, (3) different

degrees of upstream pollutions restricting the water use in downstream catchments, (4) Interbasin water transfer breaking the long-established balance of water quality and quantity in a basin. There are different instruments to solve these conflicts. General speaking, these instruments include the widely used economic instruments and direct regulation, and comparable newly developed game theoretic approach (Fig.1.1).

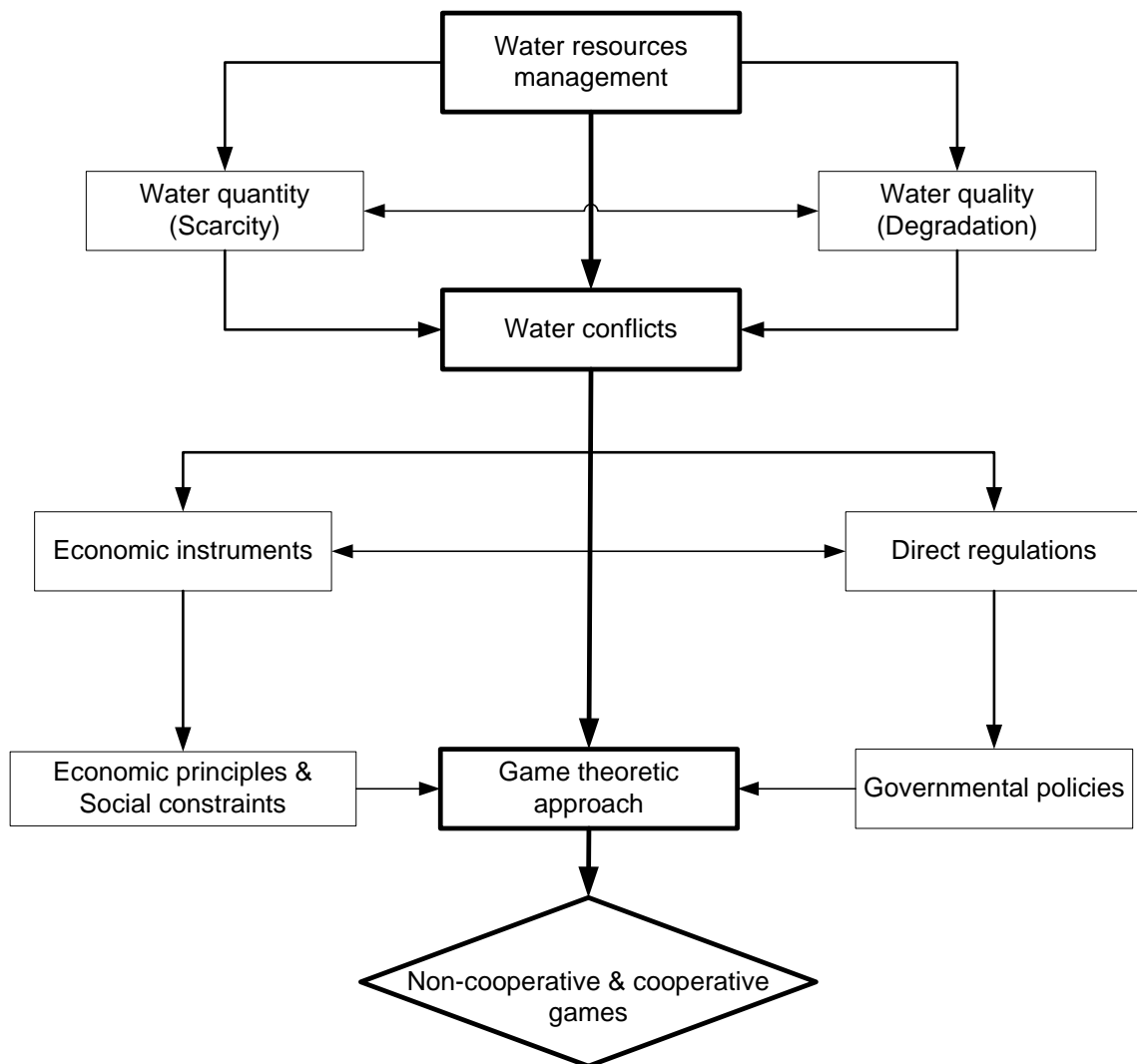


Figure 1.1: Instruments to solve water conflicts

Dinar et al. (1997) and Wang et al. (2003) analyzed four basic institutional mechanisms for water allocation, i.e. public allocation, user-based allocation, marginal cost pricing, and water market allocation. Bonnie and D'estree (2000) and Mostert (1998) presented four methods - litigation, market transactions, political deal-making and alternative dispute resolution techniques - to resolve water conflicts.

Public allocation refers to allocation by governments, which is the main approach used in most countries. This mechanism can allocate water fairly, but it has usually not addressed economic efficiency and often causes water waste and water mis-allocation. Marginal cost pricing means that a price is set on water to equal the marginal cost of using the last unit of that water. Dinar et al. (1997) pointed out that it was theoretically efficient, but it tends to neglect equity. In addition, it is difficult to define marginal cost itself (Saunders et al., 1977). User-based allocation mainly refers to that water users organize collective institutions with authority to make decisions. This method is very flexible and efficient to allocate water to meet users' requirement. However, Meinzen-Dick et al. (1997) argued that the institutions were not always powerful enough to allocate water efficiently.

Water markets approach is one frequently cited in the literature (Burness and Quirk, 1979; Howe et al., 1986; Colby, 1990; Green and O'Connor, 2001; Bhaduri and Barbier, 2003). On the one hand, water market methods can provide water users incentives to use water efficiently and reduce the pollutant discharge into water. Water markets really exist in some countries, such as Australia (Pigram et al., 1992), California (Howe and Goodman, 1995), Chile (Hearne and Easter, 1995), India (Saleth, 1996), and Spain (Reidinger, 1994), etc. However, on the other hand, it requires defining the original water rights, creating institutional and legal mechanisms, and establishing basic infrastructures for water trade (Holden and Thobani, 1996; Wang et al., 2003) before water market can operate well. Therefore, water market is a good theory, but it is hard to establish a real water market in most countries. Just as the argument of Dellapenna (2000) there were rare water markets in reality and they are not real free market.

However, besides alternative dispute resolution techniques, all other methods can be categorized into two classes, direct regulations and economic instruments (OECD, 1989; Markanya et al., 1993; Wei and Gnauck 2007b). Direct regulation is also known as the "command and control" strategies, and economic instruments make use of market mechanism and price incentives. Economic tools include water rights, water pricing, subsidies, compensation, tradable permits, and green taxations (Table 1.2). Carraro and Filar (1995) argued that environmental resource problems and its interrelationships with economic activities and the dynamic ecosystem were very complex and could not be solved with simple policy tools. Command and control strategies lack incentive, because it mainly in virtue of legislation, power or force. Wei and Gnauck (2007 b) stated that the existing economic and regulation instruments do not work so well in solving those conflicts.

Table 1.2: Policy instruments to solve water conflicts (adapted from OECD, 1989; Markanya et al., 1993; Wei and Gnauck 2007b)

Instrument	System	Terms
Economic instruments	Market mechanism	Redefining property rights, tradable permits; liability insurance registration.
	Tax/charge systems	Effluence charges, user charges, product charges and administrative charges.
	Subsidies	Financial aid in installing new technology; subsidies to environmental R & D expenditure
	Deposit-refund system	Combining charges and subsidies so as to provide incentives to return waste water for recycling
Direct regulations	Standards	Effluent, ambient and technology standards.
	Resources use quotas	Emission quotas, harvesting quotas; by allowing quotas to be traded among market agents, the quota system would be transformed to a system of tradable permits.

From a technical strategy point of view, multi-objective optimization models have been used early to maximize the overall benefit in order to solve transboundary water conflict in a river basin (Zeng et al., 2001; Yang and Zeng, 2004). However, on the one hand, simplified model is difficult to illustrate the complex relationships among different elements in a large system. On the other hand, the interests and benefits of different actors in the basin are neglected.

With development of society, the concept of considering the different interests and benefits of all the stakeholders are widely accepted in the world. Kaufman et al. (1997) and Yang and Zeng (2004) argued that the conflicts of different stakeholders in a river basin should be solved by negotiation based on their interests and benefits. The essence of negotiation-based resolution techniques for water conflicts is to look for a fair multi-beneficial solution in the existing situation.

In the absence of market and exclusive property rights, conflicts between the multi-stakeholders on competing uses over water are still unavoidable (Pethig, 1992; Wei and Gnauck, 2007c). Game theory can be an appropriate approach to simulate and resolve such conflicts. Comparing with those instruments, game theory is a newly developed approach. From negation point of view, game theoretic analyzing method is an efficient tool to support negotiation in the conflicts since it studies the interests and benefits of the stake-

holders. The disciplines involved in game theory mainly include mathematics, economics and the other social and behavioral sciences. In this sense, game theory works as a distinct and interdisciplinary approach and it needs support of other instruments. Furthermore, decomposition-coordination approach has been developed, which can provide technical methods to construct and solve big non-linear water resource management models (Chaubey, 1990; Cai et al., 2001).

1.3 Selected literature on game theory for water resources management

The literature of game-theory application in environment and water resources management is comparatively less, and such literature mostly has focused on transboundary pollution (Folmer and Hanley, 1998). Mäler's Acid Rain Game (1989) should be one of the earliest paper which attempts to apply game theory to analyse the acid rain and its spillover in Europe. Rules, Games, and Common-Pool resources (Ostrom et al., 1994) mainly deals with the dilemma of overexploitation of the common pool resources (CPR) - "the tragedy of the commons", and the different outcomes resulted from rules changes by using the analytical tools of non-cooperative game theory, institutional analysis and an empirical foundation. Besides, game theory has also been used to analyze the common resources management, such as Berkes (1989), Blaikie and Brookfield (1987), Blomquist (1992), Ostrom (1996). With the further research, some publications, specializing on game theoretical models of environmental and natural resource management, have come out. For examples, Control and Game-Theoretic Models of the Environment, by Carraro and Filar (1995), is a collection of some recent works on the application of dynamic game and control theory to the analysis of environmental and natural resources problems. Conflicts and Cooperation in Managing Environmental Resources by Pethig (1992) presented some application of recently developed game theoretical concepts to the international environmental conflicts and cooperation.

As for water resources management, game theory was early realized to "be applicable to the description of relations between organisms in the phase of evolution" (Warburton, 1967; Slobodkin and Rapoport, 1974). Lewandowski (1979) used a game-theoretic approach to model the behaviour of water users in a quality control problem, and he proposed a game-theoretic solution to different uses of a water system. At the beginning, practical solution of game-theoretical models are only for simple cases, i.e. two or three players

(Straškraba and Gnauck, 1985). Just as the argument of Straškraba and Gnauck (1985) that this theory will become applicable to the description of highly involved properties, game theory has experienced a great development in water management since 1980s. Game theory was originally applied into the cost distribution in joint water resource projects. Thus the methods of equally cost allocation have been developed, such as Minimum Core, Shapley value, Nash Bargaining Solution, etc. (Heany and Dickinson, 1982; Lejano and Davos, 1995). Later on many studies have been focused on application of game theory into water conflicts. The essence of the methods is to simulate behaviors of different actors by means of non-cooperative and cooperative games, and then the added values derived from cooperation are fairly allocated to different actors based on their interests (Tisdell and Harrison, 1992; Becker and Easter, 1995; Bielsa and Rosa., 2001). In general, so far game theory has been mainly applied to solve the following problems:

- (1) The cost distribution of joint water resource projects, i.e. waste water treatment and disposal facilities (Giglio and Wrightington, 1972; Dinar and Howitt, 1997), and water supply projects (Heany and Dickinson, 1982; Young et al., 1982; Driesen & Tijs, 1985; Dufournaud and Harrington, 1990, 1991; Dinar et al., 1992; Lejano & Davos, 1995; Lippai & Heaney, 2000);
- (2) Equitable allocation of waste loads to a common receiving medium (Kilgour et al., 1988; Okada and Mikami, 1992; Wei and Gnauck, 2007d);
- (3) Allocation of water rights (Tisdell and Harrison, 1992);
- (4) Water allocation (Rogers, 1969, 1993a, b; Tisdell and Harrison, 1992; Okada and Sakakibara, 1997; Wang et al., 2003; Wei and Gnauck, 2007 a, b);
- (5) Pollution of transboundary river, including inter-country river (van der Veeren and Tol, 2003) and intra-country river (Zeng and Yang, 2004; Yang and Zeng, 2004);
- (6) Analysis of water police making (Wang, 2005);
- (7) Water dispatch compensation to solve benefit conflict (Xiao et al., 2005).

So far most game theoretic models have not solved the water problems where there exist conflicts of both quality and quantity. In details, water quantity models have just considered how game theory is applicable to optimize water allocation in order to solve the conflicts of water insufficiency, but they have not considered the effect of water quality. Water quality models cannot be used to solve the optimal allocation water quantity, although some models have been applicable to the control of water pollutant amount based on the

assumptions of different hydrological frequency and runoff. There are only a few papers have applied game theory to deal with both water quality and quantity. For example, Yang and Zeng (2004) developed a practical transboundary and coordination models to solve water conflicts of both water scarcity and water pollution between transboundary regions in north China using a decomposition approach and game theory. However, the cost to pollution damage has been neglected in these models. Considering the facts that water quality and quantity affect each other and water quality and quantity conflicts are coexisting in most cases, this thesis develops new simulation models which combine both water quality and quantity. In addition, China is seeking new methods to solve water conflicts involved in the Hanjiang River Basins (HRB), and game theoretical modelling approach has not been applied into HRB case so far.

1.4 Research objectives, methodology, and structure of thesis

Generally speaking, the overall objective of this research is to develop a practical methodology and mechanism to promote the maximization of the public welfare in river basins from socio-economic and environmental perspectives by means of game theory. In details, this overall research objective includes the following main sub-objectives:

- 1) To analyze the conflicts and find solution to solve water conflicts both qualitatively and quantitatively;
- 2) To construct cooperative and non-cooperative game theoretic models for water resources management of any river basin;
- 3) To analyze why the players do as they do in a given situation;
- 4) To help players use the best way, i.e. strategy to play a 'game' better;
- 5) To apply cooperative and non-cooperative game approaches to simulate and resolve conflicts or problems of water resources management of the Hanjiang River Basin in China; and
- 6) To find out how the Middle Route of South to North Water Transfer (MRSNWT) projects influence the industry, domestic life and agriculture of the Hanjiang River Basin;
- 7) To allocate water and protect water from pollution in efficient, fair and sustainable ways;
- 8) To facilitate a stronger comparison of the different groups of water users (including environment) in developed and undeveloped urban and rural areas;

- 9) To help water policy makers and water managers solve water conflicts and make decisions on important water management issues.

Both qualitative and quantitative analyses methods are included in this research on the application of game theory into water resources management. Figure 1.2 shows the general technical route of the research.

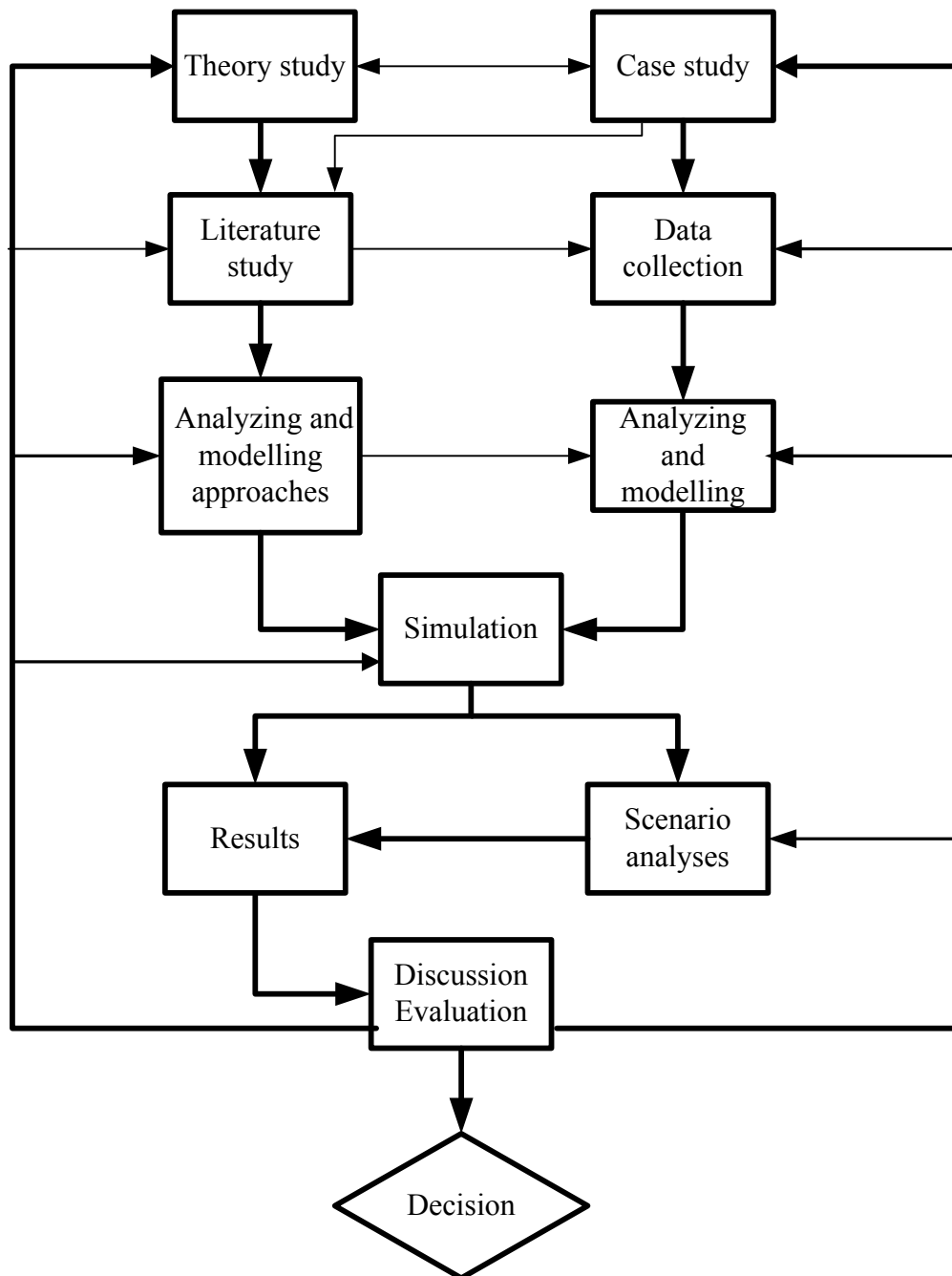


Figure 1.2: Sketch of technical route of the research

This route can be divided into two parts: theory study and case study. Theory study mainly includes the study of game theory and water resources management. Case study refers to

the application of game theory in water conflicts involved in the Hanjiang River Basin in China. The tasks of the first part mainly include literature study on analyzing and modeling approaches. The tasks of the second part mainly include data collection, analyzing and modeling the case. Based on the theory and modeling approaches, water conflicts are modeled and simulated as games. Different scenarios are designed to analyze the risks and uncertainties in the game simulations.

Water conflicts only include the conflicts concerning water quality and quantity in this thesis. Water conflicts are modelled and simulated as a game or a set of games so that the problem can be analyzed and solved in the framework of game theory. Non-cooperative and cooperative game methods are used separately to model and simulate the water conflict (real or potential). Non-cooperative modelling approach is used to find out what the real utility of different players, and cooperative game modelling is to get the best solution. The main aim of studying non-cooperative game is to find the best solutions for cooperation. The game theoretical modelling and simulating process consist of defining the conflicts, formulating these conflicts as games, solving the games, interpreting the results as well as scenarios analyses.

In order to formulate the payoff functions of the players, statistical and econometric regression methods are used. In detail, regression models (linear regression, semilog regression, double-log regression, polynomial regression and vector auto-regression) are used to establish population models, models of added values, water demands, and pollutants discharge of industry, household and agriculture. From each model set, the best model is selected based on statistical and econometric tests and practical test. In order to account for serial correlation, Autoregressive (AR) and/or Moving average (MA) terms are included in the some equations of the models. The models are evaluated by forecasting and scenarios analyses. Empirical survivor is used to model the different probabilities of water supply, and 20%, 50%, 75% and 95% hydrological years refer to wet years, normal years, moderate dry years and high dry years, respectively. In order to model the agriculture added values and nitrogen fertilizer consumptions, balanced panel data and its related modelling approaches are used. For water annual flows of the Danjiangkou reservoir, the method of frequency filter of full sample asymmetric is used to establish the model of the water annual flows.

Demand-supply principle (DSP), cost-benefit analysis (CBA) and economic valuation methods (EVMs) are applied to compare the outcomes and results of the game modeling. EVMs are also to estimate of benefit and loss in monetary term. Wei (2005) presented various different economic valuation methods, which are commonly used in environmental economics. EVMs included in this research are shadow engineering method (SEM), market value method (MVM), opportunity cost or benefits method (OCM/OBM) and the replacement cost approach (RCA). For nitrogen pollutant reduction game, the forward and backward algorithms are used for calculating the discharge and reduction amount of nitrogen pollutants in the Danjiangkou Reservoir. Scenarios analyses are also applied to analyses the risks and uncertainty in the future. Based on the developing characteristics of the input parameters and constrains, the baseline scenario is given at first. The baseline scenario is the business as usually scenario, i.e. the trend analyses of input variables in the future according to their past and current developing characteristics. Another three scenarios are designed based upon the baseline.

Data in the studied area are collected mainly from the following sources:

- Different monitoring stations and numerous controlling sections along the Hanjiang River and its tributaries,
- Database of the Changjiang Water Resource Protection Institute (DB-CWRPI),
- Online Database of National Bureau of Statistics of China (DB-NBSC),
- Chinese statistic yearbooks in related fields at different administration levels,
- Official reports and planning documents,
- Previous studies,
- Other local online information systems and data resources concerning the Hanjiang River Basin, MRWT projects, and their related administrative regions at different levels.

The main types of data include climatological and hydrological data (1986-2005), water quality data (1995-2004) and socio-economic data (1978-2005). Climatological and hydrological data include such as precipitation, amount of water resources (surface water and underground water), water flows, water levels and water velocity. Water quality data include pollutants concentrations, point pollution sources (industrial waste discharge and urban domestic waste water discharge) and non-point pollution sources (agricultural fertilizer consumptions, soil erosions, rural domestics and animal husbandry). Those socio-

economic data mainly include urban and rural population, water supply and water demand, added values of industry and agriculture per capita net incomes.

Based on these basic situations, theories, methodology, and objectives, this thesis was written, which is composed of 5 chapters. It starts with an introduction chapter presenting background of water resources management. In this chapter, the first section interprets the principles and objectives of water resources management. The second section presents the methods to solve water conflicts. Then it turns on to review the selected literatures on game theory for water resources management in the third section. The last section interprets the research objectives, methodology and structure of the thesis. Chapter 2 interprets game theory and water resources management, which mainly deals with the methods of game theory. In this chapter, it begins with presenting game theory and the general principles of the theory. Section 2 presents game theoretical models, which mainly interprets non-cooperative cooperative games, strategic (or normal) games and extensive games as well as some special game models widely used in literature. Section 3 illustrates game theoretic approach for water resources management, and it mainly includes the game types of water resources management and methods to construct game models to solve conflicts. Section 4 and 5 are the main sections of this chapter, in which non-cooperative and cooperative game models are constructed for water resources management at scale of a river basin, and the data are required for those models. The third chapter is the case study, and it demonstrates how the game theoretic models are applied to solve the water conflicts involved in the Hanjiang River Basin in China. This chapter firstly presents the water quantity and quality situations of the Hanjiang River, conflicts and games involved in the basin, game models for water conflicts in the basin, the game simulations process, simulation evaluation as well as the design of four scenarios. In the fourth chapter the simulation and scenario results are presented and discussed. The fifth chapter summarizes the thesis, discusses the limitation of the thesis and proposes the future research on game theory.

2. Game theory and water resources management

A game exists in the situation where the actions of actors (individuals or groups) are interacting and interdependent and the choices of all actors affect the outcome (Scharpf, 1997). A model is an abstraction of the real world system. It is not the real world but merely constructed to help us better analyze and understand the real world. Game theory is a set of analytical tools designed to model interactive or interdependent situations, in which the rational behavior of one player affects not only his or her own gains and losses, but also those of others. Water resources management involves conflicts between interacting multi-stakeholders. Therefore, game theory is appropriate to model these water conflicts. However, the questions are how to translate these problems into game models, and how these models work to analyze and solve the problems. This chapter illustrates the theory of game, general principles of game theory, game theoretical models, methods to establish game models for water resources management, cooperative and non-cooperative game theoretic models for river basin management, as well as the data (or information) used for game models.

2.1 Theory of games

Game theory was launched by John von Neumann, a great mathematician, and Oskar Morgenstern in 1944. Game theoretical modelling concepts and reasoning have been widely applied in economic, commercial, social, political, biological, and many other sciences to help people analyze and understand social and behavioural phenomena.

A game is a metaphor of the rational behaviors of multi-actors in an interacting or interdependent situation, such as cooperating or coalition, conflicting, competing, coexisting, etc. (Wei and Gnauck, 2007 b). An actor may be a country, a region, a group, an individual, organism, abiotic and biotic constituents or even nature proper. The essence of this theory is to analyze the interaction of one with others, to study the strategies and equilibrium of the actors as well as how they can do better.

A game is defined as follows:

$$G_T \triangleq \langle N, A, P, I, O, E \rangle \quad (2.1)$$

where:

- G_T – a game. It includes mainly two forms: Strategic (or Normal) games, denoted by G , and Extensive games by Γ ;
- N – set of players. $N = \{1, 2, \dots, n\}$ is a finite set. Every player is denoted by i ; the other $n - 1$ players or i 's opponents in some senses, denoted by $-i$; $\forall i, -i \in N$;
- A – the profile of action (or move) of the players. An action by player i is a variable of his decision, which is denoted by a_i . The set of $A_i = \{a_i\}$ is player i 's action set, i.e. the entire set of actions available to him. The ordered set $a_i = \{a_i\}, i \in \{1, 2, \dots, n\}$, is an action combination for each of the n players in a game. In the action set, S is the strategy set (called strategies space) of the players. Strategy is the rule to choose actions. Player i 's strategy space, denoted by S_i is the set of all the strategies which player i can choose from;
- P – payoff (or utility). A payoff is the value of the outcome to the players. It refers to both actual payoff and expected payoff. Payoffs are based on benefits and costs of actions and outcomes of each player. $u_i(s_i, s_{-i})$ means player i 's payoff function, which is determined by the strategies chosen by himself and the other players;
- I – information set. It is players' knowledge about another player, such as the characteristics, action profile, and payoff function in the game. If the payoff function of every player is a common knowledge among all the players, then it is complete information. Otherwise, it is called incomplete information. If the information is complete and perfect, it means that the players know well the former process of the game before he chooses his next move at each step. If the player who will choose his next move does not know the prior processing of the game at some steps, it is called complete but not perfect information;
- O – outcomes of the game. An outcome is a strategy profile resulting from the action/moves combination chosen by all the players at the end of a game;
- E – equilibrium or equilibria. In the equilibrium, each of the players can maximize his payoff. $s^* = \{s_1^*, s_2^*, \dots, s_n^*\}$ is a best strategy combination of the n players. For

player i , s_i^* is player i 's best response to the strategies specified for the $n-1$ other players, i.e. $u_i\{s_i^*, -s_i^*\} \geq u_i\{s_i, -s_i^*\}$.

Generally speaking, the elements of game theory includes N - Players, A - Action (Moves), P - Payoff (or Utility), I - Information, O - Outcome and E - Equilibrium i.e. NAPI-OE. NAPI are collectively known as the rules of a game and OE are the game results. The main task of constructing a game model is to define the rules (NAPI) in mathematic language and get the solution from OE. The detailed game theory can be referred to Friedman (1991), Gibbons (1992), Kreps (1993), Straffin (1993), Gardner (1995), Fudenberg and Tirole (1996), Stahl (1999), Osborne (2000), Gintis (2000), etc.

Every player has different strategies. However, the optimal strategy for an individual player is to maximize his benefits by using the game rules; and the optimal strategy for the player of a society as whole is to maximize the common welfare of the society through the rules. Game theory models involve the following conditions and assumptions:

- 1) Players in the game models are regarded as "intelligent and rational". Rational payer means that each player will choose an action or strategy which can maximize his expected utility given he thinks what action other players will choose. Intelligent player means that each player understands the situation, and he knows the fact that others are intelligent and rational;
- 2) Each player considers not only his own knowledge and behaviour but also others' during pursuing exogenous aims;
- 3) Each player has more than one choice or sequence ("plays");
- 4) All possible combinations of choices or plays result in a well-defined outcome: win or lose, or mutual gains and losses;
- 5) The players know the rules of the game and the options of other players, but they do not know the real decisions of other players in advance. Therefore, every player has to choose options based on his assumption of what other player will choose;
- 6) Each player knows that his actions can affect the others, and the actions of others affect him;
- 7) Each player makes the best possible move, and he knows that his opponent is also making the best possible move.

2.2 Game theoretical models

Game theoretical modelling is beginning to become an indispensable approach to analyze, understand, and solve many water problems in today's world. Like other sciences, game theory itself is comprised of a collection of models. There are different methods to classify these models. In general, they are summarized as follows:

- binding agreements: non-cooperative and cooperative games;
- numbers of players: single player game (decision problem), two-persons game and multi-persons game;
- order of actions (moves): static and dynamic games;
- elements of actions (moves) set: finite and infinite games;
- sum of payoffs: zero-sum and non-zero sum games;
- information set: complete information and incomplete information games;
- numbers of the same play in a game: one-shot game and repeated game.

2.2.1 Cooperative and non-cooperative models

Game theoretical models are usually divided broadly into two branches, either non-cooperative game or cooperative game. It does not mean that these two branches are applied to analyze different kinds of games, but they are just two ways to view the same game (Chwe 1994, Hart and Mas-Colell 1997, Aumann 1997, Gibbon 1996, Zhang 1996).

(I) Non-cooperative game

Non-cooperative game can be defined from the following aspects:

- modelling the situation of lacking binding agreements;
- what actions (moves) that players can take;
- how players interact with each other to maximize individual welfares;
- solutions concepts: Nash equilibrium, sub-game perfect Nash Equilibrium, Bayesian Nash Equilibrium and perfect Bayesian (sequential) Equilibrium;
- mainly stressing individual rationality, individual optimal strategies and payoff;
- the results may be efficient and may be not.

(II) Cooperative game

Cooperative game can be defined by:

- modelling the situation of binding agreements;

- what coalitions forms that players can use to maximize the collective welfare of all the players;
- how the available total value split in a satisfactory way;
- most popular solution concepts: the stable set, equity-based rule, the core Shapley value as well as Nash bargaining solution;
- Stressing mainly collective rationality, efficiency and fairness;
- the results are usually social optimum.

In summary, the non-cooperative and cooperative game theories are like the positive and normative approaches that economists use. In economics, the positive approach describes what the real world is, and it usually deals with analyzing and prediction. However, normative approach deals with what the world should be, and it focuses on studies the methods to change the world. With reference to non-cooperative and cooperative game theories, non-cooperative game theory is strategy oriented and it studies what players expect to do and how they do it. Cooperative game theory studies what the players can achieve and how they can achieve it.

2.2.2 Strategic and extensive game theoretical models

Generally speaking, non-cooperative game models can be divided into two kinds, namely strategic (or normal) games and extensive games.

(1) Strategic games

A strategic game (or normal game) is defined as follows:

$$G \triangleq \langle N, (S_i), (u_i) \rangle \quad (2.2)$$

where $N = \{1, 2, \dots, n\}$ is the set of players, $(S_i) = \{S_1, S_2, \dots, S_n\}$, S_i is the strategies profile of player i , $(u_i) = (u_1, u_2, \dots, u_n)$ is the payoff function of player i .

Strategic (or normal) games are usually applied to model the static (or simultaneous-move) games in which every player chooses a strategy simultaneously. The strategy profile of all the players determines the payoff of every player. Static games can be either with complete information or with incomplete information. Simultaneous choice does not mean that one player chooses the strategy with other players at the same time, but it just means that a player does not know the choice of the others. The simple model of a strategic game is a two-person game, which can be constructed as a bi-matrix.

- Who plays in the game?
- When do they play?
- What can they do?
- What do they know?
- What are the payoffs?
- What can the nature do?

An extensive game is usually used to model dynamic (or sequential) games with complete information or incomplete information. The extensive form is a special method to illustrate a game of sequential moves (Fig. 2.1). In this game, there are three players and each player has two strategies. Player 1 moves first, and then player 2 moves after he sees the moves of player 1. And then player 3 chooses his moves after he sees prior moves of player 1 and 2. The numbers in parentheses on the right side are the payoffs of the players, and the first one belongs to player 1 and the second and the third player 2 and player 3 respectively. A dynamic game with complete information probably includes more Nash equilibria, but some of them include the unbelievable actions and threatening. Sub-game perfect Nash equilibrium is a proved equilibrium which deletes such action and threatening.

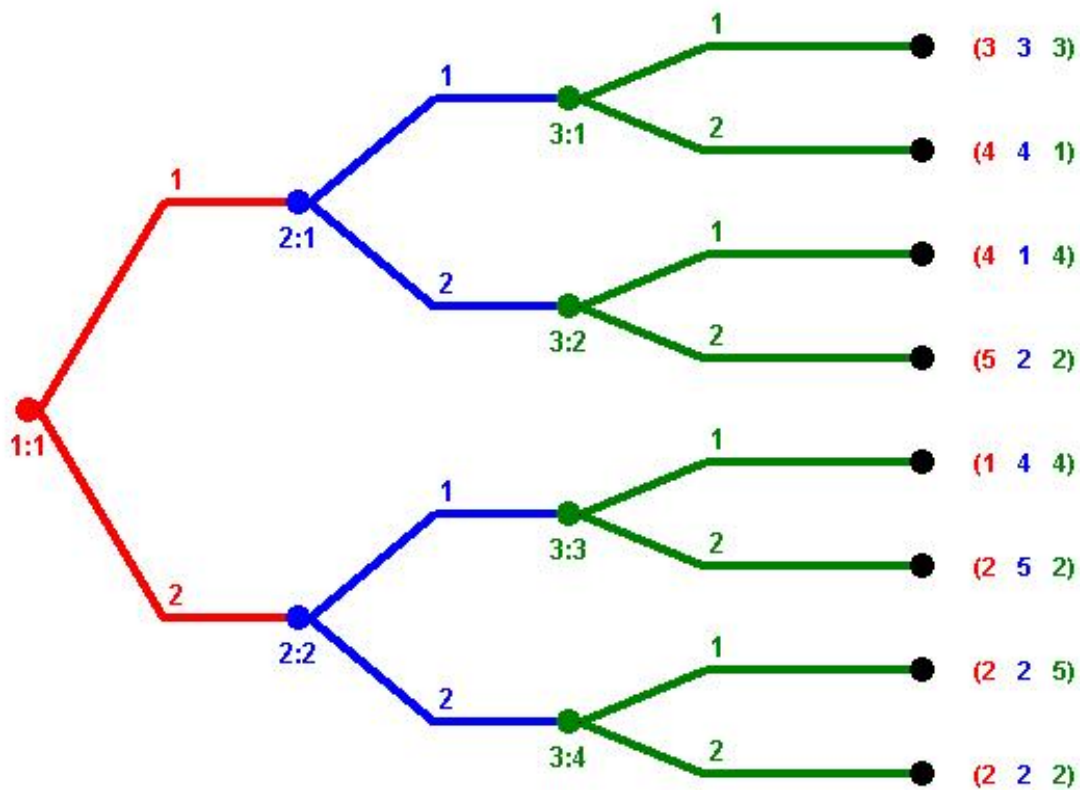


Figure 2.1: A game tree used to illustrate dynamic games with three players

2.2.3 Special game models

Some games have been widely used to model, analyze and illustrate problems of environmental and natural resources. Due to their importance, they are discussed separately in this sector.

(1) Two-person zero sum game model

In the 2-person zero sum game, another will lose if one win and the sum of their payoffs is always zero, i.e. $\sum_{i=1}^2 \mu_i(s) = 0$. Such game can be expressed as matrix $A = [a_{ij}]$. Because the payoffs of player j are opposite to player i , it usually just lists the payoffs of player i . This game is also called “strictly competitive” game due to the diametrically opposed interests of the players. The two-person zero sum game can be used to model a situation in which the multi-actors have contradictory interests or benefits, such as different water users in water scarcity areas.

$$A = \begin{pmatrix} a & -b & c \\ -a & b & -c \\ -c & a & -b \end{pmatrix}$$

(2) Prisoner’s dilemma game model

The second well-known game is the game of Prisoner’s Dilemma. This game models a situation in which there are gains from cooperation but each player has an incentive to “free ride” whatever the other player does. A 2-person game of prisoner’s dilemma (Fig. 2.2) is to model the collective decision-making situations where non-cooperation is always the dominant strategy of every player, regardless of the other player’s strategy (Scharpf 1997).

$$\begin{array}{ccc} & \rightarrow & \\ \downarrow & \left[\begin{array}{cc} (4,4) & (1,5) \\ (5,1) & (3,*3) \end{array} \right] & \downarrow \\ & \rightarrow & \end{array}$$

Figure 2.2: Game of prisoners’ dilemma

The model is a very useful tool to analyze the conflicts between individual rationality and collective rationality (Ostrom et al. 1994). The individual optimal strategy leads to a sub-

optimal equilibrium outcome for all players, because there is at least another one outcome which can make players better off. For every player in such situation, cooperation involves risk and uncertainty. Every player will risk the lowest payoff if others defect. A number of other situations have been illustrated by the model of Prisoner’s Dilemma game, such as overusing public goods and common resources. The way of solving the dilemma is to design a mechanism to change the rules, which can drive the players to reach collective rationality.

(3) The chicken game model

The chicken game is usually used to model the situation in which one player occupy one resource and others would like to take up other resource. In this game, there are usually multiple equilibria, players have no dominant strategy. (Fig. 2.3).

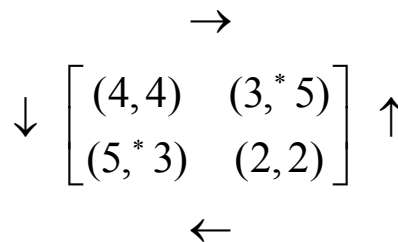


Figure 2.3: Chicken game

(4) Assurance game model

The assurance game also has multiple equilibria. (Fig. 2.4) One player’s contribution is not sufficient to gain a collective benefit but two players’s contributions can produce a joint benefit.

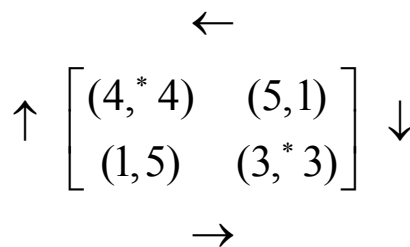


Figure 2.4: Assurance game

In this game, players have no dominant strategies, and the strategies depend on the expectations of others. There are usually an incentive for other players to cooperate if one player cooperates. Reversely, if one player does not cooperate, the others have an incentive not to cooperate. In this game structure, the risk and uncertainty still exist. Maybe one would like to cooperate during period of time, but he will not cooperate during another

period of time. In a multi-person assurance problem, Runge (1992) shows that the highest benefits can be achieved when everyone cooperates, but beneficial outcomes for the group can also be achieved when a critical mass cooperates.

(5) Driving force game model

Given that the risk and uncertainty in assurance game can be removed by external or internal driving forces, then a more optimal outcome will be formed. The driving forces usually refer to something like laws, regulations, contracts and other binding agreement. In contract with those legislation methods, economic methods such as tax, fine, compensation and so on, are also such kinds of driving forces. The players have the incentive to choose cooperation due to external or internal driving forces. In this sense, the game is called driving force game (Fig.2.5).

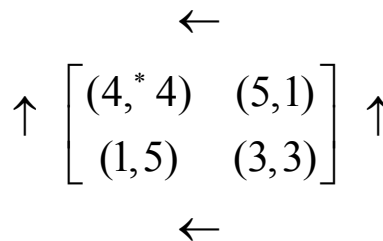


Figure 2.5: Driving force game

(6) Transforms of games models

The methods to solve the dilemma are to design a mechanism, which can change the rules and drive the players to reach collective rationality by cooperating with each other (Wei and Gnauck 2007d). Cooperation may be self-organized through negotiations or it may be formed due to driving forces. Players might design binding rules in an effort to discourage non-cooperative behaviors completely. They do so because they are aware that repeated cooperation is ultimately much better than the defection outcome in the prisoners’ dilemma game. Furthermore, the assurance will be transferred into driving force game if the driving forces provide more detailed information on players’ behaviors, high sanctions is imposed on non-cooperative behaviors, and/or high subsidize is awarded to the cooperative players.

Fig. 2.6 show transforms of games of prisoners’ dilemma, chicken, assurance and driving forces. In the payoff matrix, the game is Prisoners’ Dilemma game if it meets the condition of $a > d$, $d > b$ and $c > a$. If the condition is $a < c$ and $b > d$, then the game is a chicken game. If the condition is $a > c$ and $b > d$, the game becomes an assurance game. If

the condition is $a > d$, $b > d$ and $a > c$, the game is changed into driving force game.

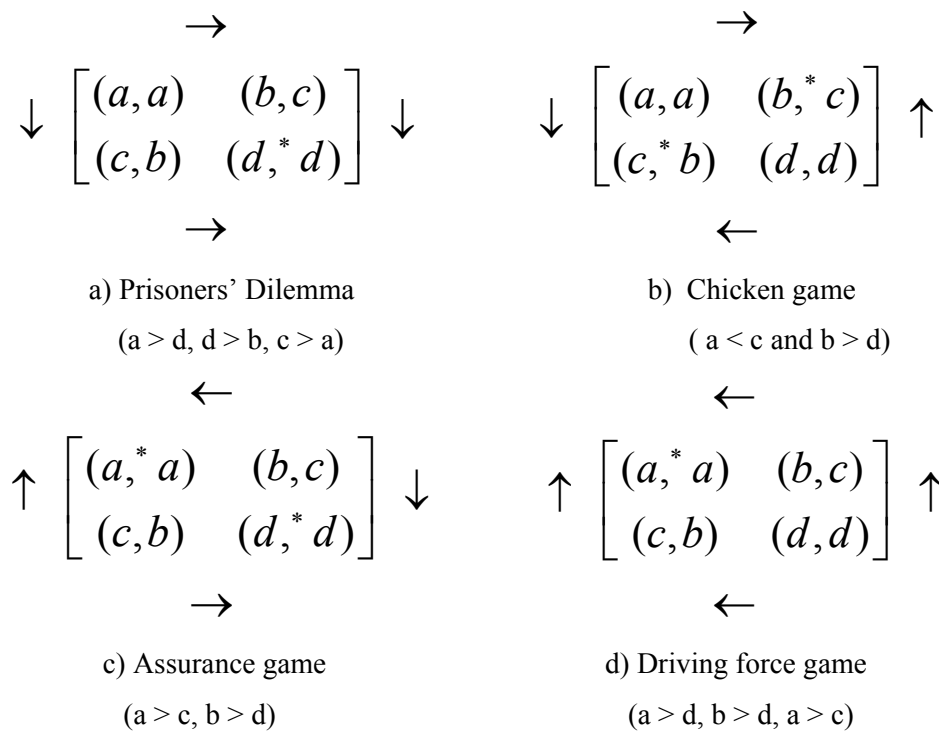


Figure 2.6: Transforms among the models of prisoners' dilemma game, chicken game, assurance game and driving force game

2.3 Game theoretic approach for water resources management

Game theory began as applied mathematics and microeconomic theory, but it serves here as a modelling approach to manage water resources. The questions arose in the game modelling of water resources management are as follows:

- (1) What kind(s) of game (games) can water resources management be modelled as? In other words, what kind(s) of game (games) is (are) involved in water resources management? Can the rational choices of multi-stakeholders be translated into a mathematical or/and economic problems? Can the rational outcome be as the "solution" to the game?
- (2) How to translate a case of water resources management into a game in mathematic or/and economic language? In details, what is (are) the player(s)? What are the strategies available to each player? What is payoff that each player can obtain from the combination of strategies chosen by the players? what methods can be used to solve for the Nash Equilibria of strategies?

- (3) What is the strategy space? In which condition does a player use pure strategies or mixed strategies? How to choose dominated strategy (strategies)?
- (4) What does it mean complete and incomplete information in the games of water resources management? What uncertainties or risks are there in a game of water resources management? How to predict them?
- (5) How to value the problems and benefits in payoff terms? How to value the payoff and make right decisions? If the game is cooperative one, how to divide the joint payoff?

2.3.1 Types of games

From the game theoretical point of view, there are full of games in human society and nature. Figure 2.7 shows the nature and human society from a game point of view, and each interacting and interdependent groups or/and individuals can be modelled as game(s). For examples, the game can be between human and rain, rivers, lakes and animals, and between animals and animals, plants and plants, animals, plants and their habitats, and so on.

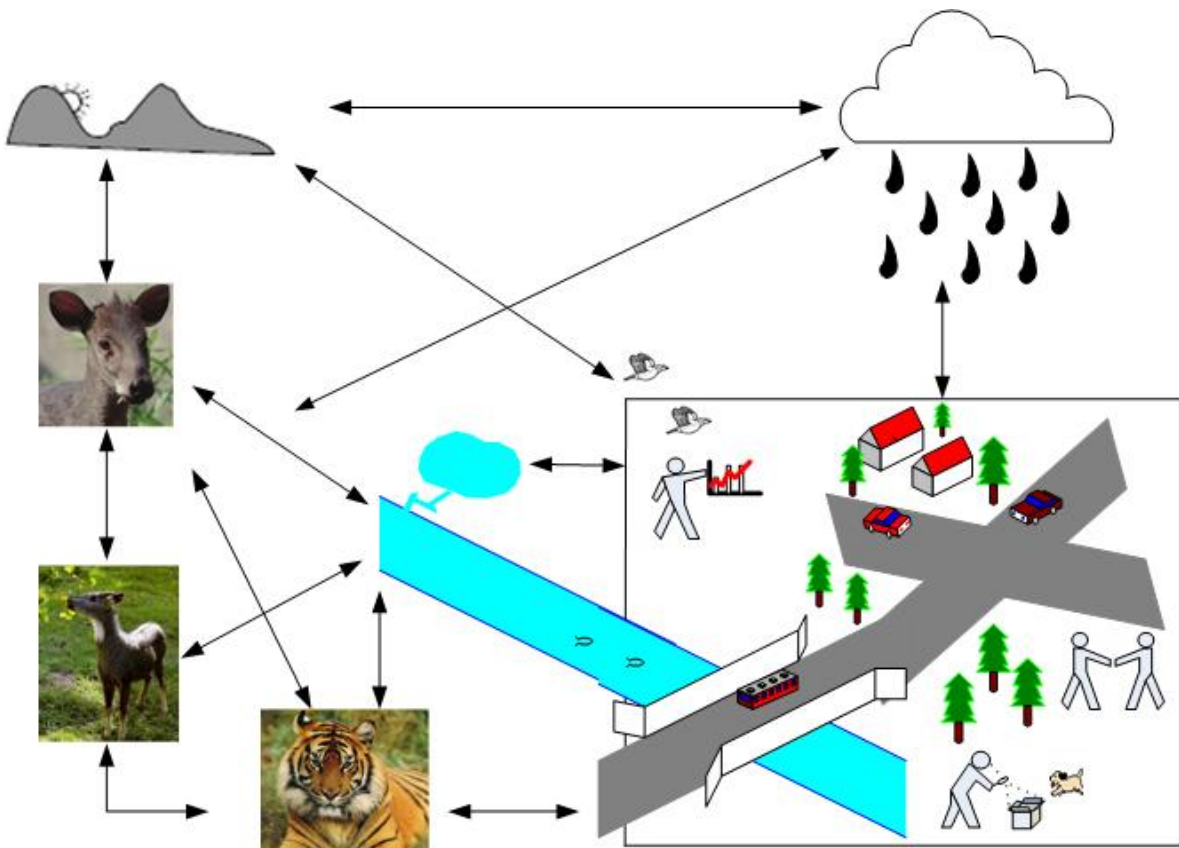


Figure 2.7: Nature and human society from a game theoretical perspective

Vrieze (1995) classified environmental games in two ways: society's game and game of exhaustion, and Kelly (2003) classified into games of skill, games of chance and games of strategy. In this study, the games involved in water or other nature resources management is classified into the following three kinds:

- 1) HH-G: Human and human games, the games played among human beings, including different countries, world regions, or areas within regions;
- 2) HN-G: Human and nature games, the games played between human beings and the nature;
- 3) NN-G: Nature and nature games, the games in nature itself.

In definition, HH games are similar with society's game and games of strategy, and HN games are similar with game of exhaustion and the combination of games of chance and games of skill. HN game is a close relative of decision theory. Parson and Wooldridge (2002) stated that decision theory can be considered to be the study of games against nature, where nature acts randomly. In the literature of game theory, the nature usually is regarded as pseudo player entering the game (Zhang 1996, Rasmusen 2001). Some people maybe do not believe that the nature can be players because they cannot move. However, there are so many examples to show that the nature really moves and strict back when human use it improperly, such as pollution, greenhouse effect and so on. If so, the question is what their strategies and payoffs are since they are players. For the NN games, there are very few studies comparing with the former two kinds. Smith (1982) analyzed the NN games in his book *Evolution and Theory of Games*.

2.3.2 A game theoretical approach to solve conflicts

The question is how to construct a game model. Figure 2.8 shows the process of using game theoretical approach to solve conflicts. Generally speaking, the process of game theoretical modeling approach can be divided into four steps:

Step 1: Defining the game

- Defining the players
- Defining their payoff functions
- Defining their moves (strategies)
- Defining information set

Step 2: Setting up game models

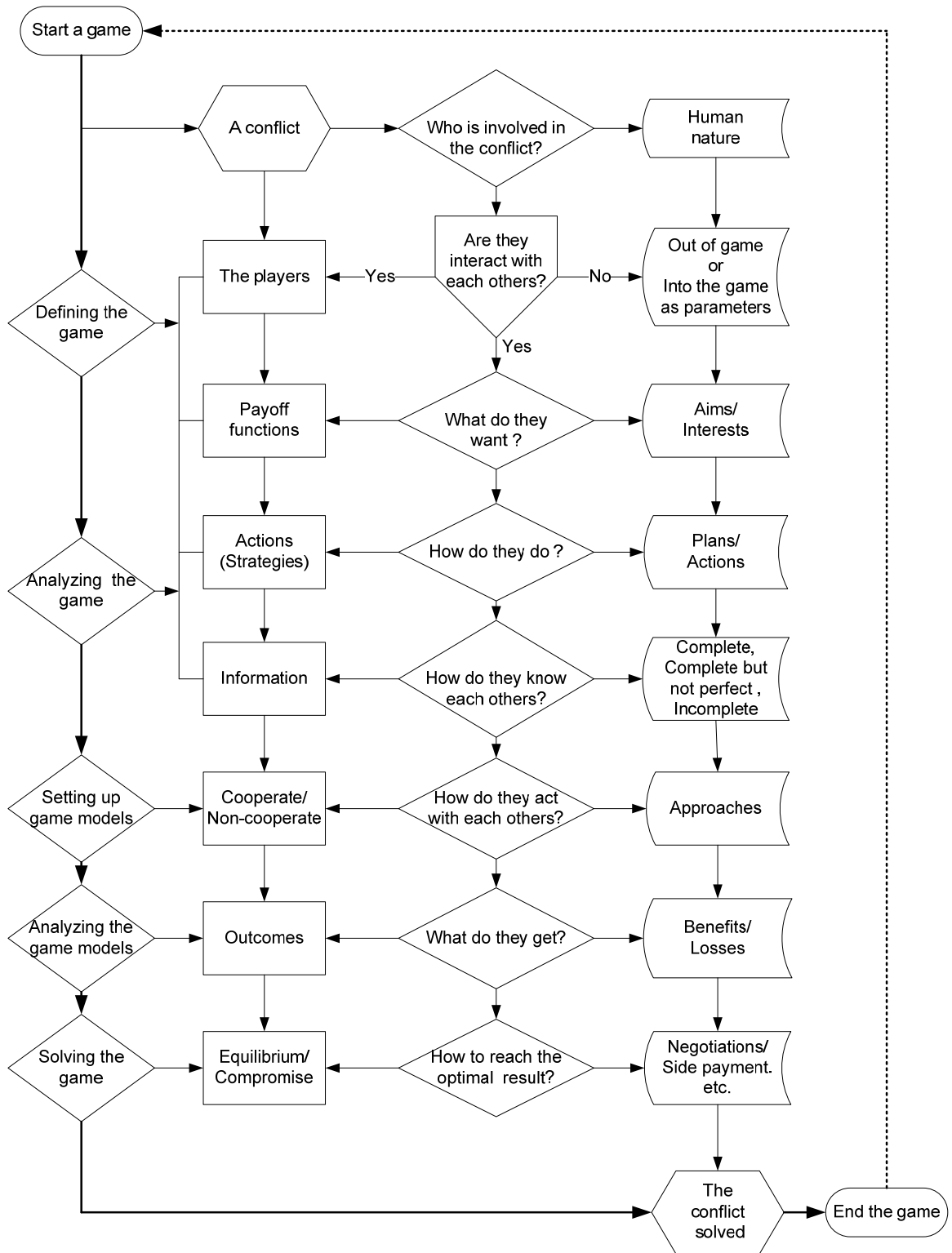


Figure 2.8: General flow chart of game theoretic approach to solve conflicts

- Non-cooperative game models
- Cooperative game models

Step 3: Analyzing the game models

- Getting the possible game outcomes

- Comparing these outcomes

Step 4: Solving the game

- Getting the equilibrium of non-cooperative games
- Getting the compromise point to share the benefit obtained from cooperative games.

This flow can be shortly summarized into the following questions:

- 1) Who involves in the conflict?
- 2) What are their actions (strategies)?
- 3) How to form the payoff function of each player?
- 4) How does every player know the payoff function of others?
- 5) Is the game one-time game, continuous game, finite game or infinite one?
- 6) How to compute the equilibrium/equilibria of the game(s) in the case of a non-cooperative game?
- 7) Is every player better off if he cooperate with others?
- 8) How to distribute the net benefit derived from cooperative games among the players?

2.4 Game theoretic methods to solve water conflicts in a river basin

Within a river basin, various factors, including hydrological, geochemical, biological or socio-economic (and even political and cultural) factors, constitute an integrated system or a web of interlinkage related with water quality and quantity. In this sense, the sources of water pollutants and the quantity of water allocation can be clearly defined only when an integrated river basin is considered. McKinney et al. (1999) expressed that a river basin is a rational and suitable water resources modeling and management unit. Jønch-Clausen (2004) also argued that a water basin is the basic planning and management unit. Analyses and discussions of water allocation between user and ecosystem need make sense only when addressed at the basin level. Almost half of the world's land area is situated in transboundary river basins (Jønch-Clausen, 2004). In a transboundary river basin, the conflicts, resulting from water quality and quantity, are common but even more complex. Chen (2003) argued that the nature of river system is an integrated system, but has been managed by many isolated units. The cross-sector and cross-boundary conflicts are the main problems in river basin management due to this isolated management.

2.4.1 Cooperative and non-cooperative games in a river basin

People in the areas of upriver, middle river and lower river usually have different interests, benefits and development planning and living standards. Developed regions try to maintain their welfares, and the developing and underdeveloped regions plan to accelerate the economic development in order to raise their living standard. A particularly serious feature of water and other environmental problems is that the private incentive of individual agency prevents the collective and whole society from achieving outcomes which can make every one better-off (Barrett, 1992). Furthermore, different regions usually have different views about the environmental problem and their obligation of causing and reducing the problems, because of their benefits and interests. In a river basin, different stakeholders and water constitutes forms very different games, non-cooperative, cooperative or partially cooperative. These games can be defined by the types of activities, or fields. In this ways, games involved in a river basin can be classified into: industry, agriculture, domestic life and nature (ecology). Another method to defined games is by the regions in which activities take place. Then the games are played between different administrative regions. According to the roles of different players in society, there are games between governments at different administrative levels, between governments and local people, between different economic bodies and governments, between these economic bodies and local people.

2.4.2 A strategy for water resources management using game theory

For water resources management using game theory on a river basin scale, it mainly includes the following three important steps (Fig. 2.10). The first important step is to decompose the river system and define the conflicting areas and/or bodies. Some of the conflicting bodies will be defined as players according to the game model flow presented in section 2.3.1. After the players are defined, their moves (or action) and strategies, their information set, their payoff function can be defined.

The second step is to define how each player to optimize water quantity in order to maximize his payoff. Rather, this step includes the socio-macroeconomic predictions (such as population, GDP, output values of agriculture and industry and the net incomes of household), predictions of water supply and water demand of different players, predictions of waste water and pollutants discarded by different players, as well as the cost of each player invest to treat his sewage. Step 2 is the benefiting process in which each player usually maximizes the output values per unit water.

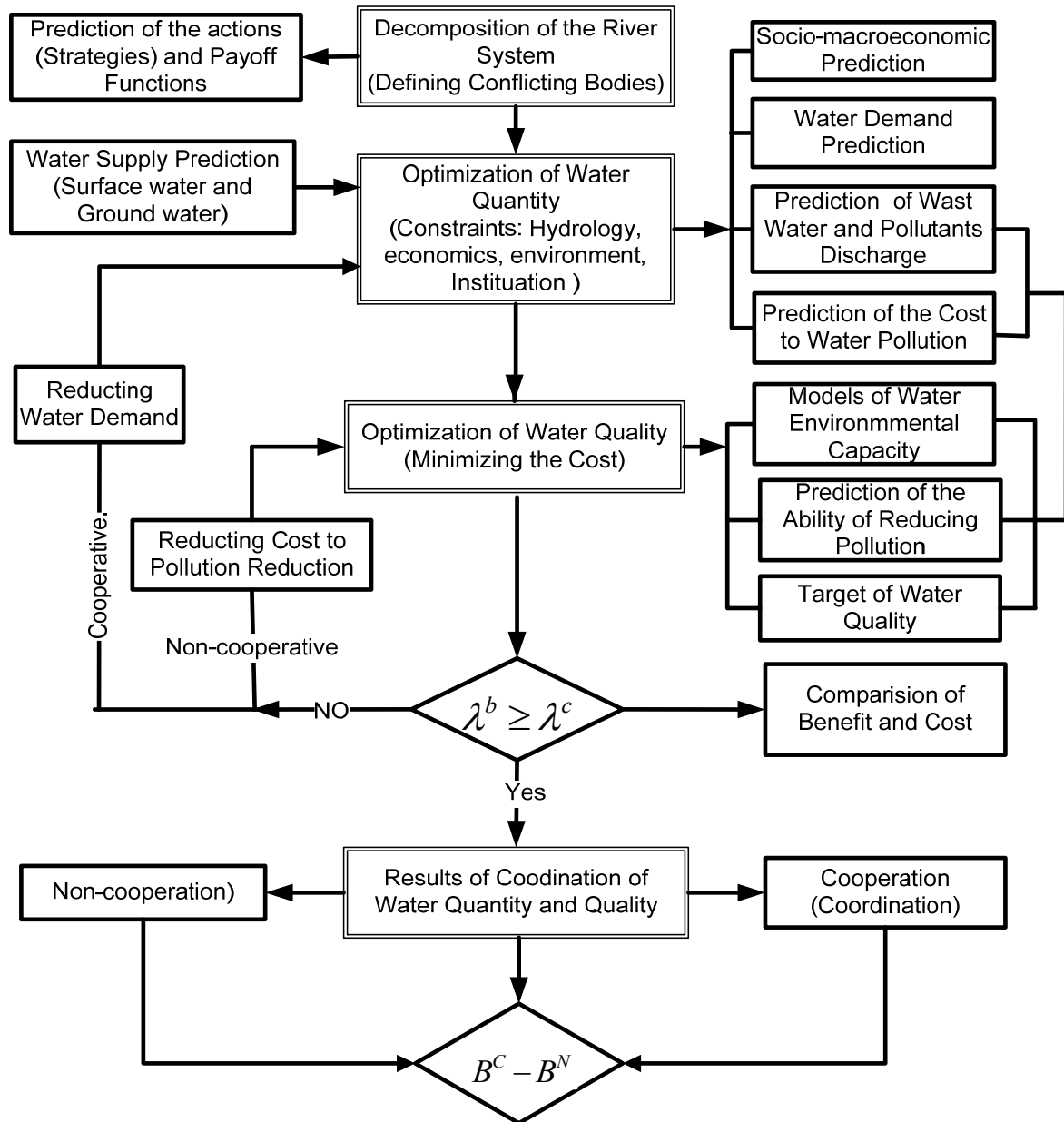


Figure 2.9: A strategy for water resources management using game theory

Third step is to optimize water quality so that every player can maximize his payoff. This step consists of setting up models of pollutant capability in different river sections, predicting each player’s ability to reduce waste water discharge and treat water pollution, and setting a target for water quality or water quality standard. In this step each player decides if they impose cost to reduce waste. The rational players will make planning by calculating the benefits and costs. From an economic point of view, waste production or pollution is public good or bad. In the non-cooperative situation, each player usually cut the waste treatment cost, and he does so because he can free-ride on other players’ achievement of waste reduction. If all the players choose the strategies of free riding, equilibrium of pris-

oner dilemma will be reached. In the cooperative situation, the players will maximize their welfare by efficient water use.

2.4.3 Cooperative and non-cooperative game theoretical models

Based on the strategy concepts of game theory developed for water resources management in the Part 2.4.2, the following non-cooperative game model and cooperative game model are constructed for water resources management in a river basin.

2.4.3.1 A non-cooperative game model

A non-cooperative game model for water resources management is that every player i maximizes the differences between benefits obtained from water demands and the costs charged to waste water reduction or treatment. The model is expressed by equation (2.4).

$$\underset{p,d,t}{\text{Max}} V_i = \int_t^n [B_i(Q) - C_i(P)] e^{-\delta t} dt \quad (2.4)$$

where V_i – payoff of every player i , Q – water consumption, P – pollutants discharged, $e^{-\delta t}$ – discount factor, $B_i(Q)$ – benefit function of water consumption of every player i , $C_i(P)$ – cost of every player i to abate pollutants production.

I: Water quantity optimization:

According to the sectors of water consumptions, industry, domestic life and agriculture are defined as three players. Because benefits of ecology consuming water is difficult to defined, ecology is not defined as a player and water demand of ecology is regarded as one of constrains. Water quantity optimization means that it consumes minimum units of water to produce per unit of economic value. In other word, it also means the consumption per unit of water will produce maximum economic values. Model of water quantity optimization is expressed by:

$$\text{Max} B_i(Q) = \sum_{t=0}^n (B_1^t Q_1^t + B_2^t Q_2^t + B_3^t Q_3^t) \quad (2.5)$$

where B_1^t , B_2^t , B_3^t – benefit coefficients of water consumption in industry, domestic life and agriculture, respectively during the period of time t (a year); Q_1^t , Q_2^t , Q_3^t – water consumption of industry, domestic life and agriculture, respectively during the period of time t .

II: Water quality optimization:

Water quality optimization means that every player minimizes the costs to reduce pollutants discharged into the water body by reducing pollutant discharge. It can be expressed as follows:

$$\text{Min}C_i(P) = \gamma_x \sum_{x=1}^n \sum_{y=1}^m [(P_{x,y-1}^t + P_{x,y}^t)(1 - k_{x,y}) - P_{x,y}^c] \quad (2.6)$$

where γ_x – cost coefficient of pollutant x ; $P_{x,y-1}^t$ – load of pollutant x from the upstream controlling section $y-1$; $P_{x,y}^t$ – load of pollutant x in the controlling section y ; $P_{x,y}^c$ – the controlling load of pollutant x in the controlling section y .

III. Constraints of non-cooperative game model

(1) Constraints for water quantity optimization:

$$Q_1^t + Q_2^t + Q_3^t + Q_4^t + Q_0^t - R^t \leq S^t + G^t - E^t - Q_5^t \quad (2.7)$$

$$Q_2^t + Q_3^t < S^t \quad (2.8)$$

$$Q_1^t + Q_3^t < S^t + G^t \quad (2.9)$$

$$Q_{y-1}^t + Q_{y-1,y}^t - \alpha Q_3^t + \mu(Q_1^t + Q_2^t) - Q_4^t - Q_0^t - E^t \geq Q_5^t \quad (2.10)$$

$$0 < R_i^t < Q_i^t, \forall i = 1, 2, 3 \quad (2.11)$$

$$\underline{Q}_i^t \leq Q_i^t \leq \bar{Q}_i^t, i = 1, 2, 3, 4 \quad (2.12)$$

where Q_4^t – Water for soil conservation; Q_5^t – ecological water demand; Q_0^t – water demand of other sectors; S^t – surface water amount; G^t – ground water amount; R^t – waste water discharged into the river or the reused waste water; E^t – evapotranspiration; α – coefficient of agriculture water consumption; μ – coefficient of industrial and domestic waste water discharged into river; Q_{y-1}^t – water inflow from previous section $y-1$; $Q_{(y-1,y)}^t$ – the water inflow in the section y ; \underline{Q}_i^t and \bar{Q}_i^t – the minimum and maximum of water demand; and others are the same as above.

(2) Constraints of water quality optimization:

$$P_{x,y-1}^t = Q_{y-1}^t c_{x,y-1}^t \quad (2.13)$$

$$P_{x,y}^t = Q_y^t c_{x,y}^t \quad (2.14)$$

$$P_{x,y}^c = Q_y^t c_{x,y}^c \quad (2.15)$$

$$Q_{y-1}^t \geq 0, Q_y > 0; cx \geq 0, K_{x,y} \geq 0 \quad (2.16)$$

where $c_{x,y-1}^t$ – the concentration of pollutant x in inflow water from the upstream section $y-1$; $c_{x,y}^t$ – the concentration of pollutant x in the section y ; $c_{x,y}^c$ – the controlling concentration of pollutant x in the section y ; others are same.

2.4.3.2 A cooperative game model

The cooperative game model means that all the players cooperate with each other to maximize the overall net benefits. It is expressed by equation 2.17. Every player in cooperative game is to maximize the net benefits which he can obtain from cooperation. It is expressed by equation 2.18.

$$\text{Max}_{p,d,t} U = \int_t^n [B(Q) - C(P)] e^{-\delta t} dt \quad (2.17)$$

$$\text{Max} U_i = V_i + \max \prod_i^n [(U_B / \Psi)_i] \quad (2.18)$$

Where U – the total benefit obtained from cooperative game; $B(Q)$ – the benefit function of water use in cooperative game; $C(P)$ – the cost to abate waste water discharged (or pollution) in cooperative game; U_i – the payoff of each player i in cooperative game; U_B – the total net benefit obtained from cooperative game; Ψ – distribution factor of cooperative benefit.

Constraints of the cooperative game model:

$$U = \sum_{i=1}^n V_i + U_B \quad (2.19)$$

$$U_B \geq 0 \quad (2.20)$$

where the variables and symbols keep the same.

2.5 Information used for game theoretic models

The main types of data include socio-economic data, climatological data, hydrological data, water quality data as well as natural resource data. Socio-economic data mainly include urban and rural population, water consumption, added values of industry and agriculture, net incomes, GDP, water prices, etc. Climatological data include precipitation, evapotranspiration, temperature of water and air. Hydrological data mainly include water flows,

water levels and water velocity. Water quality data consist of pollutants concentrations, point pollution sources and non-point pollution sources. Natural resources data comprise water resources volumes, land data and forest data. (Table 2.1)

Table 2.1: The data (information) used for game theoretic models

Data class	Data
Socio-economic data	Population data <ul style="list-style-type: none"> • urban population • rural population Water consumption data <ul style="list-style-type: none"> • water supply • water demands of agriculture, industry, domestic life and ecology • water prices for agriculture, industry, domestic life Gross domestic product (GDP) or gross regional products <ul style="list-style-type: none"> • added values of industry (AVI) • added values of agriculture (AVA) • net incomes of residences and index • indices of Gross Domestic Product • consumer price Indices (CPI) Cost to reduce waste water
Climatological data	<ul style="list-style-type: none"> • precipitation • evapo-transpiration • temperature of water and air
Hydrological data	<ul style="list-style-type: none"> • water flows, • water levels • water velocity
Water quality data	Pollutants concentrations <ul style="list-style-type: none"> • different monitoring stations Point pollution sources <ul style="list-style-type: none"> • industrial waste discharge • domestic waste water discharge Non-point pollution source <ul style="list-style-type: none"> • agricultural fertilizer consumptions, • soil erosions, • rural domestics • animal husbandry Water standards for different water bodies
Natural resources data	Water resources data <ul style="list-style-type: none"> • total water resources volume • surface water volume • underground water volume • water area in land Land data <ul style="list-style-type: none"> • cultivated area • soil erosion • public green area Forest resources data <ul style="list-style-type: none"> • forest area • forest-coverage rate • afforestation area or number of planned trees

3. Game-theoretic approaches to river water management in China

River system is an integrated system in nature, but it has been managed by different isolated units. Stakeholders in these isolated administrative regions or areas have different interests and aims. Water scarcity and water quality degradation are two critical problems in water resources management, and they usually cause conflicts between these stakeholders. The cross-sector and cross-boundary conflicts are the main problems in river basin management due to this isolated management. Chapter 2 have been illustrated that game theory, as a modelling approach, is an appropriate approach to solve the conflicts. This chapter demonstrates how game theoretic modeling and simulating approaches are applied to solve water conflicts involved in the Hanjiang River Basin in China.

China possesses total water resources of 2812.4 billion m³, ranking the 6th in the world, and but the available water amount per capita only takes one fourth of the world's average due to the heavy population (World Bank, 2002; Wei, 2007). On the one hand, water resources in China are much unevenly distributed in time and space, and water shortage has been a long-time and widespread problem in Northern regions of China. On the other hand, the rapid economic development produces increasing amounts of waste water. Most waste water has been discharged into the water bodies without treatment, which degrades the water body. The situation of water resources in China can be referred to Wei (2007).

In order to mitigate the existing crisis of water resources, the engineers in China proposed the South to North Water Transfer (SNWT) Projects after 50 years' study. SNWT Projects comprise of Western Route Project (WRP), Middle Route Project (MRP) and Eastern Route Project (ERP). The WRP will transfer water from the upper stream of Yangtze River. The MPR will transfer water from the middle stream of Yangtze River. The ERP will transfer water from the lower stream of the Yangtze River. The three routes will connect the four big rivers and form a structure of four lateral and three longitudinal lines. Of the three route project, the MRP is the study focus of many water resources experts. This project will divert water from the Danjiangkou Reservoir in the Hanjiang River Basin for 20 big cities and 100 counties in Beijing and Tianjin Municipalities, Hebei and Henan Provinces.

It covers a total area of about 155,000 km² and it crosses about 200 river channels or canals with the total canal distance of 1,246 km. Figure 3.1 and 3.2 show a map and a sketch of South-to-North Water Transfer Projects, respectively.

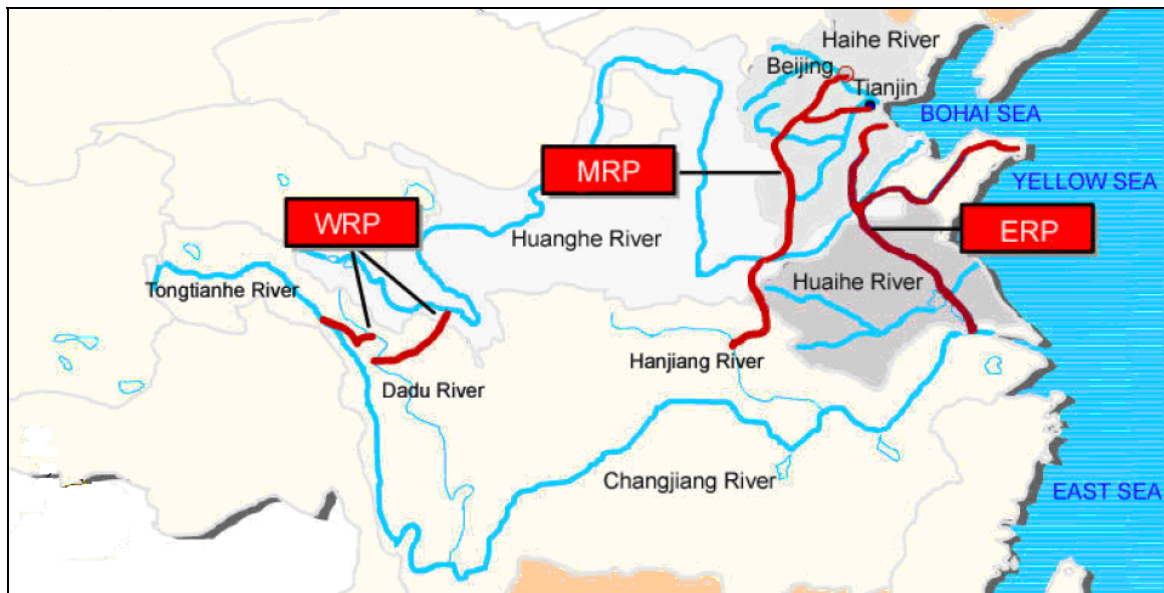


Figure 3.1: Map of South-to-North Water Transfer Projects

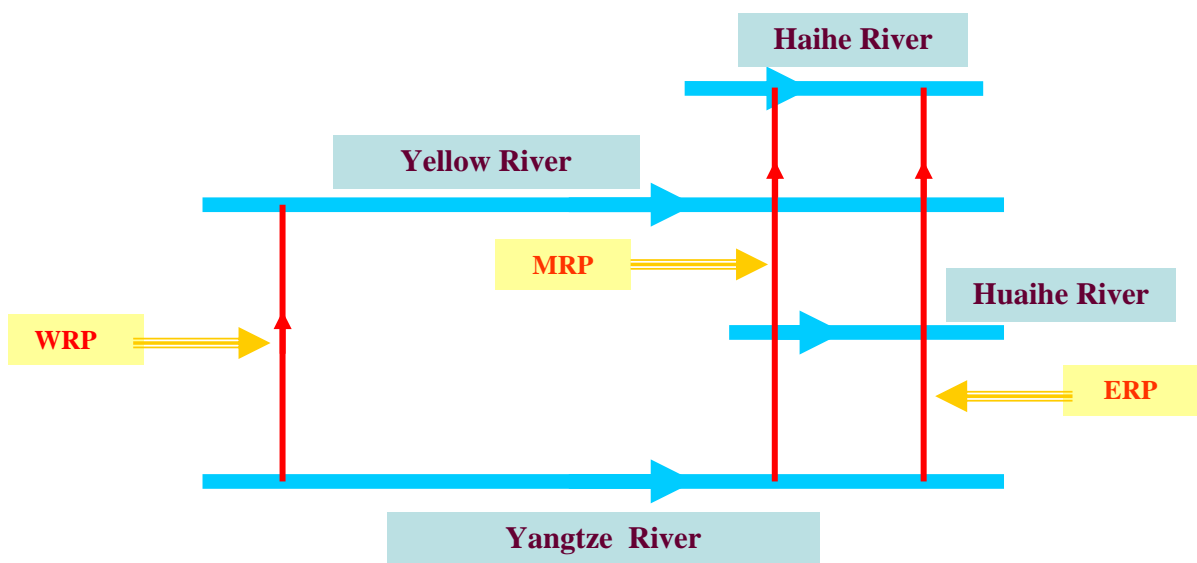


Figure 3.2: Sketch of South-to-North Water Transfer Projects

The Chinese government, the Changjiang Water Resources Commission (CWRC) and the Changjiang Water Resources Protection Institute (CWRPI) have been carried out several research projects on the water quality and quantity of the Hanjiang River and the Danjiangkou Reservoir, and environmental impacts of water transfer on the River. Besides, many studies on water resources management have also taken by researchers from different

aspects. One focus is the study and analyses of the impacts and effect of water diversion on the Middle-lower Hanjiang River Basin, and these impacts and influences mainly include: (1) water resource utilisation (Liu et al., 2003, 2005; Liang, 2001) and hydrologic situation (Guan et al., 2005; Gu et al., 2005), (2) economic development (Du et al., 1999; Zhang, 2004; Zhang, 2005), (3) water environment, especially algae blooms (Xie et al., 2004; Dou et al., 2002; Liu et al., 2005; Zhang et al., 2004; Zhang and Ao, 2004), (4) ecological environment (Zhang et al., 2000), etc..

Interbasin water transfer is a multidisciplinary problem (Yevjevich, 2001), and such projects usually bring about more fundamental issues concerning the social, economical, administrative and legislative aspects (Shao and Wang, 2003) as well as environmental and ecological sides. Interbasin water transfer projects to reduce water shortage are not new things at all in China. However, the Middle Route of South-to-North Water Transfer (MRSNW) Projects is different from other existing water transfer projects in China, because it includes two Municipalities and four provinces. Water transfer projects within a region can be effectively managed through the coordination of local government and regional river administration, while it is more difficult to manage when water transfer involving different regions. The conflicts involved in the Hanjiang River are mainly resulted from MRP. MRP involves different provinces with different interests and benefits. The water transfer project will change the runoff and water level of the rivers, and break the long-established balances of benefits between different groups. Therefore, it must impact on the socio-economic development and ecology and environments of the Hanjiang River Basin. If they are not properly solved, and water diversion project will face tremendous difficulties. Therefore, it is one of the first tasks to coordinate all the parties, balance their interests and reduce their conflicts. However, so far no studies on the methods to solve the potential conflicts resulting from the interbasin water transfer project in the Hanjiang River Basin.

3.1 The Hanjiang River Basin

The Hanjiang River Basin lies in $30^{\circ}08' \sim 40^{\circ}11' \text{N}$ latitude, $106^{\circ}12' \sim 114^{\circ}14' \text{E}$ longitude. The river originates in the southern part of Shaanxi Province, northwest China, flows through Shaanxi and Hubei provinces and joins the Yangtze River at Wuhan, capital city of Hubei province. It is about 1577 km long, the longest tributary of Yangtze River; and the basin covers a watershed area of $159,000 \text{ km}^2$, the second largest river basin in Yangtze River Catchment. The stream above the Danjiangkou is the upriver, 925 km long. The

middle and lower reach of the Hanjiang River, is about 652 km in length, among which from Danjiangkou City to Zhongxiang City is the middle reach with length 270 km, from Zhongxiang City to the mouth is the lower reach with length 382 km (CWRPI, 2005; Zhang, et al., 2000). Figure 3.2 shows sketch of the Hanjiang River Basin, and the physical characteristics of the three parts of the Hanjiang River simply summed up in Table 3.1.

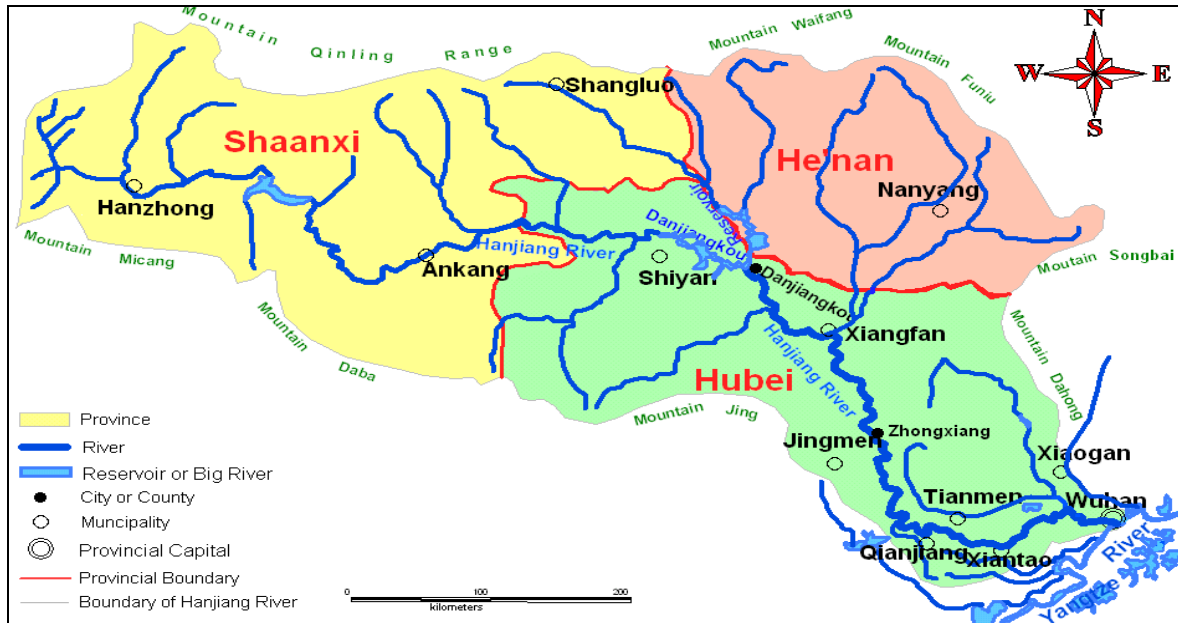


Figure 3.3: Sketch of the Hanjiang River Basin

Table 3.1: Flow division and characteristics of the Hanjiang River (Data from CWRPI, 2005; Zhang, et al., 2000)

River division	Range	Distance (km)	Area ($\times 10^4 \text{ km}^2$)	Topographical characteristics
Upper river	Source to Danjiangkou City	925	9.52	Wider river bed, steep hillsides by banks, deep cutting river valleys, rapids and riffles.
Middle river	Danjiangkou City to Zhongxiang City	270	4.68	hilly and multiple basin valleys, Winding river course, excessive gravels and riffles, high silt concentration in water (multi- annual means 2.39 kg/m^3).
Lower River	Zhongxiang City to the River Estuary	382	1.7	Plain region, curving river course, comparatively slow water flow, sand-natured river bed, the silt concentration is about $0.0034 \sim 0.055 \text{ kg/m}^3$.

The u-shaped Danjiangkou Reservoir lies in $110^\circ \sim 112^\circ \text{E}$ longitude, $32^\circ \sim 33^\circ \text{N}$ latitude. It covers an area of 1050 km^2 and has a total storage capacity of $17.45 \text{ billion m}^3$ with a

normal pool level 157m. It services as flood prevention, electricity generation, water supply for production, irrigation, navigation and so on. On general, the fluctuation of the water level in front of the dam is 18 m; the biggest water depth in front of the dam is about 90 m.

3.1.1 Water quantity

The Hanjiang River Basin belongs to subtropics monsoon area. The climate is temperate and moist, and annual precipitation is 873 mm. The Hanjiang River Basin is rich in water resources. According to the data of hydrology series from 1956 ~ 1998, the river has total water resource of 58.2 billion m^3 and average annual natural runoff is 56.6 billion m^3 . Based on the data of 1956 ~ 1998, the average annual precipitation above the Danjiangkou city is 890.5mm. The average annual inflow of the Reservoir is 38.78 billion m^3 approximately occupying 70% of water volume of the entire basin. The maximum inflow volume is 79.5 billion m^3 in 1964, and the minimum is 16.9 billion m^3 in 1997. The upper basin of the Hanjiang River includes part of provinces of Shaanxi, He'nan and Hubei. The amount of surface water is 36.796 billion m^3 , the ground water is 10.647 billion m^3 , and the overlap amount is 10.387 billion m^3 (Table 3.2).

Table 3.2: Water resources in the upper basin of Hanjiang River (Data from CWRPI, 2005)

Province	Municipality	City	Counting area (km^2)	Surface water ($\times 10^8 m^3$)	Ground water ($\times 10^8 m^3$)
Shaanxi	Hanzhong		19559	94.42	27.67
	Ankang		23391	104.16	26.30
	Shangluo		16529	53.54	13.94
He'nan	Nanyang	Xixia	3131.6	7.37	3.723
		Xichuan	2821.5	6.99	3.355
	Sanmen	Lushi	1238.2	2.91	1.472
Hubei	Shiyan	Downtown	1181	3.16	1.404
		Danjiangkou	2935	7.48	3.490
		Yun	3860	11.19	4.590
		Yunxi	3506	10.57	4.169

The total water resources of middle and lower reaches in the Hanjiang River Basin is 19.5 billion m^3 , occupies 32.2% of water resource of the entire basin. The surface water resources is 18 billion m^3 , ground water resources 76.01 billion m^3 , redundant water volume 61.01 billion m^3 , and the water-producing modulus $30.6 \times 10^4 m^3/km^2$ (Table 3.3).

Table 3.3: Water resources of different zones in middle-low reaches of the Hanjiang River (Data from CWRPI, 2005;)

Zone	Area (km ²)	Surface water (×10 ⁸ m ³)	Ground water (×10 ⁸ m ³)	Overlap (×10 ⁸ m ³)	Total water (×10 ⁸ m ³)	Modulus of water pro- duction (×10 ⁴ m ³ /km ²)
Danjiangkou~ Xiangyang	8,385	30.7	12.2	12.2	30.7	36.6
Baitang River	26,376	57.9	24.2	19.5	62.6	23.7
Xiangyang~ Huangzhuang	12,898	34.5	11.4	10.9	35.0	27.1
Huangzhuang ~ River Estuary	16,124	57.0	28.1	18.4	66.7	41.4
Total	63,783	180.1	75.9	61.0	195.0	30.6
Entire Basin	159,000	591.0	190.0	175.0	606.0	38.1

3.1.2 Water quality

Before 1990, the Hanjiang River had fine reputation of “East Rhine” due to pure water with rich oxygen and least pollutant concentrations in all rivers in China. However, with the socio-economic development, increasing population of the basin, great amount of waste has been discharged into the River without being treated. Therefore, the river has been deteriorated in recent years, and it mainly reflects the increase of concentration of nutrients like nitrogen and phosphorus. Table 3.4 shows the monitoring results of water quality in the Hanjiang River from 2000-2005 according to Chinese Environmental Quality Standards for Surface Water (CEQSSW) (GB 3838—2002) (AQSIQ and EPA, 2002). CEQSSW divides water quality into 5 classes, namely Classes I, II, III, IV and V. The water quality inferior to Class IV are usually included into Class V.

Table 3.4: Monitoring results of water quality in the Hanjiang River from 2000-2005 (CESY, 2000-2005; HEPB, 2004-2005)

Year	Main branch					Tributaries			
	I	II	III	IV	VI	I~III	IV	V	VI
2000	0.00%	52.00%	0.00%	40%	8%	55.60%	0.00%	44.40%	
2001	7.70%	50.00%	42.30%	0.00%	0.00%	45.50%	18.20%	0.00%	36.40%
2002	0.00%	56.00%	44.00%	0.00%	0.00%	36.40%	27.20%	27.20%	36.40%
2003	0.00%	61.50%	38.50%	0.00%	0.00%	45.50%	18.20%	18.20%	18.20%
2004	0.00%	72.00%	28.00%	0.00%	0.00%	58.3%	8.30%	8.30%	58.3%
2005	0.00%	80.00%	20.00%	0.00%	0.00%	37.50%	6.30%	12.50%	43.70%
Average	1.28%	61.92%	28.96%	6.67%	1.33%	44.10%	13.03%	13.24%	33.68%

During 2000 to 2005, water quality of the main branch conforms to water Class II ~ III of Chinese Environmental Quality Standards for Surface Water. In details, from 2000 to 2005 average probabilities of water quality of the main branch are that water Class I takes 1.28%, Class II 61.9%, Class III 28.96%, Class IV 6.67% and Class VI 1.33%. However, the water quality in the tributaries has been polluted severely. Classes I-III takes 44.10%, Class IV 13.03%, Class V 13.24% and Class VI 46.9%.

The Danjiangkou Reservoir is the water source of MRSNWT project, and thus the water quality is very critical to the success of this project. There are 16 important monitoring water stations on water quality and water quantity of the Danjiangkou Reservoir (Fig. 3.4). Three monitoring stations - Dam, Tanzishan (TZS), Taocha (TCA) – are selected as data collection pots, and they are numbered by 1, 2 and 3, respectively in figure 3.4.

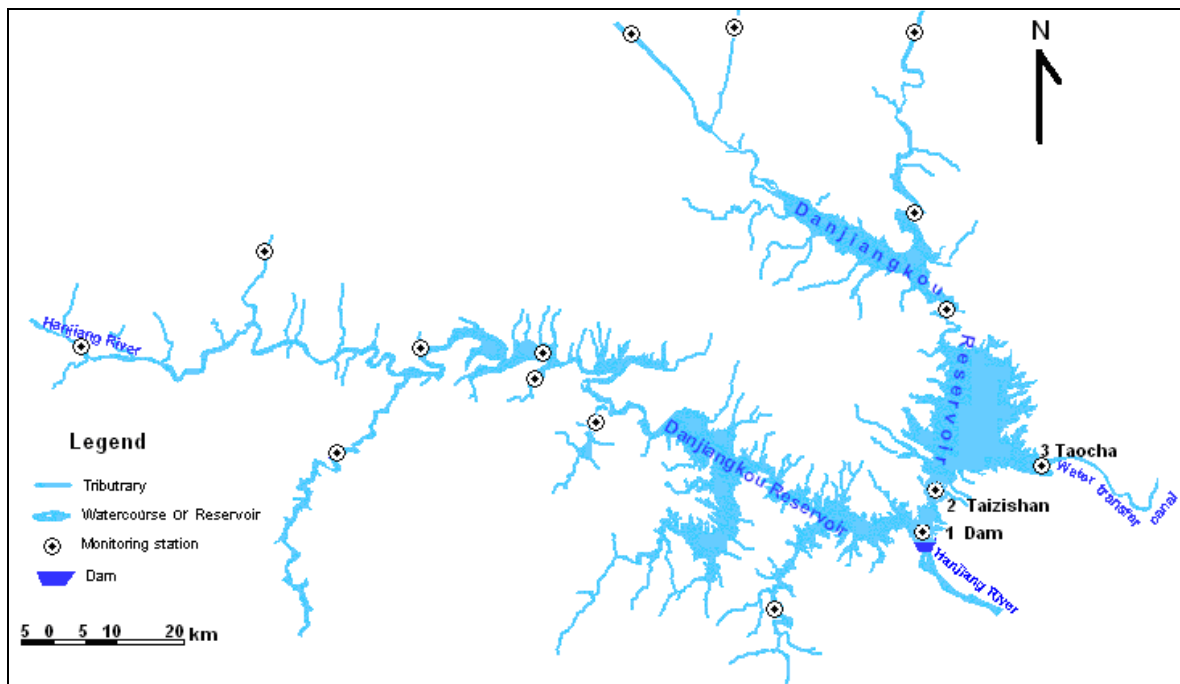


Figure 3.4: The Danjiangkou Reservoir and the water monitoring stations

Figure 3.5 illustrates the annual average concentration of BOD₅, DO, COD_{Mn}, NH₃-N, TP and TN in the three monitoring stations during 1995 to 1996. The annual average concentrations of BOD₅ range from 0.68 mg/L to 2.2 mg/L, which are better than class II (3.0 mg/L). The concentrations of DO vary between 7.5 mg/L and 9.4 mg/L, which meet the Class I (7.5 mg/L). The concentrations of COD_{Mn} are in the range of 1.4-2.3mg/L, which meet the Class II (4 mg/L). The concentrations of NH₃-N are between 0.05-0.24 mg/L, conforming to Class II (0.5mg/L). The concentrations of TP reached 0.6mg/L and

0.06mg/L, which cannot conform to the standard of Class II (0.025mg/L) in 2001 and 2003 in Taocha, but they meet the standard in other years. However, the concentration of TN cannot conform to the Class II, and it belongs to Class IV and V. Therefore, the deterioration of Reservoir is mainly reflected by the increase of concentration of total nitrogen.

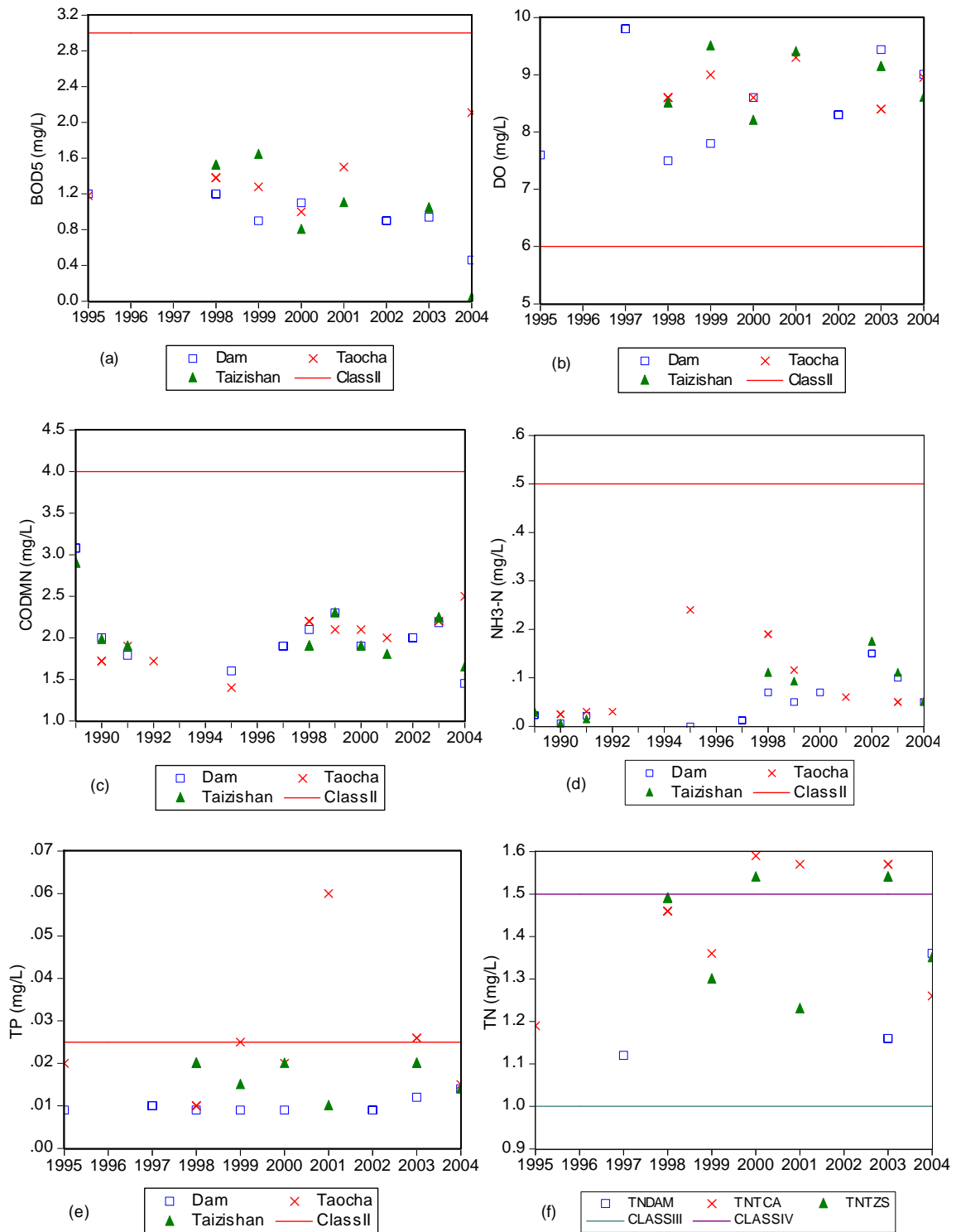


Figure 3.5: Water quality of the Danjiangkou Reservoir

From the concentrations of total nitrogen and the total phosphorus in the reservoir, the reservoir is at present in the mesotrophic condition. Therefore, the main task to increase water quality in the Reservoir is to reduce TN concentration.

Figure 3.6 shows the 11 main tributaries of the Danjiangkou Reservoir. The tributaries like Shending River and Laoguan River have been polluted severely due to pollutants discharged from Shiyan city, Xixia county and Xichuan county. The water quality in these tributaries usually passes water surface standard of Class V. In addition, other tributaries also suffer pollution and the water quality usually conforms to Classes III ~ IV. During the high flow period the water quality is obviously deteriorated because great amount pollutants of non-point sources, such as agriculture and soil erosion are washed into the river by the runoff of rainfall.

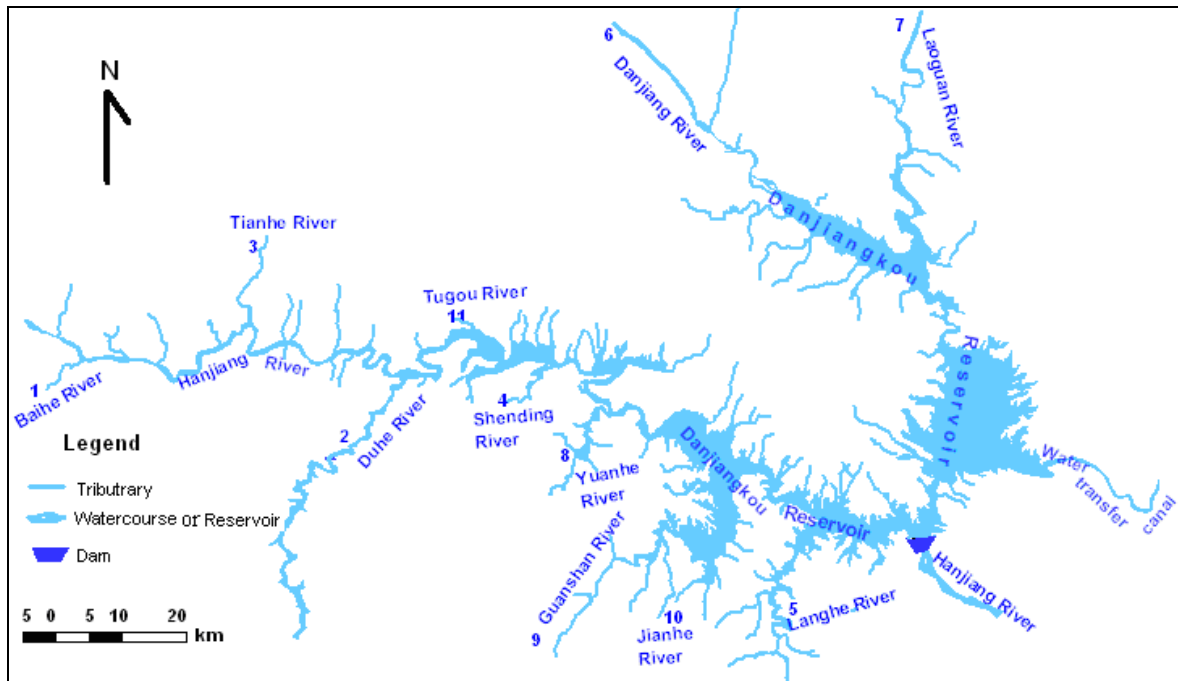


Figure 3.6: Main tributaries of the Danjiangkou Reservoir

Figure 3.7a-d compares the concentrations of COD_{Mn} , $\text{NH}_3\text{-N}$, TN and TP in 11 main tributaries of the Danjiangkou Reservoir between 1995 and 2004. In 1995 the concentrations of COD_{Mn} , $\text{NH}_3\text{-N}$, TN and TP were 0.8-20.5mg/L, 0.051-11.9mg/L, 0.275-12.4mg/L and 0.025-1.84mg/L, respectively. However, in 2004 they reached 1.6-64.9mg/L, 0.078-37.30mg/L, 1.26-37.9mg/L and 0.08-2.47mg/L, respectively. The comparisons clearly show that the water quality in the main tributaries of the Danjiangkou Reservoir has been

greatly deteriorated in recent years. The water quality deterioration of the tributaries is threatening to the water quality of the Danjiangkou Reservoir.

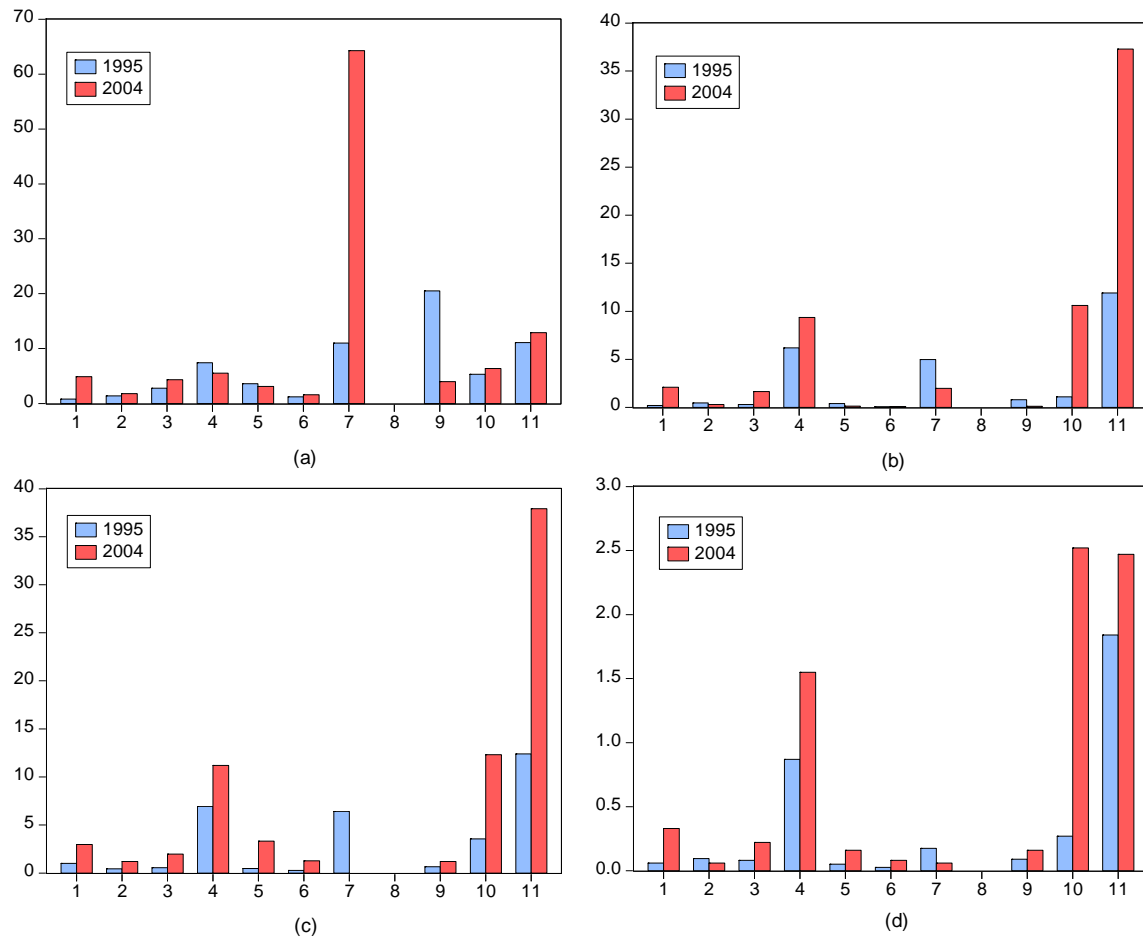


Figure 3.7: Comparison of pollutants concentrations (mg/L) of the main tributaries of the Danjiangkou Reservoir between 1995 and 2004 (a) COD_{Mn} , (b) $\text{NH}_3\text{-N}$, (c) TN and (d) TP

Water quality of middle and lower reaches of the Hanjiang River has also been deteriorated in recent years. Eutrophication problems have been intensified mainly because of the increase of concentration of nutrients like nitrogen and phosphorus. It has happened four serious algae blooms in Downstream of the Hanjiang River since 1992. The concentration of total phosphorus and total nitrogen reached to 0.17 mg/L and 2.30 mg/L respectively in Hankou Monitoring Station during the algae bloom in February 2003. Algae bloom refers to the biological phenomenon that certain algae (commonly cyanobacteria) in water body grows very quickly and forms the thicker algae membrane in the water surface. When algae blooms occur, water body transparency drops and stench, dissolved oxygen (DO) is reduced and the water environmental ecosystem is severely destructed. Algae bloom usually occurs in the lakes, reservoirs or stagnant water, but it is rare to occur in big flowing water. Different from the blue-green alga in most lakes and reservoir, algae blooms in the

Hanjiang River are diatomaceous (*cyclotella caspia*) blooms, and they usually occurs in dry flow period at the end of the winter and the beginning of spring. The total algae cells are gradually increased from the middle reaches to the downriver. From the river sections and algae cells, it shows that algae blooms have a deteriorating tendency (Table 3.5).

Table 3.5: Comparison of the four algae blooms in middle and lower reaches of the Hanjiang River (Data from Xie et al., 2004; Dou et al., 2002; Liu et al., 2005; Zhang and Ao, 2004)

Algae bloom	Starting date	Duration (days)	Distance to river estuary (km)	Algae cell ($\times 10^4/L$)
1 st	1992-2-17	18	240	1,570
2 nd	1998-2-16	20	300	2,200
3 rd	2000-2-28	45	400	4,000
4 th	2003-2-8	42	400	3,100

3.1.3 Sources of water pollution

Generally speaking, the socio-economic development produces a large amount of waste in the Hanjiang River Basin. There are more than 40 waste water discharge mouths in downstream of the River. Water pollutant sources include point and non-point sources. Industry waste water and urban domestic sewage are regarded as point sources, which discharge directly into the regional surface waters. However, pollutants produced by the sector of agriculture are non-point, including consumption of fertilizer and chemical pesticides, manure of animals and poultry, and soil erosion. All these sources produced by human development are the main source of pollutants.

Figure 3.8a and b show respectively the scatter plots between industrial waste water (IWW) discharge and the growth of GDP and between domestic sewage discharge and the increase of population in the provinces of Hubei (HUB), He'nan (HN) and Shaanxi and (SX) from 1981 to 2005. The relationships of GDP and industrial waste water discharge in the three provinces have a slight difference. In Hubei, with the growth of GDP the waste water increased, and then decreased. From 1981 to 2005, GDP growth of Hubei increased from 219.8×10^8 RMB to 6520.1×10^8 RMB, and industrial waste water discharge only decreased from 13.2×10^8 tons to 9.2×10^8 tons. However, in other two provinces, with the growth of GDP the waste water decreased slight first, and then increased. With reference to relationships between domestic waste water (DWW) discharge and population growth, the situations of the three provinces are the same. With the growth of population, domestic waste water discharge has been increased in these three provinces. From 1981 to 2005, the population in-

creased about 1.3 times from 47.40 million persons to 60.31 million persons, from 73.97 million persons to 97.68 million persons and from 28.65 million persons, respectively in Hubei, He'nan and Shaanxi.

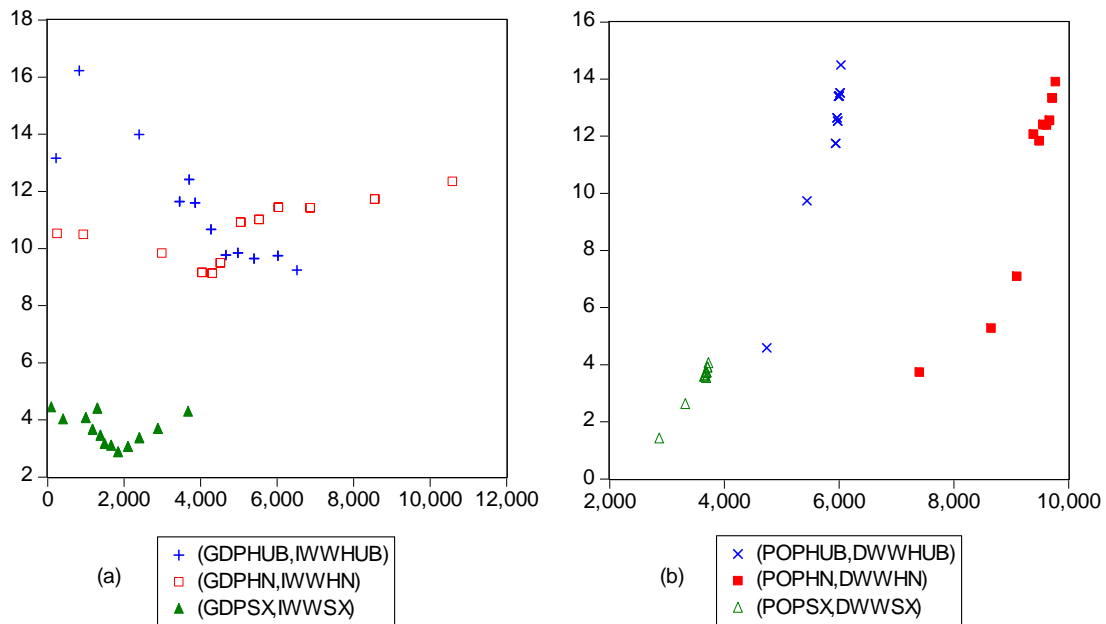


Figure 3.8: Scatter plots of waste water discharge ($\times 10^8$ tons) vs. GDP ($\times 10^8$ RMB) and population ($\times 10^4$ persons) in Hubei (HUB), He'nan (HN) and Shaanxi (SX). (a) industrial waste water discharge on GDP, (b) domestic waste water discharge on population

As for the fertilizer consumption, the growth of both total fertilizer consumptions and nitrogen fertilizer consumptions show rapid increasing trend based on the data from 1979 to 2003 (Fig. 3.9).

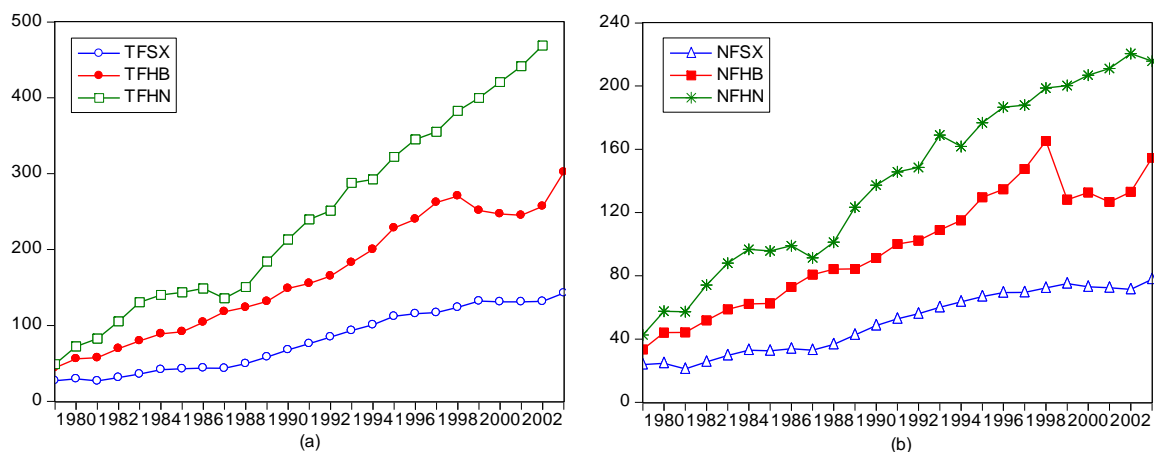


Figure 3.9: Fertilizer consumptions (tons) by 100% effective component in the provinces of Hubei (HUB), He'nan (HN) and Shaanxi (SX) (a) The total fertilizer consumptions (TF), (b) nitrogen fertilizer consumption (NF).

In the upstream river basin, the total soil erosion area covers 48,407.23 km² based on the third national remote sense investigation in 2000 (Table 3.6). According to the study (Song et al., 2006; Yang et al., 2006), 1 km² of soil erosion lose about 0.21 tons of nitrogen this area. Based on the data of local statistical yearbooks, there are about 1.5 million of large animals, 6.7 million of hogs, 35.4 million of poultry as well as 3.4 million of sheep and goats in the upstream river basin (Table 3.7). Those domestic animals produced about 194,126 tons of nitrogen in 2005, and about 15,609 tons enter the Danjiangkou Reservoir.

Table 3.6: Soil erosion in different provinces in the upstream river basin (km²) (Data from Hu and Zhang, 2003; Zhang, 2003; Wang and Li, 2003)

Soil erosion intensity	Shaanxi	Hubei	He'nan	Total
mild	13323.2	4509.5	1130.0	18962.7
moderate	10687.4	2431.0	124.5	13242.9
intensive	6507.7	3583.7	1778.6	11869.9
extreme intensive	2514.3	397.6	197.7	3109.6
severe	1221.0	1.1		1222.1
Total	34253.6	10922.9	3230.7	48407.2
annual soil loss (10 ⁴ tons)	12100.0	6425.0	1185.0	19710.0
average annual erosion modulus (t/km ² .a)	3528.0	3220.0	2938.0	4071.7

Table 3.7: Number of domestic animals and poultry in the upstream river basin in 2005 ($\times 10^4$ units) (Data from SXSB, 2006; HBSB, 2006; HNSB, 2006)

Region	Large animal	Hog	Poultry	Sheep and goat
Shaanxi	83.39	474.72	1834.58	200.23
Hubei	26.98	128.90	721.00	64.86
He'nan	35.31	67.77	983.29	72.57
Total	145.68	671.39	3538.87	337.67

3.2 Conflicts and games involved in the Hanjiang River Basin

Various different kinds of games can be defined in the Hanjiang River Basin. However, the games concerning water quantity and quality are studied in the research. In order to define the games involved in the Basin, it should decompose the river system and find the main conflicts and conflicting bodies.

3.2.1 Conflicts involved

In the case of the Hanjiang River, the conflicts are mainly resulted from the water transfer project. The regions in the Hanjiang River are economically undeveloped or developing,

but they have rich water resources. However, the regions in Northern China are economically developed, but water shortage will limit their further economic development. The Per capita GDP and Per capita water resource are good indicators to reflect respectively the welfare of a region and the wealth of water resource in a region. Figure 3.10a and b compare respectively the Per capita GDP and Per capita water resource between the provinces in the Hanjiang River and the some provinces in Northern China. The conflicts are reflected in following aspects:

- Firstly, water transfer sets a higher standard on water quality in the Danjiangkou Reservoir, which will raise cost to reduce pollutants discharged from the cities on the upper rivers and around the reservoir.
- Secondly, a substantial amount of water diverted will cause a reduction of runoff and water level, and thus it will change the ecological condition in the downstream of the river. Furthermore, the reductions of runoff and water level will in turn break the balance of water demand and supply of the main river, which will aggravate the conflicts of water demand and supply, and exacerbate the existing pollution (eutrophication) problem.
- The reductions of runoff and water level will in turn break the balance of water demand and supply of the main river, which can aggravate the increasing conflicts of water demand and supply and lead to the worsening of the existing pollution (eutrophication) problem there.

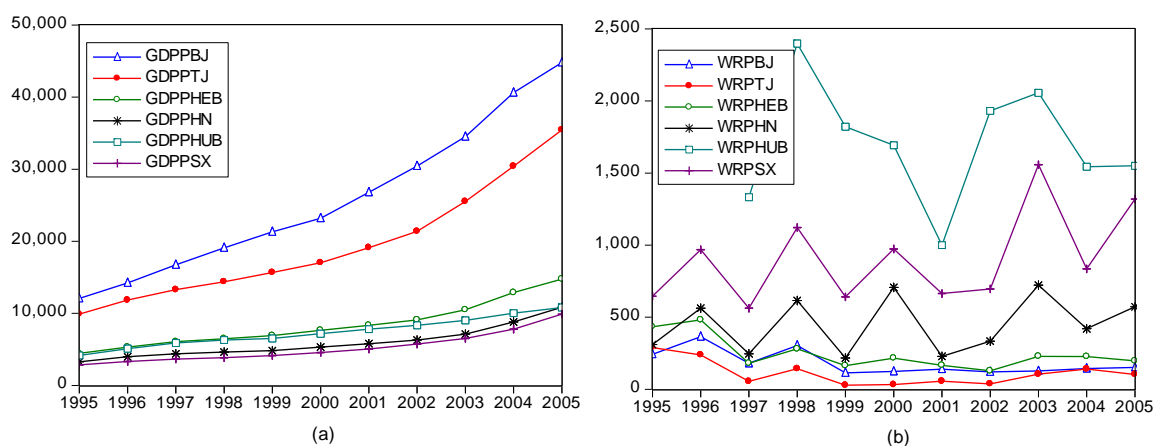


Figure 3.10: (a) Per Capita GDP (RMB) and (b) Per Capita water resource (m³) in Beijing (BJ), Tianjin (TJ), Hebei (HEB), He'nan (HN), Hubei (HUB) and Shaanxi (SX)

The regions in the Hanjiang River Basin are generally called as the Water Source Area (WSA), which includes the provinces of Shaanxi (SX), He'nan (HN) and Hubei (HUB).

The regions transferring water from the Hanjiang River are termed as the Water Beneficial Area (WBA), which include the Municipalities of Beijing (BJ) and Tianjing (TJ), and the Provinces of Hebei and He'nan. He'nan Province belongs to both WSA and WBA because one part of it lies in the Hanjiang River Basin and another part will transfer water. Generally speaking, the conflicts involved in the Hanjiang River Basin are the conflicts between WSA and WBA. In the Hanjiang River Basin, the conflicts can further classified into: the regions in the Upper River Basin (URB), the Reservoir Area (RA) and the Middle-Low River Basin (MLRB) based on the interests and benefits of the regions (Fig. 3.11).

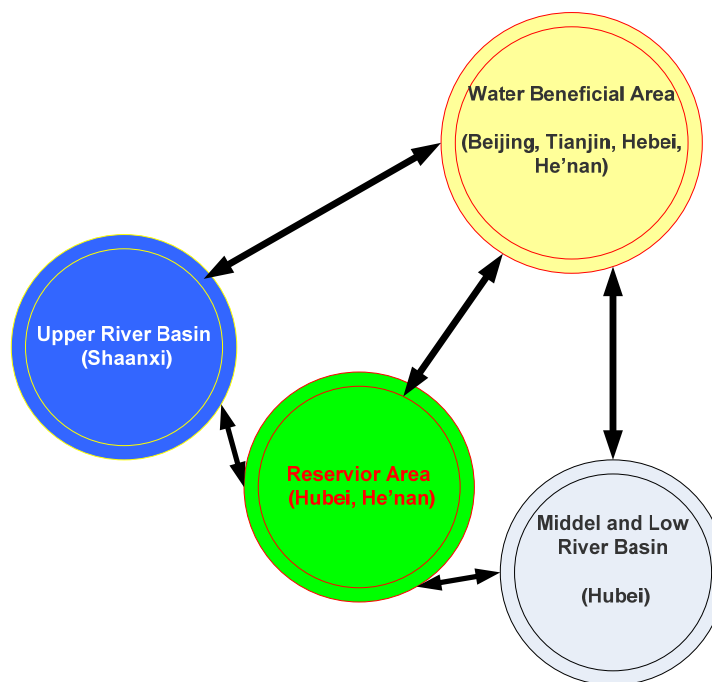


Figure 3.11: Conflicts involved in the Hanjiang River Basin

In each region, the conflicts can be between different water users or water polluters, such as industry, agriculture, household, and environment or ecology. In the WBA, water resource cannot meet the water demands of water users (Fig. 3.12). Take Beijing for an instance, table 3.8 shows the water resource in different hydrological years, and the hydrological years of 20%, 50%, 75% and 95% represent a wet year, normal year, moderate dry year and high dry year, respectively. In the 20% wet year, the water supply ability is only $37.7 \times 10^8 \text{ m}^3$. However, water demand is more than $40 \times 10^8 \text{ m}^3$ in most years. Therefore, industry often overuses ground water and overtakes water from agriculture and urban ecology. It estimates that the total overexploited groundwater is about 3.96 billion m^3 during 1961 to 1995 in Beijing (Jiang, 2004; Ma, 2006). Figure 3.13 illustrates the changes of

groundwater table of Beijing from 1959 to 1990. The groundwater table of Beijing was 28-78m in 1959, while it had only 4-52m in 1990 (CWRPI, 2005).

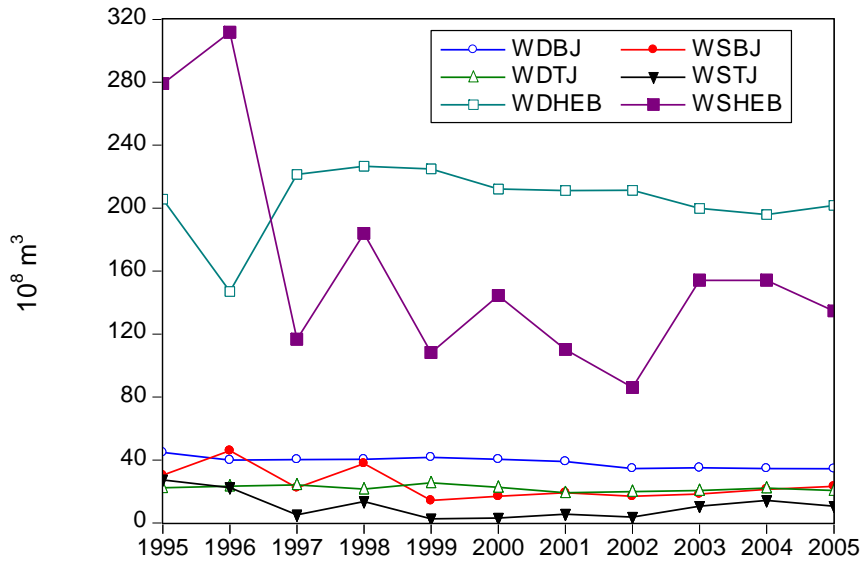


Figure 3.12: Total amount of water resources (WS) and water demand (WD) ($\times 10^8 \text{ m}^3$) of Beijing (BJ), Tianjin (TJ) and Hebei (HEB) (1995-2005)

Table 3.8: Water resources in different hydrological years in Beijing during 1986-2005 ($\times 10^8 \text{ m}^3$) (Data from BJWB, 2005; CWA, 1998-2004; BJSB, 2001-2007; Wu and Zhang, 2005)

Hydrological year	Surface water	Ground water	Overlap	Total water
20%	17.83	29.21	8.70	37.70
50%	10.94	15.18	3.68	22.44
75%	7.780	15.70	4.28	19.2
95%	5.16	12.81	3.75	14.22
Annual mean	13.93	19.95	6.01	27.83

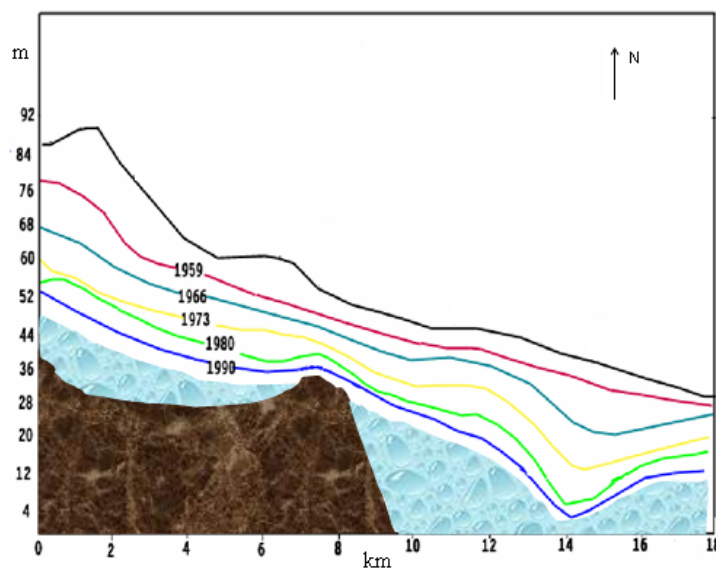


Figure 3.13: Ground water table of Beijing

The contradiction between water supply and demand sharpens water conflicts between different water users, industry, agriculture, household, and ecology. It is not rare that fighting for water among users between downstream and upstream, between the right bank and left bank of the rivers (CWRPI, 2005; Wei and Guanck, 2007 a). For the treatment of water quality in the Danjiangkou Reservoir, there are conflicts between the industry, agriculture, household in URB and RA.

3.2.2 Games involved

One method to define games is by the types of activities, or fields. By this method, games involved in the Hanjiang River Basin can be classified into: industry, agriculture, domestic life and nature (ecology). Another method to defined games is by the regions in which activities take place. Figure 3.14 illustrates how to decompose the area and define the games.

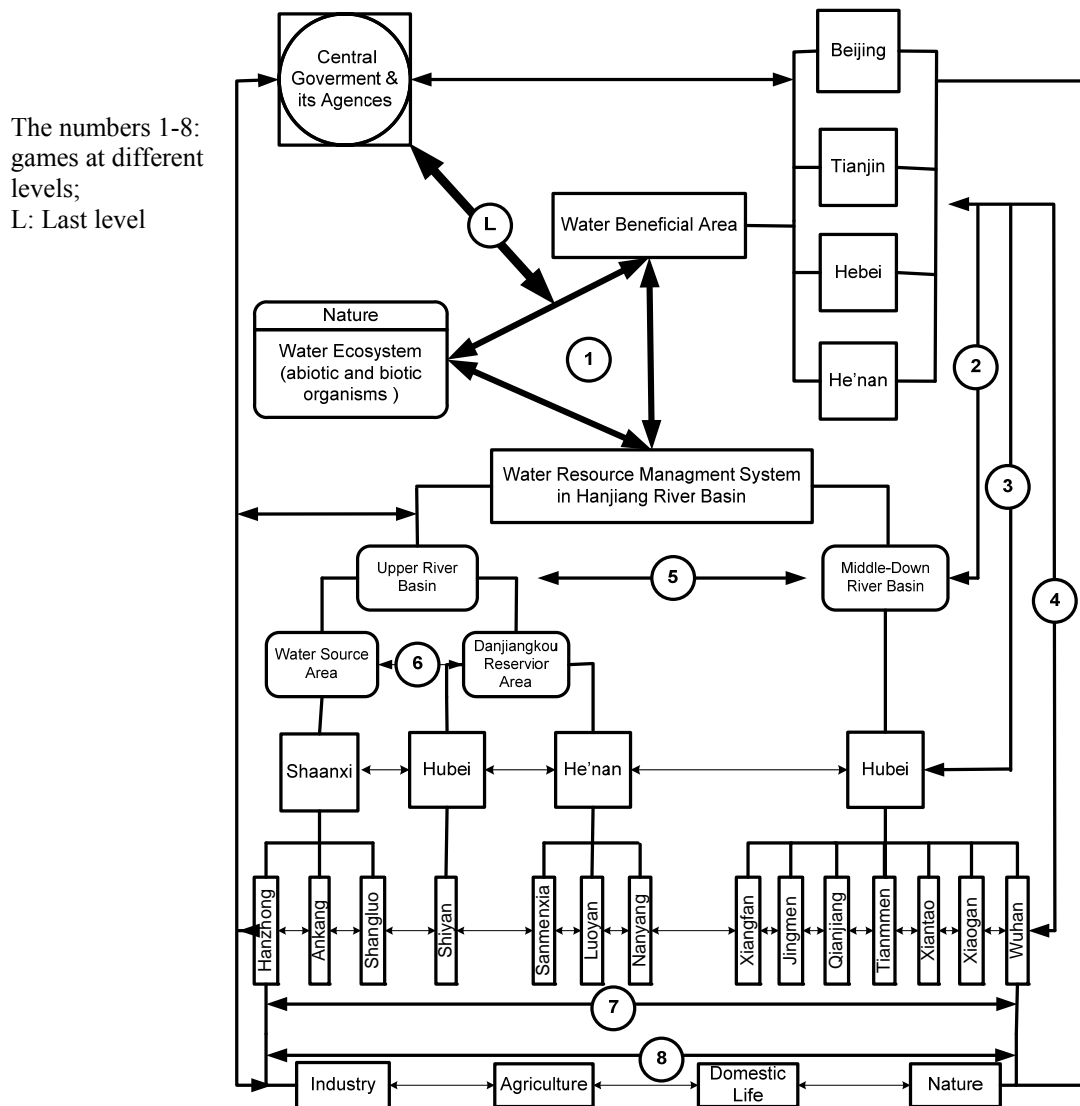


Figure 3.14: Games involved into the Hanjiang River Basin

According to these methods, the games involved in the River Basin can be defined by different levels. Based on different administrative regions and their interests, the study area can be divided into different-level games. At first level, the conflicts can be generally simulated into a 3-persons game, and players are water beneficial area, water source area and the nature. At the second level, WBA, URB and MLRB form a 3-persons game, and the games are played by the 5 regions in WBA and 3 regions in WRA at the third level. The fourth level is the game formed by 14 cities in WRA and 5 regions in WBA. With much deeper levels, the games will be more detailed and concrete, and the units of players will be much smaller. The last unit of players should be the individual person or species. The game results are usually not stable and full of risks because of free-rider problems. Therefore, it is necessary that central government and its agencies enter to stable the results at the end of the game at different levels.

Only some games are modeled as an illustrative example in the next section. 6 cities of the 3 provinces (Shaanxi, He'nan, Hubei) and 1 municipality (Beijing) are included in the game simulating example (Table 3.9). The players are those 6 cities, 3 provinces and 1 municipality, and their strategies are to maximize the welfares of their industry, agriculture, household and ecology. Industry, agriculture and residential life here do not refer to a certain industry, agriculture and residential life, but they are general terms for all the industries, agricultures and residences in the study area.

Table 3.9: The regions included in the game models

Province	City or Municipality	Code	ID
Beijing	Beijing	BJ	R ₁
Shaanxi (SX)	Hanzhong	HZ	C ₁
	Ankang	AK	C ₂
	Shangluo	SL	C ₃
He'nan (HN)	Xixia	XX	C ₄
	Xichuan	XC	C ₅
Hubei (HUB)	Shiyan	SY	C ₆

3.3 Game theoretical models for the Hanjiang River Basin

R₁ will transfer water from the Danjiangkou Reservoir (R) in the Hanjiang River. Water transfer requires the cities (C₁, C₂, C₃, C₄, C₅, C₆) reducing their pollutants discharge in order to improve the water quality in the Reservoir. However, it will raise their cost to re-

duce pollutants discharge (Fig. 3.15). In this connection, the conflict in this study area is unavoidable if the interests and benefits are not balanced well.

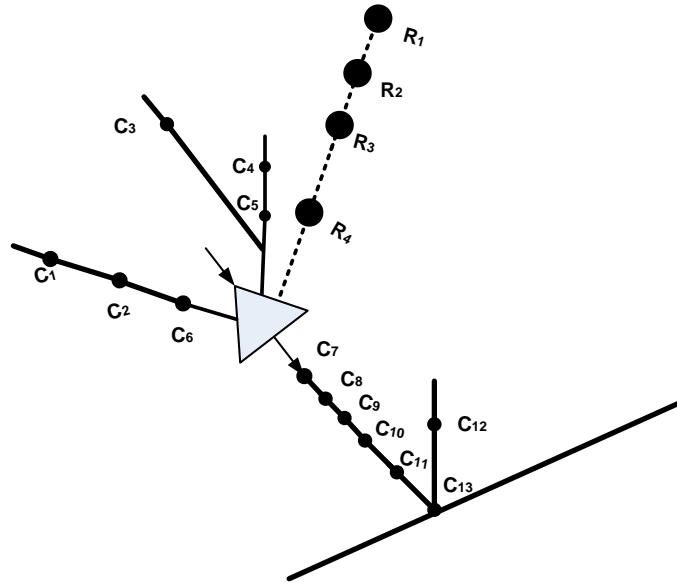


Figure 3.15: Sketch of the regions involved in the Hanjiang River Basin

3.3.1 Formulating the game models

The situations are modeled as a set of games with two levels, including one game and 4 sub-games. This is expressed as follows:

$$G_i = \langle N_i, S_i, V_i \rangle \quad (3.1)$$

$$G_{ij} = \langle N_{ij}, S_{ij}, V_{ij} \rangle \quad (3.2)$$

$$G_{ij} \subseteq G \quad (3.3)$$

$$i = 1, 2, 3, 4 \text{ and } j = 1, 2, 3 \quad (3.4)$$

where G_i – the set of games, i – every player, N – the set of players, S – the strategy profile, G_{ij} – the sub-games, j – every sub-player, V – the payoffs.

Definition of the players: The set of players N_i can be expressed as follows:

$$N_i = \{1, 2, \dots, i\}, i = 1, 2, 3, 4 \quad (3.5)$$

$$N_{ij} = \{11, 12, \dots, ij\}, j = 1, 2, 3 \quad (3.6)$$

Among them:

$$1 = \{R_1\} \text{ and } N_{1j} = \{11, 12, 13\} \quad (3.7)$$

$$2 = \{C_1, C_2, C_3\} \text{ and } N_{2j} = \{21, 22, 23\} \quad (3.8)$$

$$3 = \{C_6\} \text{ and } N_{3j} = \{31, 32, 33\} \quad (3.9)$$

$$4 = \{C_4, C_5\} \text{ and } N_{4j} = \{41, 42, 43\} \quad (3.10)$$

where $i1$ - industry, $i2$ - household, $i3$ - agriculture, R_m - the regions, C_n - the cities.

Definition of the strategies: Generally speaking, every player has two strategies: cooperation and non-cooperation. They can be expressed as follows:

$$S_{ij} = \begin{cases} S_{ij1} = C \\ S_{ij2} = N_c \end{cases} \quad i = 1, 2, 3, 4, j = 0, 1, 2, 3 \quad (3.11)$$

In the cooperative game, the player $1j$ will transfer water from the Danjiangkou Reservoir and they would like to compensate other players' losses resulting from the water transfer. Player $2j$, $3j$ and $4j$ agree with the water transfer and they are also willing to reduce their waste water discharge. In the non-cooperative situation, players have their different strategies. The strategies of $1j$ are the measures or plans to obtain sufficient water (Q) for his development in different periods of time t (year), and they are expressed by:

$$s_{ij} = Q_{ij}^t \in S_{ij} = [0, \infty), \quad i = 1, j = 0, 1, 2, 3 \quad (3.12)$$

For player $2j$, $3j$, and $4j$, their strategies are to reduce the waste water discharge in time t (year), and they are expressed by:

$$s_{ij} = P_{ij}^t \in S_{ij} = [0, \infty), \quad i = 2, 3, 4, j = 0, 1, 2, 3 \quad (3.13)$$

Definition of the payoff functions: In the non-cooperative game models, the payoffs of $1j$ is the benefits obtained by using water, and therefore his payoff function is formulated by water demand models and the economic values. For player $2j$, $3j$, and $4j$, their payoffs are the cost to reduce waste water discharge, and thus their payoff functions are formulated by the model of waste water discharge and the cost to reduce the waste water. Equation (3.14) expresses the payoff function of the players.

$$V_{ij}^t = \begin{cases} f(\pm Q_{ij}^t), & i = 1, j = 0, 1, 2, 3 \\ g(-P_{ij}^t), & i = 2, 3, 4, j = 0, 1, 2, 3 \end{cases} \quad (3.14)$$

where V_{ij}^t - payoff of every player ij in time t , $+Q_{ij}^t$ - water obtained by every player ij in time t , $-Q_{ij}^t$ - water lost by every player ij in time t , $-P_{ij}^t$ - pollutants reduced by every player ij in time t .

Assumptions

- The games are finite with incomplete information;

- All the players are rational, and their aim is to maximize their welfares;
- If every player takes cooperative strategy, the game becomes cooperative game;
- The observation of water consumption of player 1 and his sub-players in each year and the observations of nitrogen discharge of players 2, 3 and 4 and their sub-players in each year are regarded as the game playing results in that year, respectively;
- There is no administrative intervention during game processing, but the game processing is influenced by the current policies;
- The cities in the same administrative regions should cooperate with each other due to the similar interests, i.e. C_1 , C_2 , and C_3 cooperation with each other; the same for C_4 and C_5 ;
- There are no losses for players of 2, 3 and 4 and their sub-players, but there is loss for play 1 in non-cooperative games;
- In cooperative situation, player of 1 and his sub-players will be better off since they have obtained the water that he need from the player 2, 3 and 4. However, players of 2, 3 and 4 and their sub-players will face losses due to pollutants reduction;
- Cooperation or non-cooperation of other players excluded from this example will depend on whether players 1, 2, 3 and 4 cooperate or non-cooperate;
- Water demand of each player keeps constant in different hydrological conditions;
- Player 1 and his sub-players have gain but no loss in the cooperative game;
- Players of 2, 3 and 4 and their sub-players have no loss in the non-cooperative game, but there are losses for them in the cooperative game;
- All data are authentic.

3.3.2 Game simulation processes

The simulation process can be illustrated in figure 3.16, which includes 5 games. These five games can be divided in two levels. Game 1 is the first level and games 1, 2, 3 and 4 are games at the second level. The games start simultaneously from the sub-games 1, 2, 3 and 4. In game 1, players 11, 12 and 13 seize water; they play both non-cooperative and cooperative games once. If either of the non-cooperative and cooperative sub-games can make every player better off, the game ends. If both the cooperative and non-cooperative games cannot make the sub-players better off, and then sub-players 11, 12 and 13 group and form player 1 and enter the game 5. The games of 2, 3 and 4 are pollutant reduction games. In these games, every sub-player will play non-cooperative games first. If the water

quality of the Danjiangkou Reservoir can meet the water quality standard based on the pollutants discharge in non-cooperative games, the games end. Otherwise, sub-players in each game will cooperate with each others and become player 2, 3 and 4 entering the game 5. In game 5, players 1, 2, 3 and 4 make non-cooperation and cooperation once. In order to simplify the problems, it is assumed that the game will be non-cooperative if any of the players does not cooperative with others. If it is a non-cooperative game, player 2, 3 and 4 maintain their current situation and the game ends. If all the players cooperate with each other, cooperative games results are obtained. Then the games come back to sub-games 2, 3 and 4, the cost-benefit results of cooperation games are obtained for every sub-player in these sub-games.

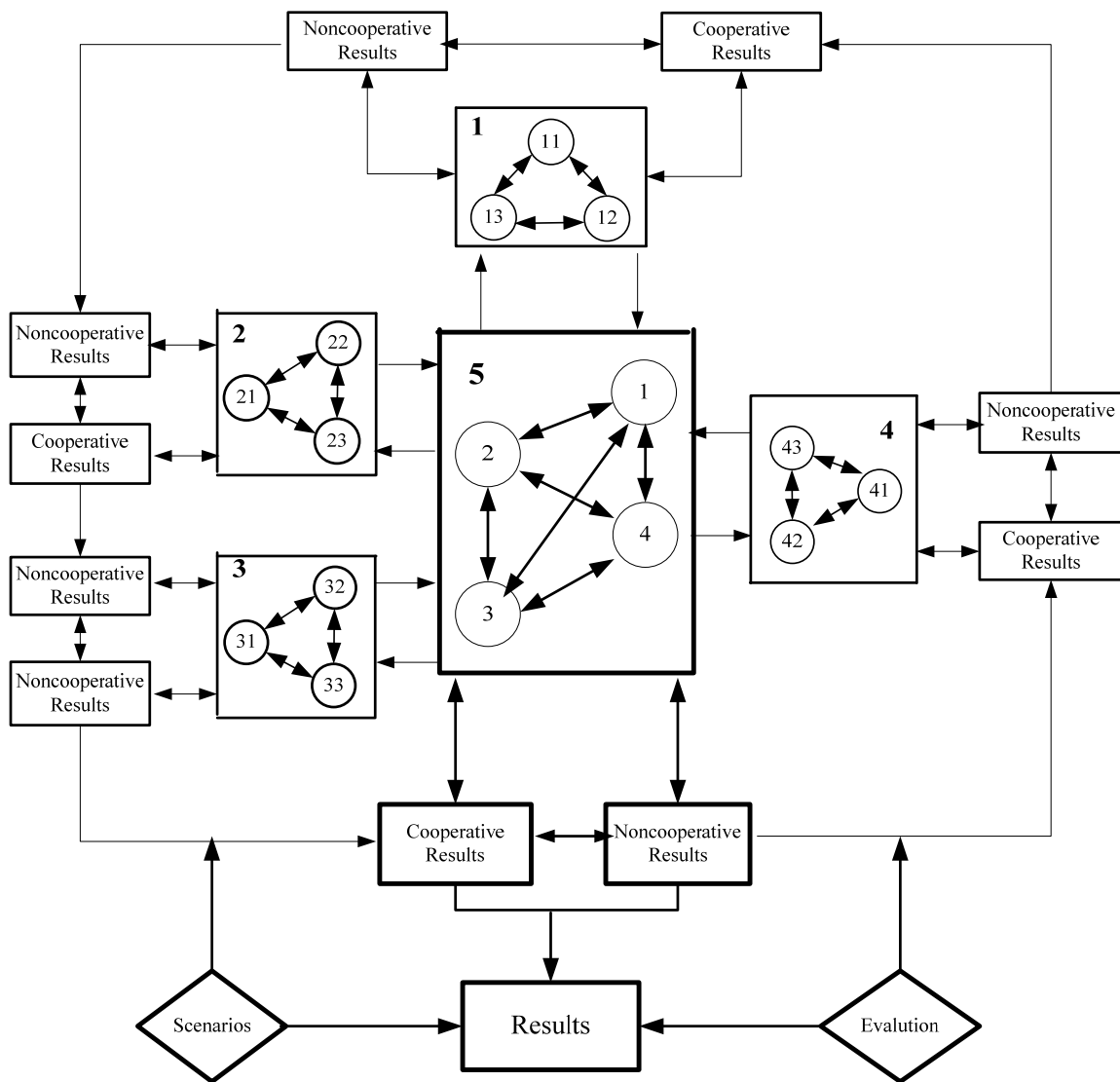


Figure 3.16: Game simulation process

Through all these games, non-cooperative and cooperative results are obtained. Non-cooperative results show the payoff that every player want to get, and cooperative results shows how they can maximize the collective benefits.

Game 1: Water seizing games

Player 11, 12 and 13 are facing severe problems of water deficits, and each player wants to get enough water for consumptions. To simplify the model, some assumptions are made as following:

- Each player has two strategies: to seize water (Y) and not to seize water (N);
- The maximum of annual water consumed by the players is equal to their real demand of that year, because that
- The game is influenced by current policy; that is to say, each player knows he cannot waste water. Government or departments concerned know or can calculate the real water demand of different players.
- The water consumed (Q_i) of every player in a year is the game equilibrium result of that year.

a) Non-cooperative game

This game can be simulated by game tree in figure 3.17. Suppose player 11 moves first, he has two strategies, overusing ecological water (Y) and non-overusing ecological water (N_n). Player 12 moves secondly, he knows player 11 has two strategies but he does not know what player 11 has really chosen. And then player 3 moves, he knows player 11 and 12 both have two strategies, but he does not know which one they have choose. In this game, every player knows that he will get more water if he does play strategy Y. Otherwise, he will have no much more water to use. Therefore, equilibrium is (Y,Y,Y), but this equilibrium sacrifices ecological water and agriculture water. Finally, the water gradually becomes much scarcer, and this causes the problem of “The Tragedy of Commons”

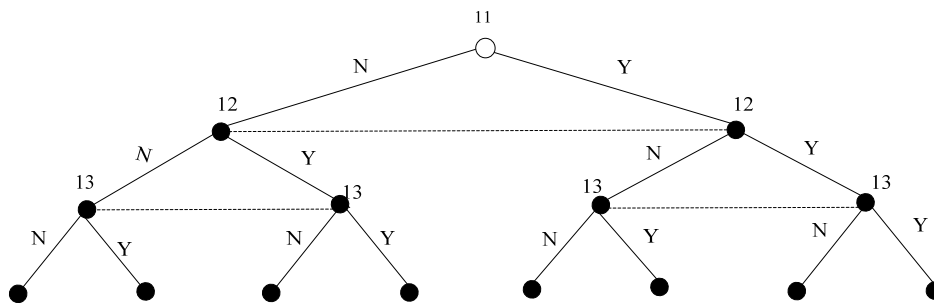


Figure 3.17: Game tree of water seizing game

In the reality, the games will be played one year by another. In this sense, the game is repeated and infinite dynamic game with incomplete information (Fig. 3.18). The parameters in the figure are defined follows:

$$\begin{aligned}
 &Q^t_{ljz} \geq Q^t_{ljx} \geq Q^t_{ljk} \text{ and } Q^t_{iz} \geq Q^t_{ljm} \geq Q^t_{ljk}, Q^t_{ljz} \geq Q^t_{ljn} \geq Q^t_{ljk}, \\
 &Q^t_{lj} > Q^t_{ljk}, \\
 &k, m, n, x, z \geq 0 \\
 &j = 1, 2, 3, t = [2010, 2015]
 \end{aligned}
 \tag{3.15}$$

where i – every player; t – time (years); Q^t_i – water consumption of different players; Q^t_{ljz} , Q^t_{ljx} , Q^t_{ljk} , Q^t_{ljm} , and Q^t_{ljn} – different water amounts that different players can get in different combined strategies; Q^t_{Ri} – real water demand of each players and Q_e^t – ecological water demand; Q^t_{ik} – water amount that every player should consume if they do not seize water.

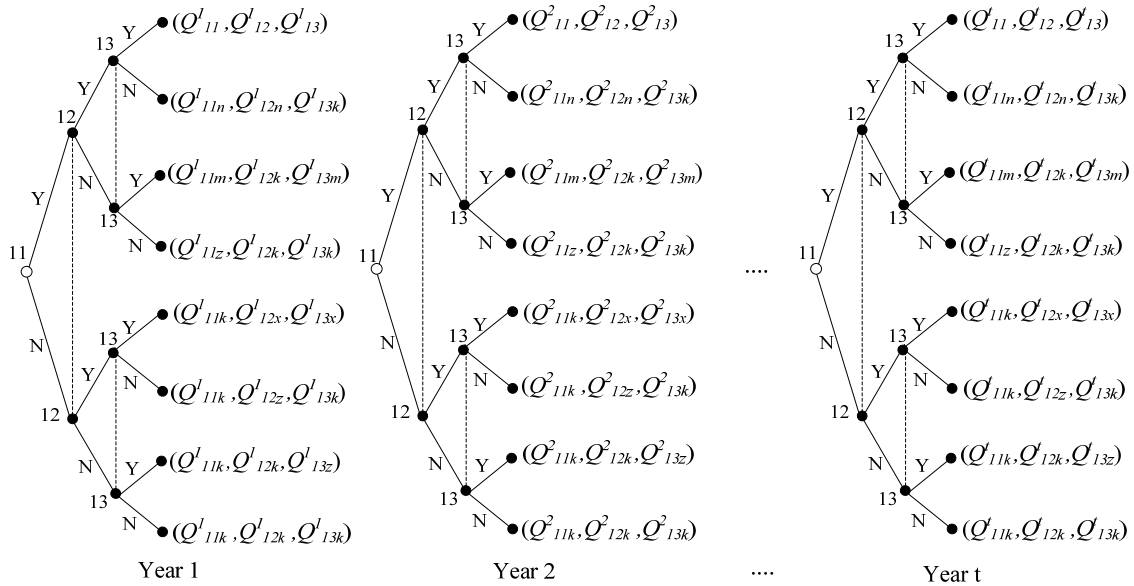


Figure 3.18: Water seizing game model

A model of Q_{11} (Fig. 3.19) is given by:

$$\text{LOG}(Q_{11}/V_{11}) = -0.179*t + 363.302 + [AR(1), MA(1)]
 \tag{3.16}$$

where Q_{11}/V_{11} – water demand per unit of added value of player 11, Q_{11} – water demand of player 11, V_{11} – added value of player 11 produced, $AR(1) = 0.672$, $MA(1) = 0.411$ with $R^2=0.993$ and adjusted $R^2 = 0.992$.

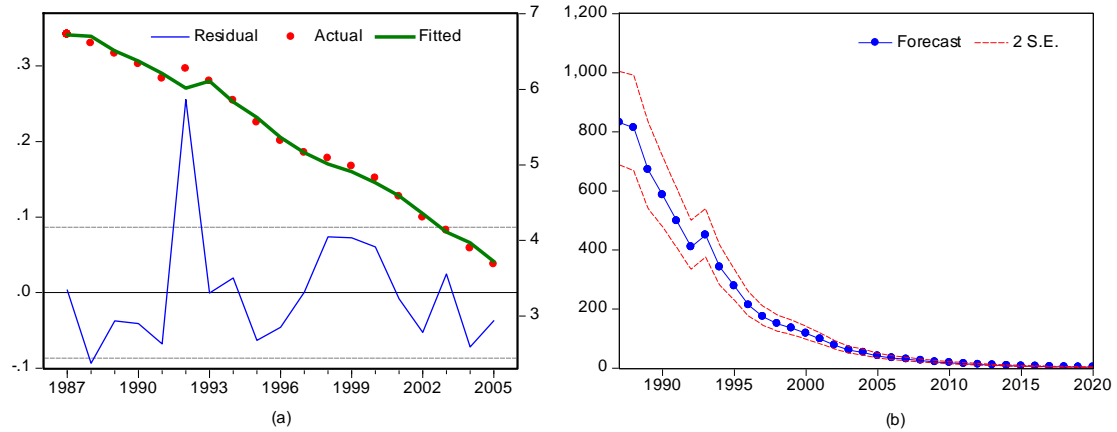


Figure 3.19: Water demand per unit added value (Q_{11}/V_{11}) ($\times 10^8 m^3/10,000$ RMB) of player 11
 (a) Semilog model, (b) The forecast

A model of V_{11} (fig. 3.20) is given by:

$$LOG(V_{11}) = -1900.353 + 250.906*LOG(t) + [AR(1), MA(1)] \tag{3.17}$$

where V_{11} – added value of player 11, $AR(1) = 0.541$, $MA(1) = 0.531$ with $R^2 = 0.997$ and adjusted $R^2 = 0.997$.

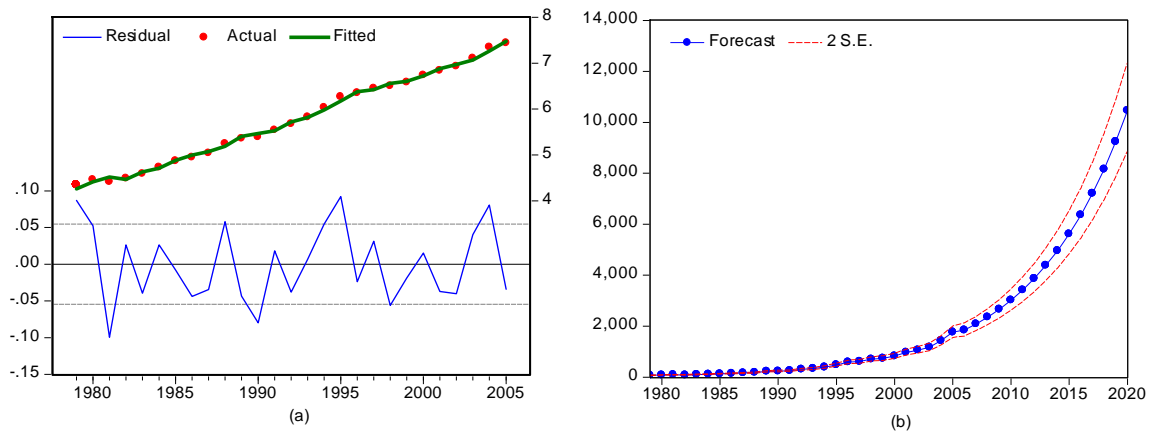


Figure 3.20: Added value (V_1) ($\times 10^8$ RMB) of player 1 (a) Double log model, (b) The forecast

A model of Q_{12} (fig. 3.21) is given by:

$$Q_{12} = 2.312*LOG(V_{12}) - 4.173 \tag{3.18}$$

where Q_{12} – water demand of player 12, V_{12} – values produced by player 12, $R^2 = 0.857$ and adjusted $R^2 = 0.849$.

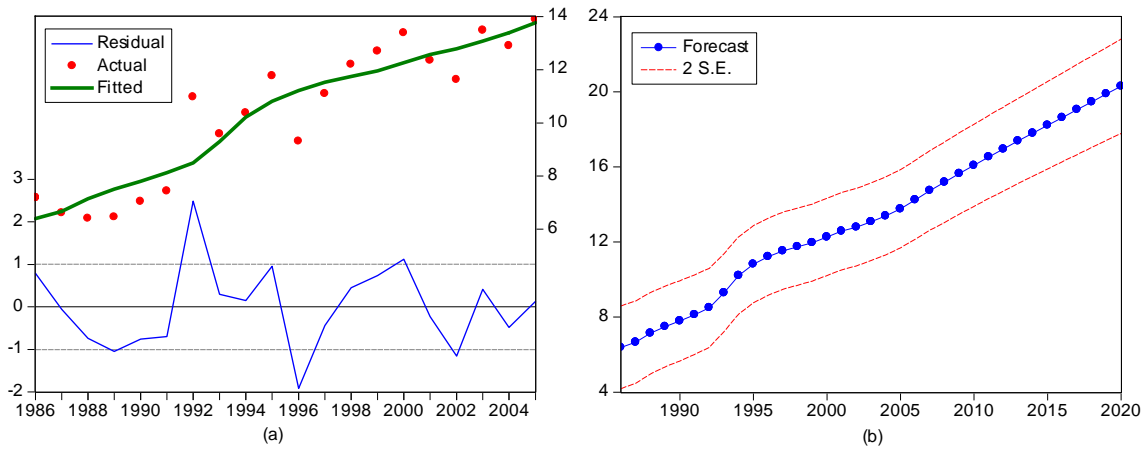


Figure 3.21: Water demand (Q_{12}) (m^3/RMB) of player 12 (a) Semilog model, (b) The forecast

A model of V_{12} (fig. 3.22) is given by:

$$LOG(V_{12}) = 0.169*t - 331.014 + [AR(1),MA(1)] \tag{3.19}$$

where V_{12} – added value of player 12, $AR(1) = 0.687$, $MA(1) = 0.997$, with $R^2 = 0.999$ and adjusted $R^2 = 0.998$.

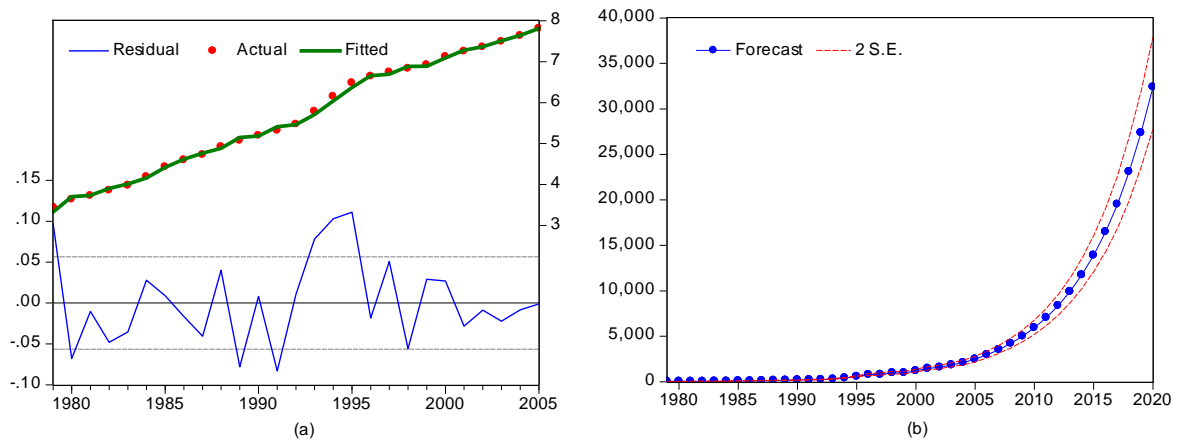


Figure 3.22: Added value (V_{12}) ($\times 10^8 RMB$) of player 12 (a) Semilog model, (b) The forecast

A model of Q_{13} (fig. 3.23) is given by:

$$LOG(Q_{13}/V_{13}) = 177.312 - 0.085*t + [AR(1)] \tag{3.20}$$

where Q_{13}/V_{13} – water demand per unit of added value of player 13, Q_{13} – water demand of player 13, V_{13} – added value of player 13, $AR(1) = 0.487$ with $R^2 = 0.969$ and adjusted $R^2 = 0.965$.

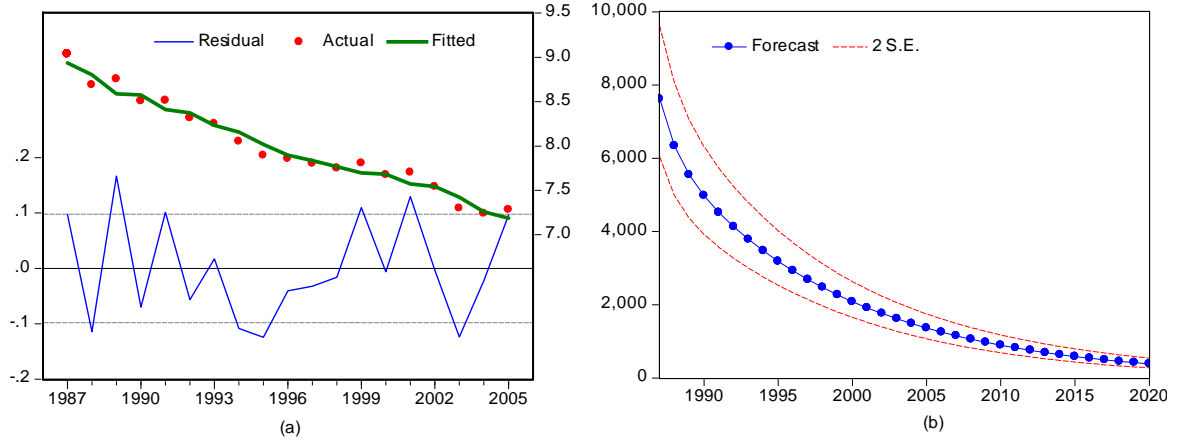


Figure 3.23: Water demand per unit of added value ($\times 10^3 \text{m}^3/10^4 \text{RMB}$) of the player 13
 (a) Semilog model, (b) The forecast

A model of V_{13} (fig. 3.24) is given by:

$$V_{13} = 3.855 * t - 7630.626 + [AR(I), MA(I)] \tag{3.21}$$

where V_{13} – added value of player 13, $AR(1) = 0.650$, $MA(1) = 0.296$ with $R^2 = 0.991$ and adjusted $R^2 = 0.989$.

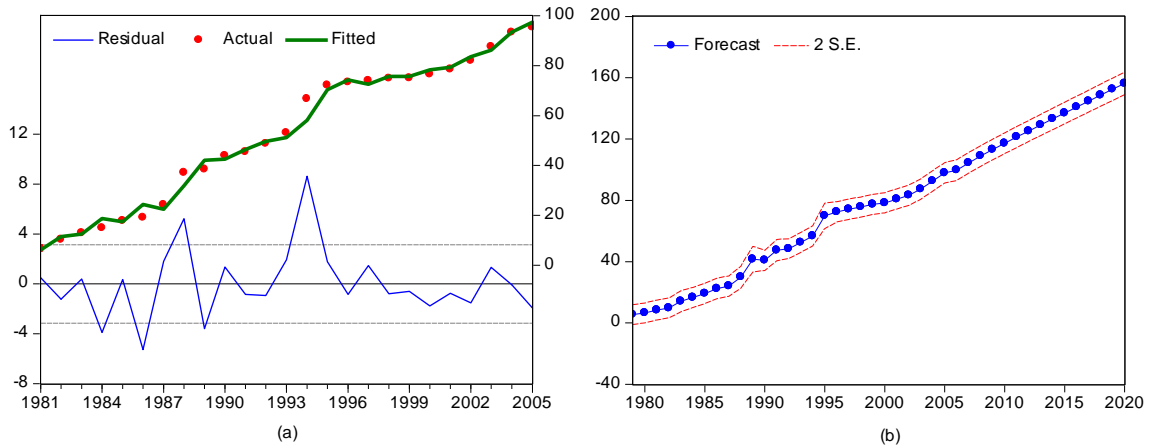


Figure 3.24: Added value (10^8RMB) of player 13 (a) Linear model, (b) The forecast

b) Cooperative game

In cooperative games, the players are willing to share their scarce water resources. The pay-offs of the players can be defined by:

$$Q_{1jk}^t = W_1^t * \psi_{1j} \tag{3.22}$$

$$W_1^t = S_1 + G_1 - O_1 + R_1^t - Q_{1e}^t \tag{3.23}$$

$$\psi_{1j}^t = Q_{1jR}^t * (\sum Q_{1jR}^t + Q_{1eR}^t)^{-1} \tag{3.24}$$

$$R_1^t = K * Q_w^t \tag{3.25}$$

$$Q_{1jR}^t = Q_{1j}^t, j = 1, 2, 3 \tag{3.26}$$

Where Q_{1jk}^t – water quartos that different players should consume if they do not seize water, W_1^t – total water resources, S_1^t – surface water resources, G_I – ground water recharge, O_I – overlap calculation between surface water resources and ground water recharge, R_1^t – reclaimed water from urban waste water, Q_{1e}^t – water consumption of the ecology, Q_{1eR}^t – real minimum ecological water demand, D_w^t – domestic waste water discharge, K – reclaiming rate of domestic waste water, ψ_{1j} – water distribution factor.

The ecological water use is influenced by planning in the area of scarcity water, and it is difficult to set up a model. Here it is assumed that future water ecological water use is the extrapolation of past and current trend. Figure 3.25(a) and (b) show the ecological water use during 2001 to 2005 and the fitting values in the future. The equation is expressed as follows:

$$Q_{1e} = -0.425 * D_t * t + 850.917 * D_t + 0.500 * t - 1000.200 \tag{3.27}$$

$$D_t = \begin{cases} 0 & \text{if } t = [2000-2001] \\ 1 & \text{otherwise} \end{cases}$$

where Q_{1e} – ecological water use, $R^2 = 0.999$ and adjusted $R^2 = 0.996$.

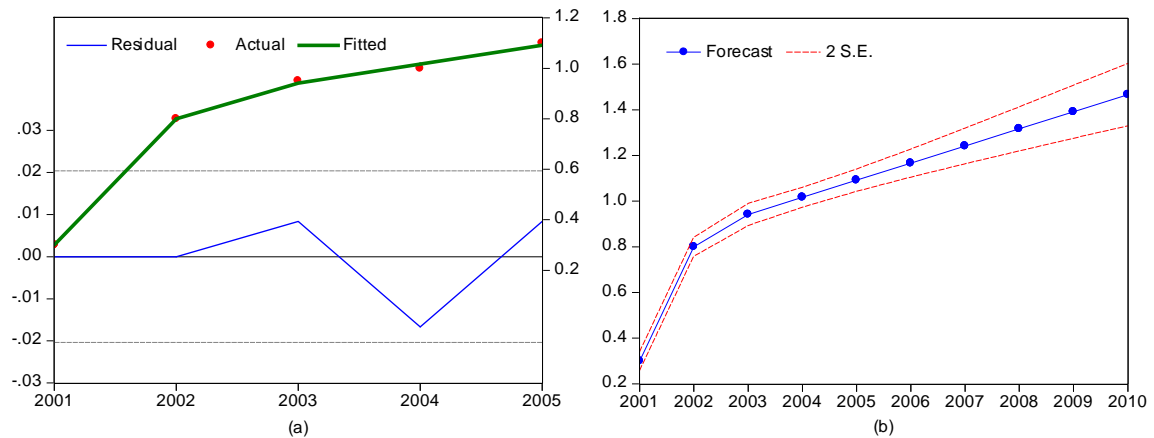


Figure 3.25: Ecological water use ($\times 10^8$ RMB) (a) Linear model, (b) The forecast

A model of D_w (Fig. 3.26) is given by:

$$D_w = 0.120 * t + 0.381 * D_t * t - 761.577 * D_t - 233.895 \tag{3.28}$$

$$D_t = \begin{cases} 0 & \text{if } t = [1986-1999] \\ 1 & \text{otherwise} \end{cases}$$

where D_w – domestic waste water discharge, $R^2 = 0.978$ and adjusted $R^2 = 0.974$

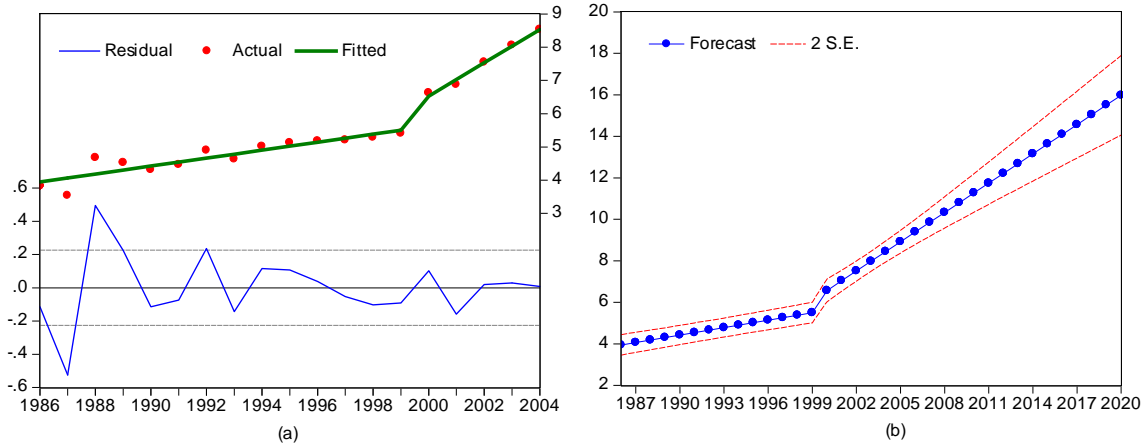


Figure 3.26: Domestic sewage discharge ($\times 10^8$ tons) (a) Linear model, (b) The forecast

The ecological water demand is the requirement of water amount to maintain and improve the balance of existing ecological system, which is composed of flora, fauna and non-organisms (Chen and Wang 2001). Therefore, minimum ecological water demand should consist of three parts: water for green plant, animals and maintaining organic balance in inorganic environment. In this paper, the minimum urban ecological water is calculated on the base urban water surface, public green area and newly planned trees. Q_{leR}^t is calculated by following equations:

$$Q_{leR}^t = Q_s^t + Q_g^t + Q_{tr}^t \tag{3.29}$$

$$Q_s^t = (E^t - P^t) * S_w * 10^{-5} \tag{3.30}$$

$$Q_g^t = S_g^t * D_g^t * 10^{-2} \tag{3.31}$$

$$Q_{tr}^t = N_{tr}^t * D_{tr}^t * 10^{-4} \tag{3.32}$$

where Q_{leR}^t – ecological water demand; Q_s^t – water demand of water surface; Q_g^t – water demand of public green area; Q_{tr}^t – water demand of trees, E^t – evaporation of water surface; P^t – precipitation; S_w – area of water surface; S_g^t – public green area; D_g^t – water quota for one unit of public green area; N_{tr}^t – the trees in a year; D_{tr}^t – water quota for a tree.

In Beijing, the urban water surface is about 598 km². The multi-annual average evaporation is 1100 mm and the multi-annual average precipitation is 587. According to the water quota to different fields, D_g^t is not more than 1m³/m² and D_r^t is not more than 3m³/tree.

A model of Q_{leR} (Fig. 3.27) is given by:

$$LOG(Q_{leR}) = 0.050*t - 98.302 + [MA(1)] \tag{3.33}$$

where Q_{leR} – ecological water demand, MA(1) = -0.997 with R² = 0.976 and adjusted R² = 0.964.

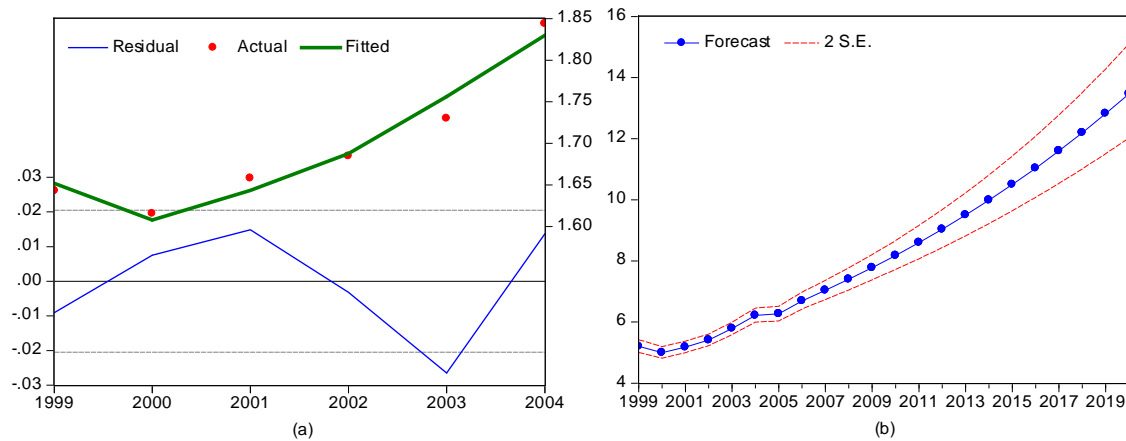


Figure 3.27: Ecological based water demand (×10⁸ m³) (a) Semilog model (b) The forecast

Games of 2, 3 and 4: Pollutants reduction games

In this section here, only non-cooperative games are illustrated because it is convenient to interpret if cooperative games are include into the game 5. Since the high concentration of total nitrogen (TN) is the main problem of water quality of Danjiangkou Reservoir, water quality management in this study refers to nitrogen reduction. Assume there are only two strategies for every sub-players $ij, i = 2, 3, 4, j = 1, 2, 3$ which are reducing pollutants (1) and not reducing pollutant (2). These games are illustrated in matrix 3.1.

Matrix 3.1: Games of pollutant reduction

$i1$		$i3$	$i2$	
			1	2
1	1	$-C^* P_{i1}^-, -C^* P_{i3}^-, -C^* P_{i2}^-$	$-C^*(P_{i1}^-+b), -C^*(P_{i3}^-+y), B_{i2}$	
	2	$-C^*(P_{i1}^-+a), B_{i3}+C_{i3}, -C^*(P_{i2}^-+e)$	$-C^*(P_{i1}^-+c), B_{i3}+C_{i3}, B_{i2}+C_{i2}$	
2	1	$B_{i1}+C_{i1}, -C^*(P_{i3}^-+x), -C^*(P_{i2}^-+f)$	$B_{i1}+C_{i1}, -C^*(P_{i3}^-+z), B_{i2}+C_{i2}$	
	2	$B_{i1}+C_{i1}, B_{i3}+C_{i3}, -C^*(P_{i2}^-+g)$	$C_{i1}^*, C_{i3}^*, C_{i2}^*$	

In the matrix, the first column represents of the strategies of sub-players $i1$, i.e. sub-players 21, 31 and 41; the second column the strategies of sub-players $i3$, i.e. sub-players 23, 33 and 43; and the third Column the strategies of sub-players $i2$, i.e. sub-players 22, 32 and 42. In each cells, the first expression is the payoff function of sub-players $i1$, and the second one the payoff function of sub-players $i3$, and the third one the payoff function of sub-players $i2$. In the cells, c is the cost to reduce one unit of pollutant, P_{i1}^- is the reducing amounts, B_{ij} is the benefit of every player get by free riding other players' achievement to reduce pollutants, C_{ij} is the cost of every player to reduce pollutant. It is defined that $c \geq b \geq 0$ and $c \geq a \geq 0$, $z \geq y \geq 0$ and $z \geq x \geq 0$, and $g \geq f \geq 0$ and $g \geq e \geq 0$. Those three games are prisoners' dilemma games, because every player has no incentive to reduce pollutants and he can benefit more by free-riding others' achievement. At the end, the deterioration of water body will increase.

The transporting process of nitrogen into the reservoir can be classified as (1) producing, (2) entering the rivers, (3) reaching into the reservoir, (4) nitrification/denitrification processing and forming the final concentration in reservoir. Part of the nitrogen will be decayed due to biochemical and ecological processes. This process is expressed as follows:

$$M_{ij}^{\rightarrow R} = P_{ij} \ell_{ij} \lambda_{ij} k_{ij} \varphi_{ij} \quad (3.34)$$

where ij – every player i and his every sub-player j , $M_{ij}^{\rightarrow R}$ – load of nitrogen discharged into the reservoir, P_{ij} – amount of nitrogen production, ℓ_{ij} , λ_{ij} , k_{ij} and φ_{ij} – generally called transport coefficients, i.e. respectively coefficient of nitrogen loss, coefficient of nitrogen into the river, coefficient of nitrogen into the reservoir as well as coefficient of nitrogen finally maintaining in the reservoir.

According to the studies (Yang et al. 2006, Cheng et al. 2006, Song et al. 2006), the values of nitrogen transport coefficients during the transporting processes from production into the reservoir are defined in table 3.10. ℓ_{ij} , λ_{ij} , k_{ij} and φ_{ij} represent respectively coefficient of nitrogen loss, coefficient of nitrogen into the river, coefficient of nitrogen into the reservoir as well as coefficient of nitrogen finally maintaining in the reservoir. Urban domestic sewage and industry waste water are transported by pipelines, and they are emitting directly into the local river surface. Therefore, nearly 100% of all nitrogen enters regional rivers, and thus rate of entering river is taken 1. This research does not consider nitrification and denitrification processes, that is to say the rate of nitrogen maintaining in the reservoir is 1.

Table 3.10: Different transportation coefficients of nitrogen

Nitrogen source	ℓ_2, ℓ_3, ℓ_4	$\lambda_2, \lambda_3, \lambda_4$	k_2	k_3, k_4	$\varphi_2, \varphi_3, \varphi_4$
Nitrogen fertilizer	0.10	0.96	0.80	0.90	1
Soil erosion	0.21	0.81	0.80	0.90	1
Urban domestic sewage	-	1.00	0.80	0.90	1
Industry waste water	-	1.00	0.80	0.90	1
Animal husbandry	0.10	0.96	0.80	0.90	1
Rural domestic life	0.10	0.96	0.80	0.90	1

The annual mean concentration of nitrogen reached in the reservoir is expressed as follows:

$$C_{ij}^{\rightarrow R} = M_{ij} * Q_f^{-1} \tag{3.35}$$

where $C_{ij}^{\rightarrow R}$ – annual average concentration of nitrogen reaching in the reservoir, Q_f – natural inflow of the reservoir.

Models of $P_{2l}, P_{3l},$ and P_{4l}

$$P_{il} = \ddot{W}_{il} * C_{iln} \tag{3.36}$$

$$i = 2, 3, 4$$

where \ddot{W}_{il} – waste water discharge of player il , C_{il} – nitrogen concentration of per unit of waste water.

A model of \ddot{W}_{2l} (Fig. 3.28) is given by:

$$LOG(\ddot{W}_{2l}) = -0.053 * t + 113.362 + [MA(1)] \tag{3.37}$$

where \ddot{W}_{2l} – waste water discharge of player 21, $MA(1) = 0.889$ with $R^2 = 0.989$ and adjusted $R^2 = 0.988$.

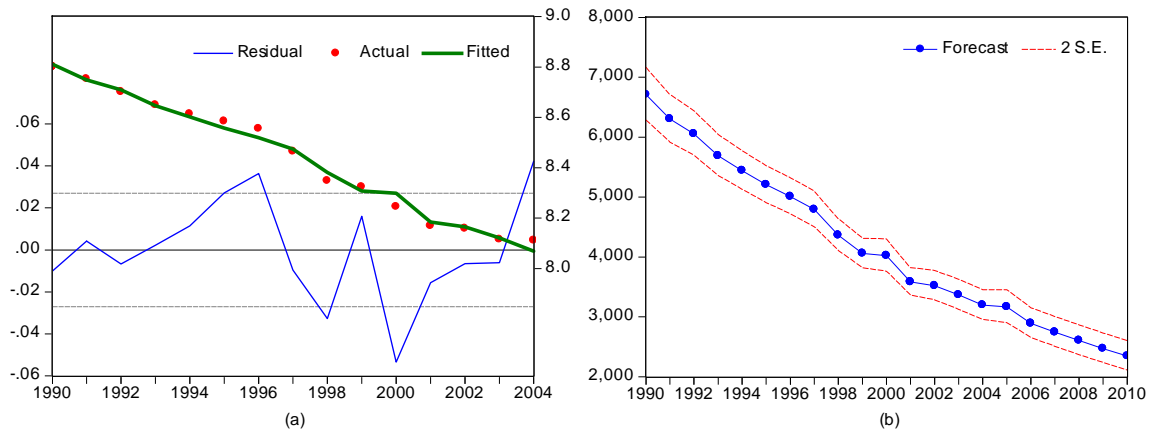


Figure 3.28: Waste water discharge (\ddot{W}_{2l}) ($\times 10^4$ tons) of player 21

(a) Semilog model, (b) The forecast

A model of \check{W}_{31} (Fig. 3.29) is given by:

$$\check{W}_{31} = -4126683.459 * D_t + 2062.973 * D_t * t + 2.164 * t + [MA(1)] \tag{3.38}$$

$$D_t = \begin{cases} 0 & \text{if } t = [1999-2000] \\ 1 & \text{otherwise} \end{cases}$$

where \check{W}_{31} – waste water discharge of player 21, MA(1) = 3.233 with $R^2 = 0.996$ and adjusted $R^2 = 0.994$.

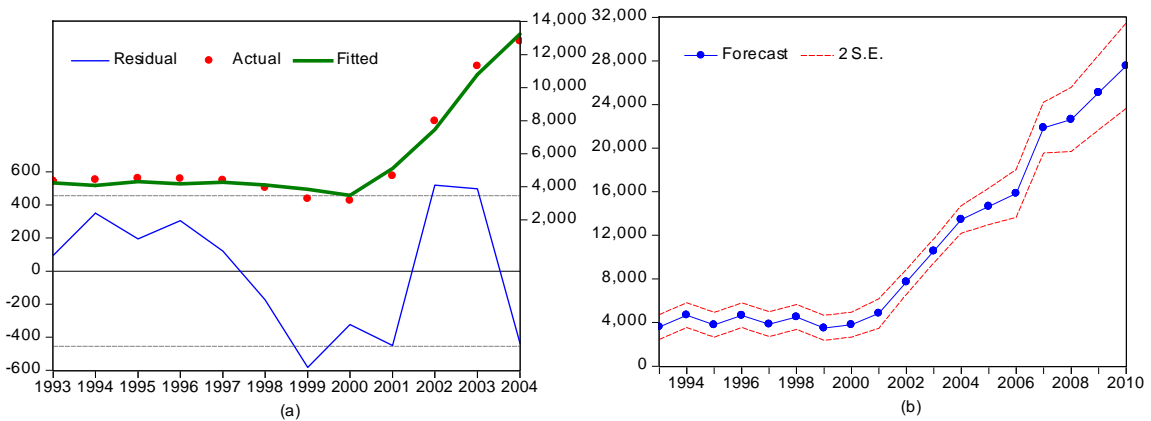


Figure 3.29: Waste water discharge (\check{W}_{31}) ($\times 10^4$ tons) of player 31
(a) Linear model, (b) The forecast

A model of \check{W}_{41} (Fig. 3.30) is given by:

$$\check{W}_{41} = 84.888 * t - 168530.538 + [AR(1)] \tag{3.39}$$

where \check{W}_{41} – waste water discharge of player 41, AR(1) = 0.031 with $R^2 = 0.993$ and adjusted $R^2 = 0.990$.

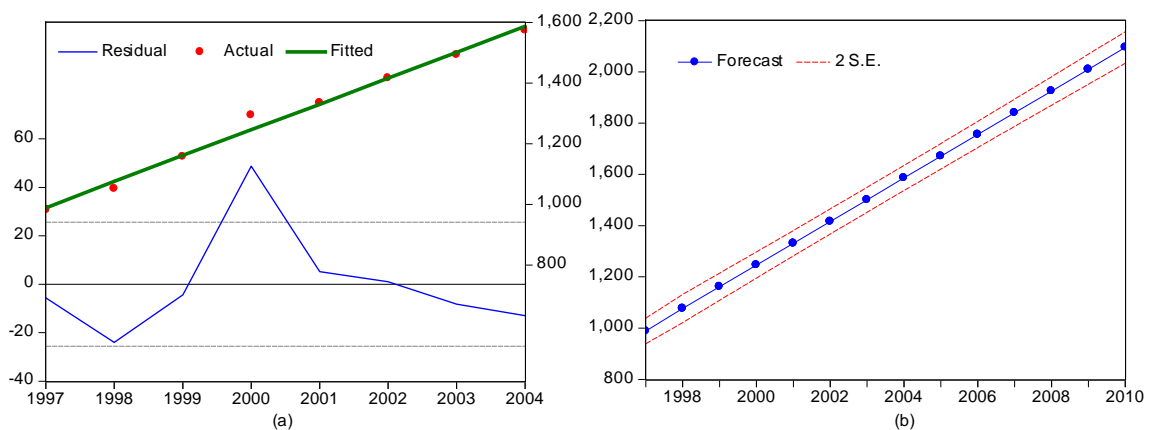


Figure 3.30: Waste water discharge (\check{W}_{41}) ($\times 10^4$ tons) of player 41
(a) Linear model (b) The forecast

Models of P_{i2} and P_{i3}

$$P_{i2U} = L_{i2U} * (J_1 + J_2) \tag{3.40}$$

$$P_{i3L} = L_{i3R} * (J_1 + J_2)$$

$$i = 2, 3, 4$$

where P_{i2} and P_{i3} – the nitrogen productions from urban and rural domestic life respectively; L_{i2U} , L_{i3R} – the urban and the rural population respectively; J_1 and J_2 – mean nitrogen amount per unit of manure and liquid of a person in one year.

According to the study on the spatial and temporal change of nitrogen and phosphorus produced by livestock and poultry and their effects on non-point pollution in China (Wu, 2005), the average annual nitrogen amounts produced by a person and a pig was presented in table 3.11.

Table 3.11: Average N amount produced by a person and a pig per year ($\text{kg} \cdot \text{a}^{-1}$)

Type	J_1	J_2	J_3	J_4
Amount	1.32	3.07	7.58	3.93

A model of L_{22U} (Fig. 3.31) is given by:

$$L_{22U} = 4.336 * t - 8538.739 + [AR(1)] \tag{3.41}$$

where L_{22U} – the urban population of player 22, $AR(1) = 0.508$ with $R^2 = 0.990$ and adjusted $R^2 = 0.988$.

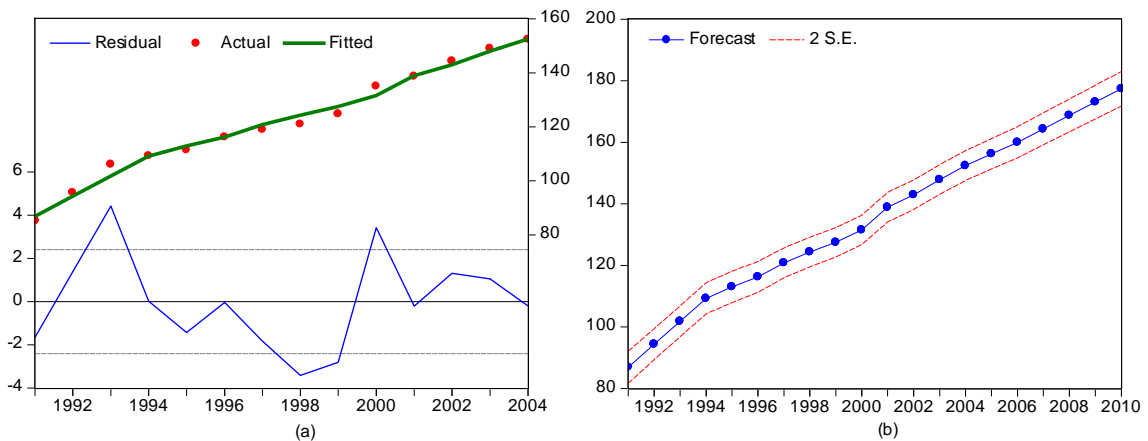


Figure 3.31: Urban population (U) ($\times 10^4$ persons) of player 22

(a) Linear model, (b) The forecast

A model of L_{23R} (Fig. 3.32) is given by:

$$L_{23R} = -1.946 * t + 4656.120 + [AR(1)] \tag{3.42}$$

where L_{23R} – the rural population of player 23, $AR(1) = 0.505$ with $R^2 = 0.936$ and adjusted $R^2 = 0.926$.

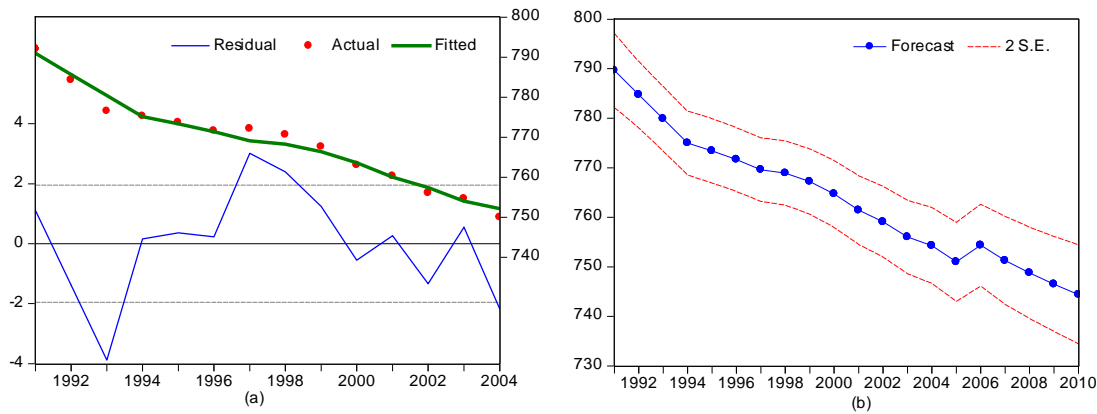


Figure 3.32: Rural population (R) ($\times 10^4$ persons) of player 23 (a) Linear model, (b) The forecast

A model of L_{32U} and L_{33U} (Fig. 3.33) is given by:

$$L_{32U} = 0.053 * t - 101.583 + [MA(I)] \tag{3.43}$$

where L_{32U} – the urban population of player 32, $MA(1) = 0.962$ with $R^2 = 0.993$ and adjusted $R^2 = 0.992$.

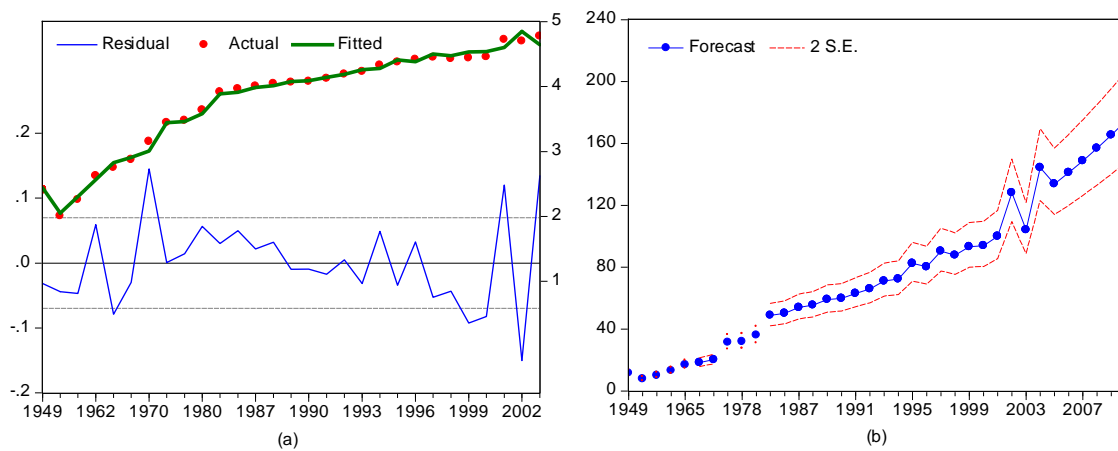


Figure 3.33: Urban population (U) ($\times 10^4$ persons) of player 32

(a) Linear model, (b) The forecast

A model of L_{33R} (Fig. 3.34) is given by:

$$L_{33R} = 2.409 * t - 5.966 * D_t * t + 11880.667 * D_t - 4525.623 + [MA(I)] \tag{3.44}$$

$$D_t = \begin{cases} 0 & \text{if } t = [1949 - 1991] \\ 1 & \text{otherwise} \end{cases}$$

where L_{33R} - the rural population of player 33, $MA(1) = 0.672$, with $R^2 = 0.973$ and adjusted $R^2 = 0.969$.

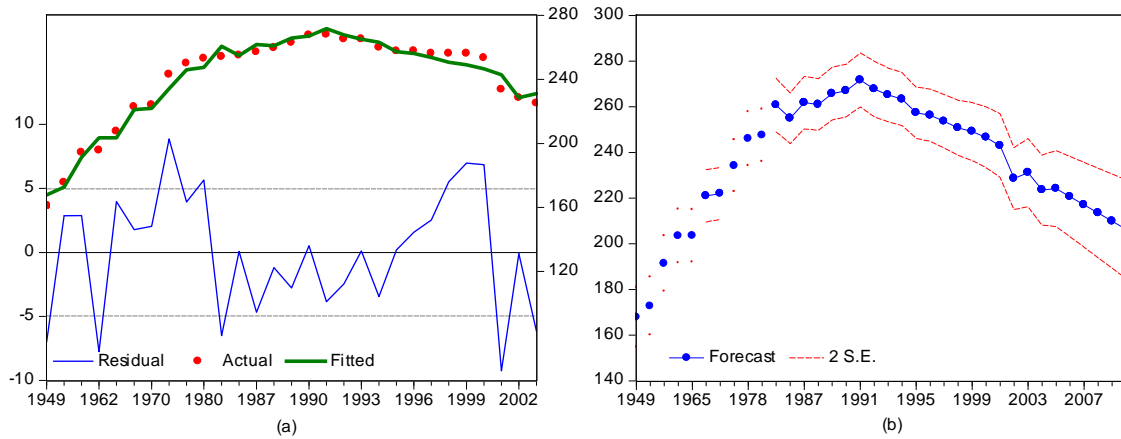


Figure 3.34: Rural population (R) ($\times 10^4$ persons) of player 33 (a) Linear model, (b) The forecast

A model of L_{42U} and L_{43U} (Fig. 3.35) is given by:

$$L_{42U} = 0.409 * t + 9.755 * D_t - 805.724 \tag{3.45}$$

$$D_t = \begin{cases} 0 & \text{if } t = [1993 - 2003] \\ 1 & \text{otherwise} \end{cases}$$

where L_{42U} – urban population of player 42, $R^2 = 0.995$ and adjusted $R^2 = 0.993$.

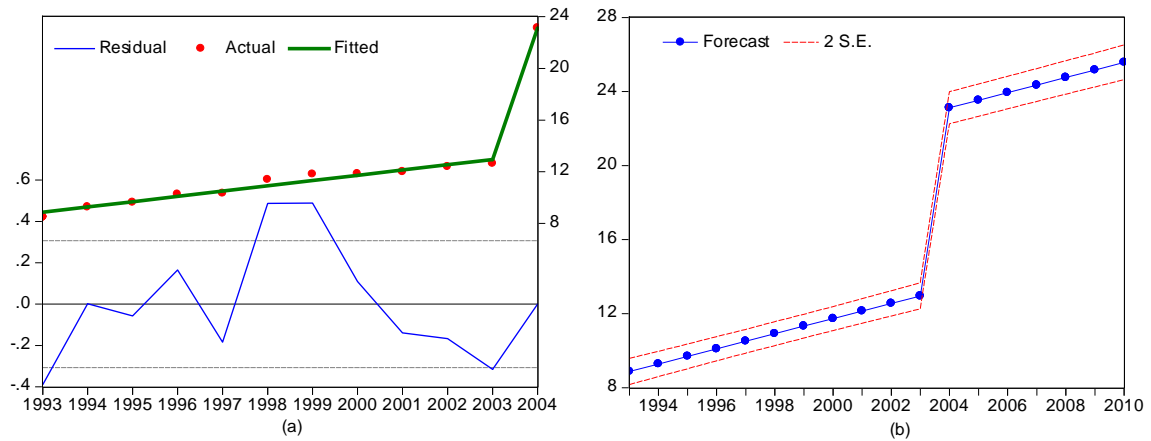


Figure 3.35: Urban population (U) ($\times 10^4$ persons) of player 42

(a) Linear model, (b) The forecast

A model of L_{43R} (Fig. 3.36) is given by:

$$L_{43R} = -3.011 * D_t * T + 6019.822 * D_t + 0.050 * t + [AR(1)] \tag{3.46}$$

$$D_t = \begin{cases} 0 & \text{if } t = [1993 - 2003] \\ 1 & \text{otherwise} \end{cases}$$

where L_{42R} – rural population of the player 43, $AR(1)=0.300$ with $R^2 = 0.982$ and adjusted $R^2 = 0.975$.

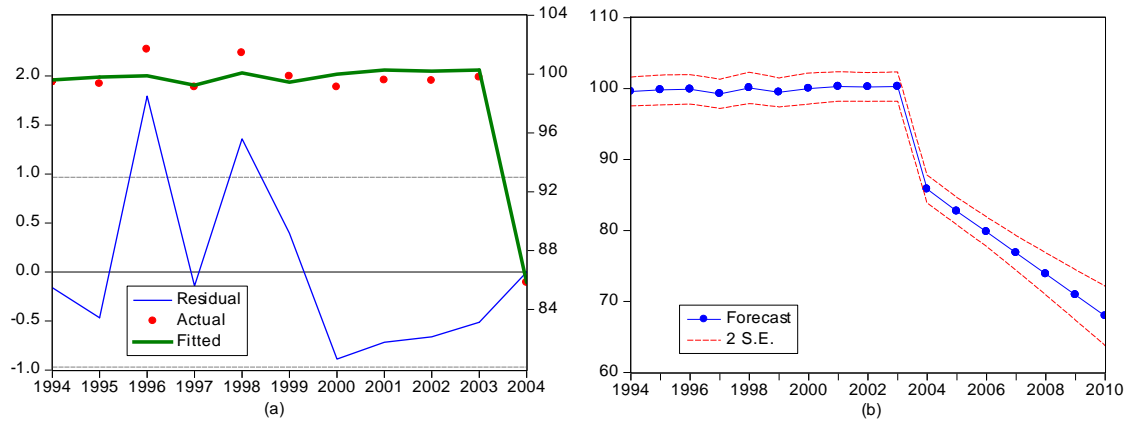


Figure 3.36: Rural population (R) ($\times 10^4$ persons) of the player 43 (a) Linear model, (b) The forecast

Models of \check{W}_{22} (Fig.3.37) is given by:

$$\check{W}_{22} = 0.787 * \check{W}_{22} (-3) - 2.186 * \check{W}_{22} (-2) + 2.405 * \check{W}_{22} (-1) \tag{3.47}$$

where \check{W}_{22} – urban domestic sewage discharge of player 22, $R^2 = 0.949$ and adjusted $R^2 = 0.938$.

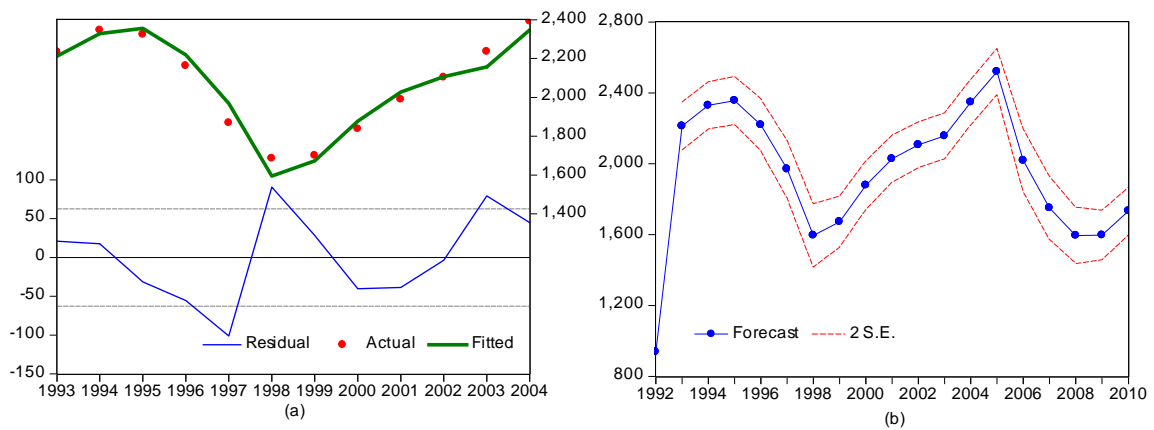


Figure 3.37: Domestic sewage discharge (\check{W}_{22}) ($\times 10^4$ tons) of player 22
(a) VAR model, (b) The forecast

Models of \check{W}_{32} (Fig. 3.38) is given by:

$$\check{W}_{32} = -320.491 * D_t * t + 637561.476 * D_t + 557.906 * t - 1105147.205 + [MA(3)] \tag{3.48}$$

$$D_t = \begin{cases} 0 & \text{if } t = [1985 - 1995] \\ 1 & \text{otherwise} \end{cases}$$

where \check{W}_{32} – domestic waste water discharge of player 32, $MA(3) = -0.862$ with $R^2 = 0.953$ and adjusted $R^2 = 0.940$.

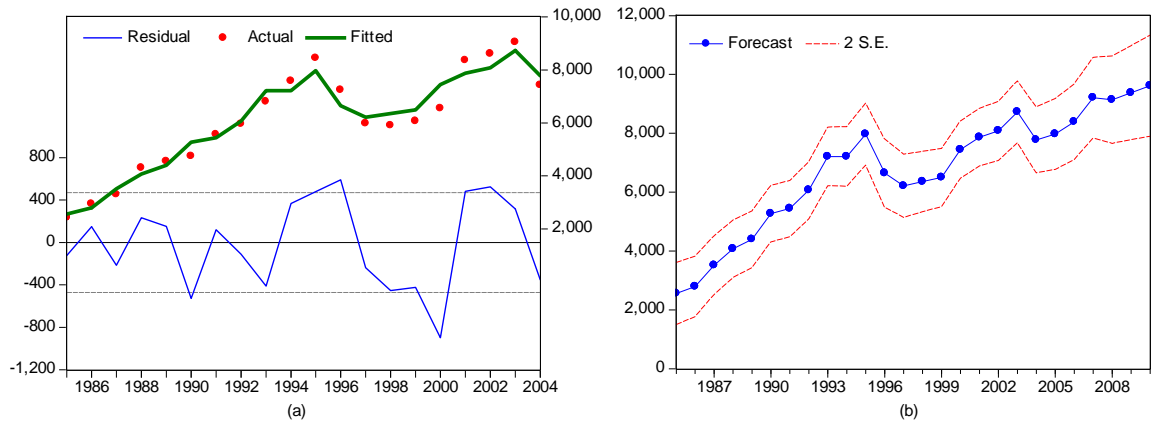


Figure 3.38: Domestic sewage discharge (\check{W}_{32}) ($\times 10^4$ tons) of player 32

(a) Linear model, (b) The forecast

Models of \check{W}_{42} (Fig.3.39) is given by:

$$\check{W}_{42} = 101.366 * D_t * t - 202650.666342 * D_t + 0.311 * t + [AR(1)] \tag{3.49}$$

$$D_t = \begin{cases} 0 & \text{if } t = [1993 - 2003] \\ 1 & \text{otherwise} \end{cases}$$

Where \check{W}_{42} – domestic waste water discharge of player 42, $AR(1) = 0.684$, $MA(1) = 0.997$, with $R^2 = 0.988$ and adjusted $R^2 = 0.981$

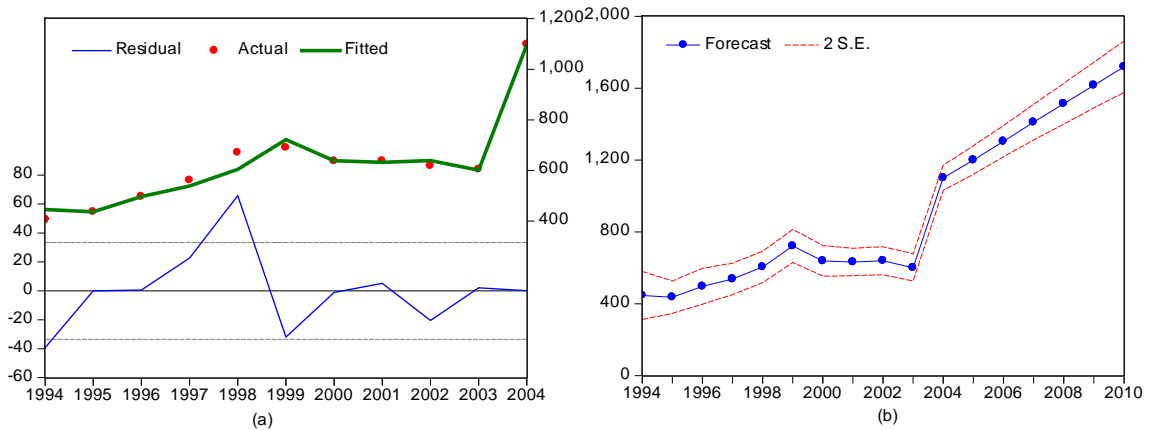


Figure 3.39: Domestic sewage discharge (\check{W}_{42}) ($\times 10^4$ tons) of player 42.

(a) Linear model, (b) The forecast

Models of P_{23} , P_{33} , and P_{33} :

A model of P_{i3}

$$P_{i3} = P_{i3A} + P_{i3F} + P_{i3S} \tag{3.50}$$

$$P_{i3A} = \sum[\ddot{O}_{i3}*(J_3+J_4)]*R_A \tag{3.51}$$

$$\ddot{O}_{i3} \approx P_g + 5*L_a + 2^{-l}G_s + 30^{-1}P_o \tag{3.52}$$

$$P_{i3F} = F_{i3}*R_F \tag{3.53}$$

$$P_{i3S} = S_{i3}*R_S \tag{3.54}$$

$$i = 2, 3, 4 \tag{3.55}$$

where P_{i3} – nitrogen produced by every player of $i3$; P_{i3A} , P_{i3F} and P_{i3S} – nitrogen produced by animal husbandry, fertilizer consumptions per year and soil erosion respectively, \ddot{O}_{i3} – number of pig equivalences, i.e. all the livestock and poultry are weighted by pig unit, J_3 , J_4 – nitrogen amount per year in the manure of livestock and poultry, R_A – nitrogen loss rate of the manure of livestock and poultry, F_N – the amount of nitrogen fertilizer used per year, R_F – the loss rate of N fertilizer, S_E – the area of soil erosion (i.e. table 3.6 in section 3.1.3), and R_S – the loss rate of N per unit of soil erosion, P_g , L_a , G_s and P_o – numbers of pigs, large animals, goats and sheep as well as poultry respectively.

A model of number of pig equivalence of player 23 (Fig. 3.40):

$$\ddot{O}_{23} = 33.229*D_t*t - 66512.422*D_t + 0.463*t + [MA(1)] \tag{3.56}$$

$$D_t = \begin{cases} 0 & \text{if } t = [1990-1996] \\ 1 & \text{otherwise} \end{cases}$$

where \ddot{O}_{23} – number of pig equivalences of player 23, MA(1) = 0.997 with $R^2 = 0.953$ and adjusted $R^2 = 0.941$.

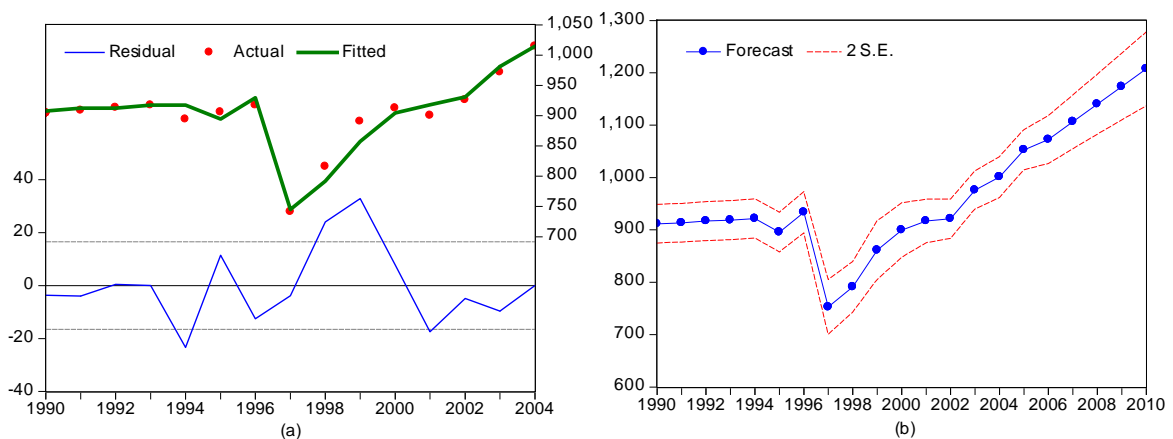


Figure 3.40: Pig equivalences (\ddot{O}) ($\times 10^4$ units) of player 23 (a) Linear model, (b) The forecast

A model of number of pig equivalences of player 33 (Fig. 3.41):

$$\ddot{O}_{33} = -0.800* \ddot{O}_{33} (-2) + 1.477* \ddot{O}_{33} (-1) + 0.050*t + [MA(1)] \tag{3.57}$$

where \ddot{O}_{33} – number of pig equivalence of player 33, $MA(1) = -0.947$ with $R^2 = 0.940$ and adjusted $R^2 = 0.915$.

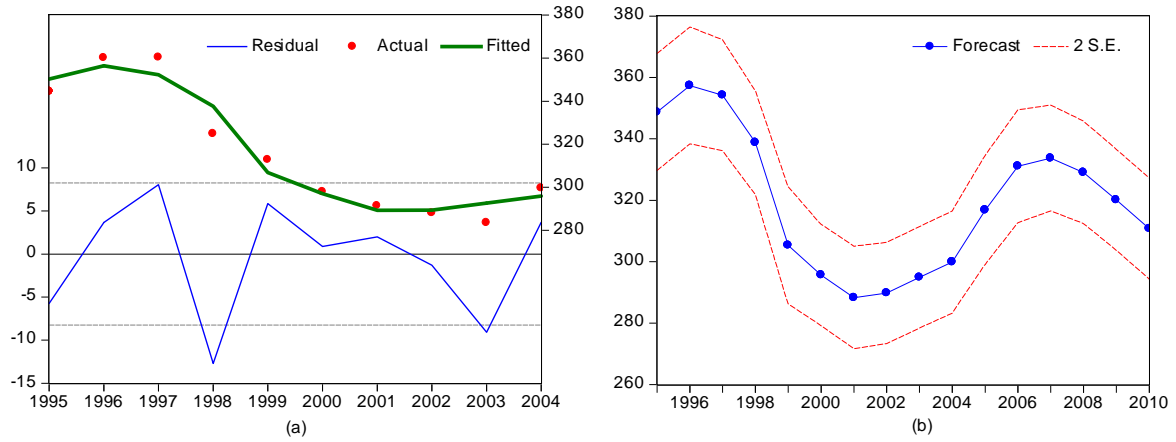


Figure 3.41: Pig equivalences (\ddot{O}) ($\times 10^4$ units) of player 33 (a) Linear model (b) The forecast

A model of number of pig equivalences of player 43 (Fig. 3.42):

$$LOG(\ddot{O}_{43}) = 0.098 * D_t * t - 196.505 * D_t - 0.042 * t + 89.764 \tag{3.58}$$

$$D_t = \begin{cases} 0 & \text{if } t = [1996-1998] \\ 1 & \text{otherwise} \end{cases}$$

where \ddot{O}_{43} – number of pig equivalences of player 43, with $R^2 = 0.988$ and adjusted $R^2 = 0.982$.

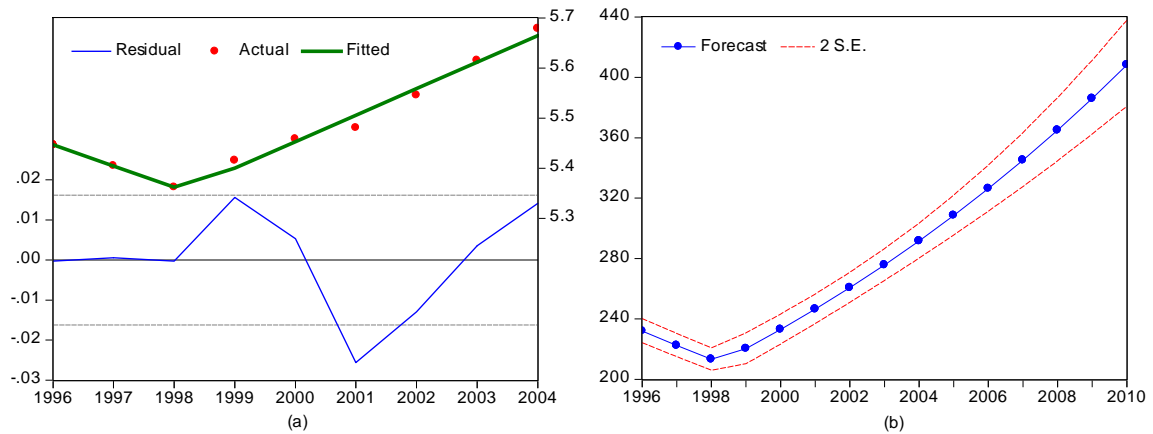


Figure 3.42: Pig equivalences (\ddot{O}) ($\times 10^4$ units) of player 43 (a) Semilog model, (b) The forecast

A model of nitrogen fertilizer consumptions of player 23 (Fig. 3.43) is given by:

$$F_{23} = 9.673 * LOG(F_{33}(-1)) - 1.496 * LOG(t) + [MA(1)] \tag{3.59}$$

where F_{23} – nitrogen fertilizer consumptions of player 23, $MA(1) = -0.997$, with $R^2 = 0.949$ and adjusted $R^2 = 0.940$.

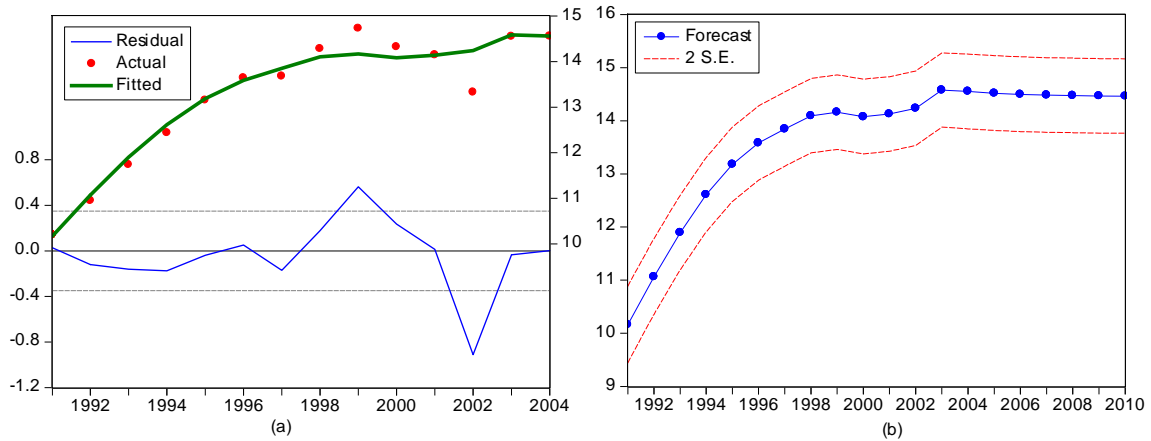


Figure 3.43: Nitrogen fertilizer consumptions (F) ($\times 10^4$ tons) of player 23
 (a) Linear model, (b) The forecast

A model of nitrogen fertilizer consumptions of player 33 (Fig. 3.43) is given by:

$$F_{33} = 0.149*t - 293.154 + [MA(1)] \tag{3.60}$$

where F_{33} – nitrogen fertilizer consumptions of player 33, $MA(1) = -0.927$ with $R^2 = 0.840$ and adjusted $R^2 = 0.810$.

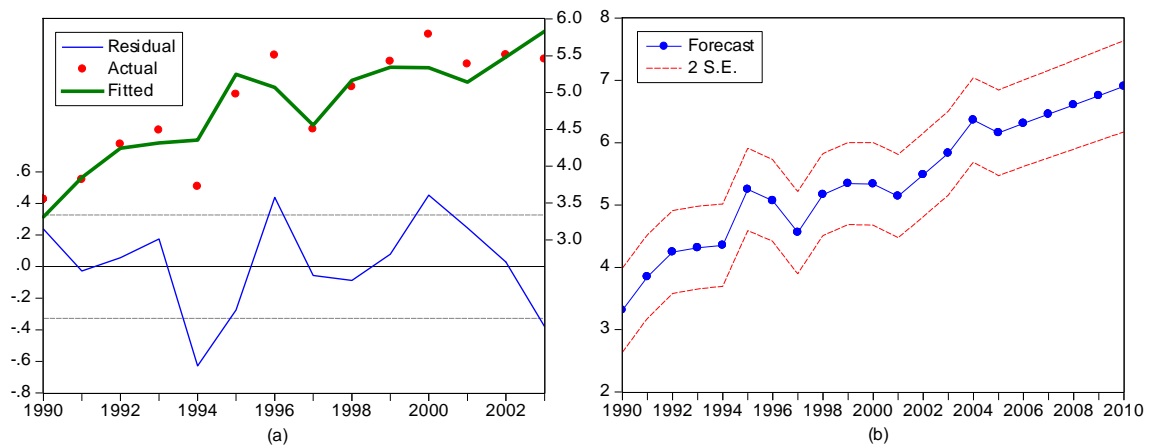


Figure 3.44: Nitrogen fertilizer consumptions (F) ($\times 10^4$ tons) of player 33
 (a) Linear model, (b) The forecast

A model of nitrogen fertilizer consumptions of player 43 (Fig. 3.44) is given by:

$$LOG(F_{43}) = 0.068*t - 135.858 + [AR(1),MA(2)] \tag{3.61}$$

where F_{33} – nitrogen fertilizer consumptions of player 43, $AR(1) = 0.866$, $MA(2) = -1.228$ with $R^2 = 0.983$ and adjusted $R^2 = 0.976$.

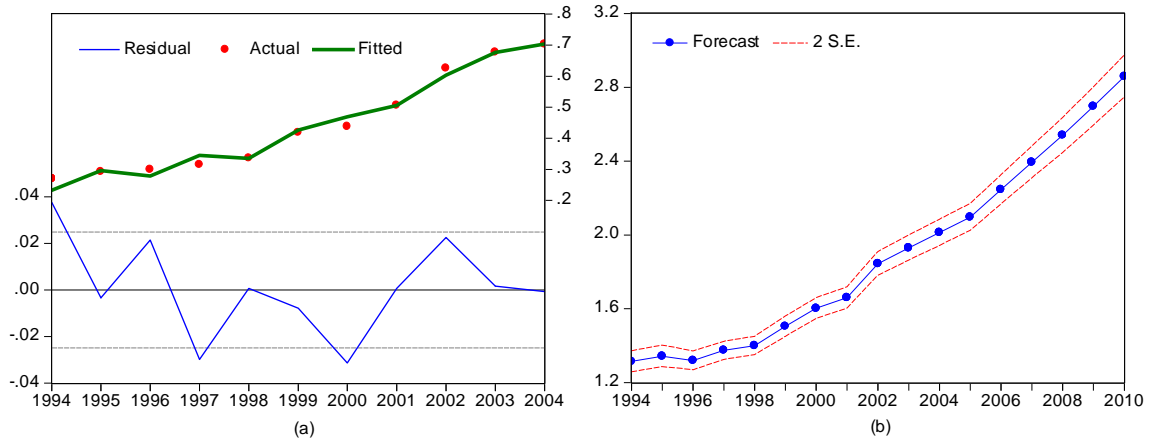


Figure 3.45: Nitrogen fertilizer consumptions (F) ($\times 10^4$ tons) of player 43
 (a) Semilog model, (b) The forecast

Game 5: TN reduction game for the Danjiangkou Reservoir

To simplify the issue, it is assumed every player in this game has just two strategies, non-cooperation (1) and cooperation (2). Player 1 moves first, and then player 2, 3 and 4 (Fig. 3.46). If player 1 does not cooperate with others, others will not cooperate with each other and the game becomes non-cooperative game. If player 1 cooperates, others will cooperate and the game becomes cooperative game. This game is a dynamic, repeated game with completed information.

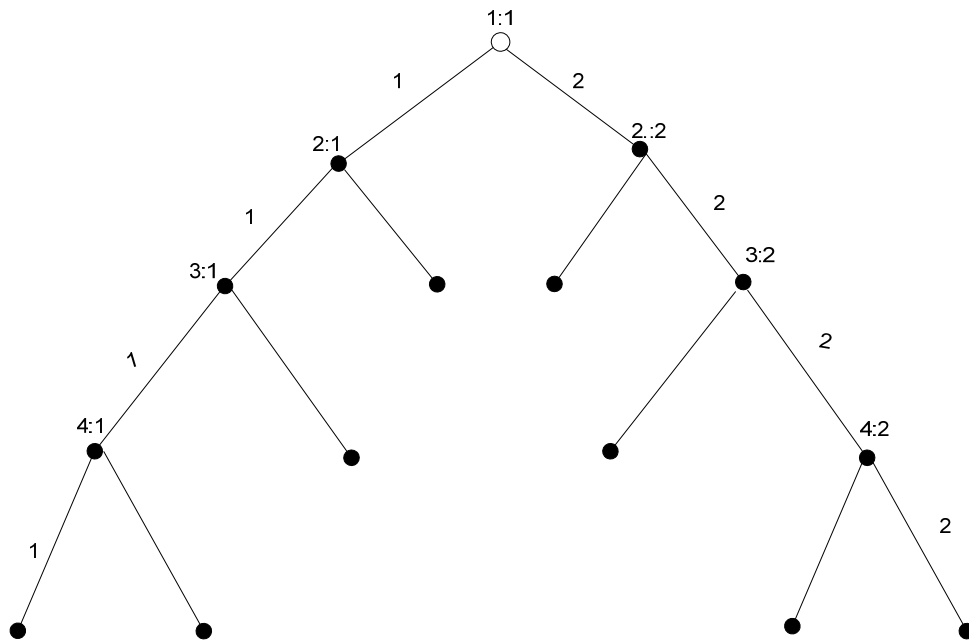


Figure 3.46: Game tree of TN reduction for the Danjiangkou Reservoir

a) Non-cooperative game

If every player is not cooperative, player 1 cannot get the water to make up his water deficit. Therefore, there is loss for him.

$$C_{1j} = \sum \beta_{1j} * (-Q_{1j}) \tag{3.62}$$

$$\beta_{1j} = V_{1j} / Q_{1j} \tag{3.63}$$

$$-Q_{1j} = Q_{1j} - Q_{1jk} \tag{3.64}$$

$$j = 1, 2, 3 \tag{3.65}$$

where C – the loss resulting from water deficit; $-Q_{1j}$ – the amount of water deficits; β – benefit coefficients, i.e. the values produced by per unit of water; V_{1j} – the added values or net income; Q_{1j} – the water consumed.

Models of β_{1j}

A model of β_{11} (Fig. 3.47) is given by:

$$LOG(\beta_{11}) = 0.184 * t - 364.348 + [AR(1)] \tag{3.66}$$

where β_{11} – Benefit coefficient of player 11, AR(1)=0.580 with $R^2 = 0.992$ and adjusted $R^2 = 0.991$.

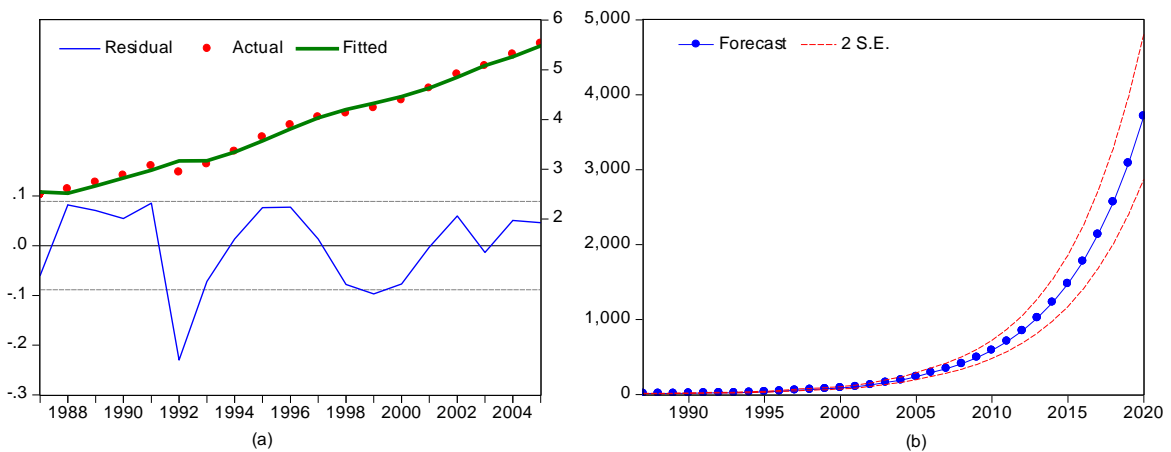


Figure 3.47: Benefit coefficient of player 11 (a) Semilog model, (b) The forecast

A model of β_{12} (Fig. 3.48) is given by:

$$LOG(\beta_{12}) = 0.134 * t - 262.913 + [MA(1)] \tag{3.67}$$

where β_{12} – Benefit coefficient of player 12, MA(1)=0.515 with $R^2 = 0.973$ and adjusted $R^2 = 0.970$

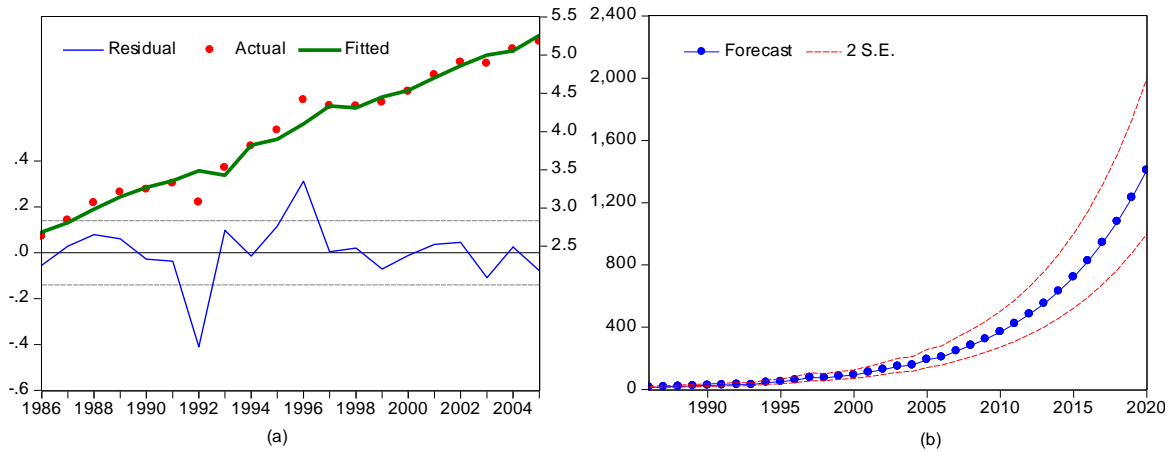


Figure 3.48: Benefit coefficient of player 12 (a) Semilog model, (b) The forecast

A model of β_{13} (Fig. 3.49) is given by:

$$LOG(\beta_{13}) = 0.085*t - 168.102 + [AR(1)] \tag{3.68}$$

where β_{13} – Benefit coefficient of player 13, $AR(1) = 0.487$ with $R^2 = 0.969$ and adjusted $R^2 = 0.965$

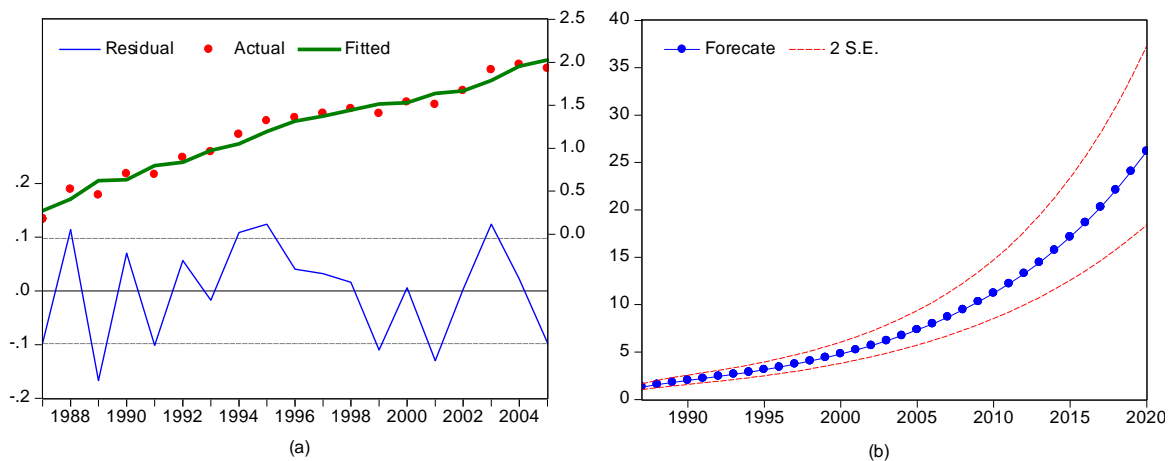


Figure 3.49: Benefit coefficient of player 13 (a) Semilog model, (b) The forecast

b) Cooperative game:

In the cooperative games, player 1 and his sub-players obtain water for development, and players 2, 3 and 4 and their sub-players are willing to impose cost to reduce nitrogen pollutants. The benefits and costs can be expressed by the following equations:

$$B_{1j} = -C_{1j}, \tag{3.69}$$

$$C_{ij} = \gamma_{ij} \dot{W}_{ij} P_{ij}^{-1} (\sum \sum P_{ij}^{-1})^{-1}, j = 1 \text{ and } 2U \tag{3.70}$$

$$C_{ij} = \gamma_{ij} L_R / 4, j = 2R \text{ and } 2A \tag{3.71}$$

$$C_{i3s} = \gamma_{ij} S_R \tag{3.72}$$

$$C_{i3F} = f(V_{i3}, F_{i3}, t) \tag{3.73}$$

$$P_{ij}^- = C_{ij}^- Q_f (\ell_{ij} \lambda_{ij} k_{ij} \phi_{ij})^{-1} \tag{3.74}$$

$$P_{ij}^- = P_{ij}^{\rightarrow R} (P^{\rightarrow R})^{-1} P^- \tag{3.75}$$

$$P^{\rightarrow R} = \left(\sum_{i=2}^4 \sum_{j=1}^3 P_{ij}^{\rightarrow R} \right) \tag{3.76}$$

$$P^- = P^{\rightarrow R} - P_s \tag{3.77}$$

$$P_s = C_s Q_f \tag{3.78}$$

$$i = 2, 3 \text{ and } 4, j = 1, 2 \text{ and } 3 \tag{3.79}$$

$$0.2 \leq C_s \leq 0.5 \tag{3.80}$$

where B_{ij} – the benefits of players, C_{ij} – the cost or lose imposed to player ij , γ – cost coefficients, S_R – the reduction areas of soil erosion, V_{i3} – the added values, F_{i3} – nitrogen fertilizer consumptions, t – time (year), P_{ij}^- – the reducing amount of pollutant of nitrogen, P^- – the total reduction of nitrogen, $P^{\rightarrow R}$ – the total nitrogen reached into reservoir, Q_f – natural inflow of the reservoir, P_s – the controlling amount of nitrogen entering into the reservoir, C_s – the controlling concentration of pollutant i or the standard in the reservoir.

As for the nitrogen fertilizer, its reduction of nitrogen will influence agricultural production, which will influence the agricultural added value. The scatter plots of added values of player $i3$ on time and nitrogen fertilizer consumption are illustrated in figure 3.50.

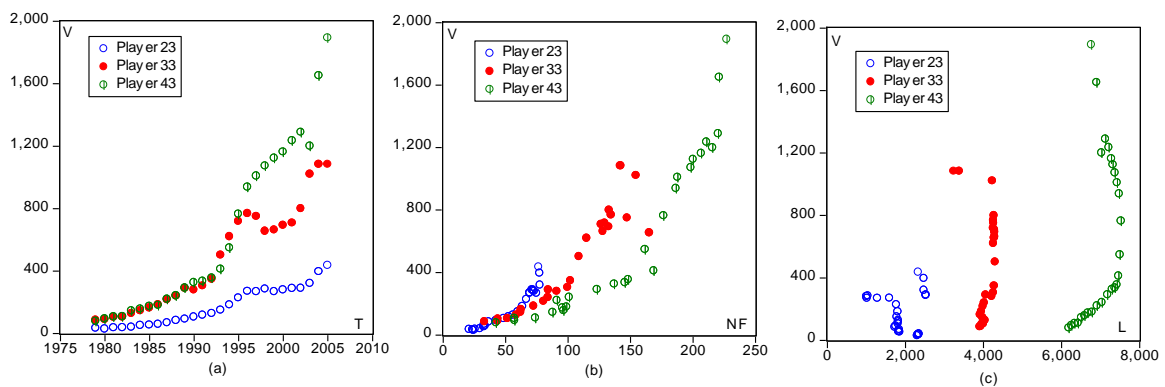


Figure 3.50: Scatter plots of added value ($\times 10^8$ RMB) vs. time (Year), nitrogen fertilizer consumption ($\times 10^4$ tons) and labours ($\times 10^4$ persons)

A model of added values (V_{i3}) of player $i3$ (Fig. 3.51) is given by:

$$\begin{cases} \text{LOG}(V_{23}) = -122.033 + 0.063*t + 0.018*F_2 \\ \text{LOG}(V_{33}) = -122.033 + 0.064*t + 0.008*F_3 \\ \text{LOG}(V_{43}) = -122.033 + 0.064*t + 0.008*F_4 \end{cases} \quad (3.81)$$

where $R^2 = 0.999$ and adjusted $R^2 = 0.999$, F-statistic = 9517.884, Prob(F-statistic) = 0.00, S.E. of regression = 0.122

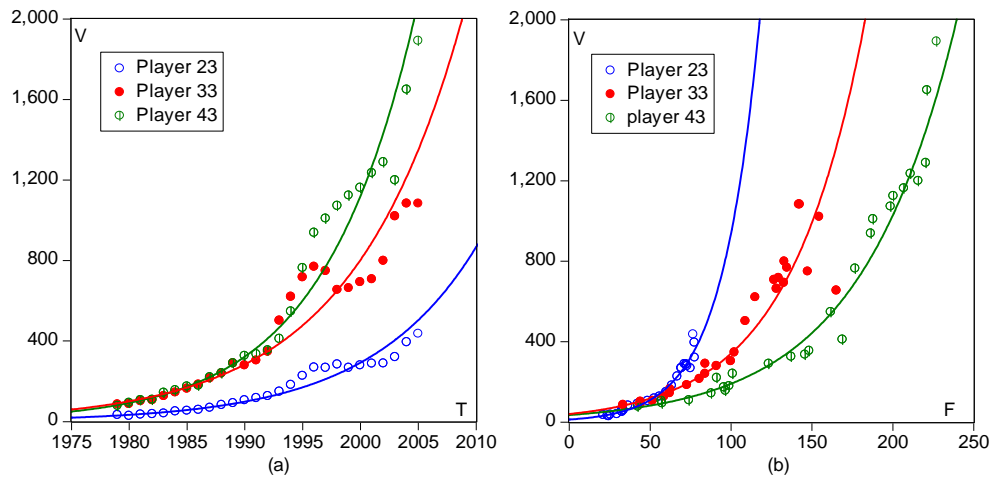


Figure 3.51: Exponential regression of added value ($\times 10^8$ RMB) vs. time (Year) and nitrogen fertilizer consumption ($\times 10^4$ tons)

A model of F_i (Fig. 3.52) is given by:

$$\begin{cases} F_2 = 2.533*t - 4992.007 \\ F_3 = 4.632*t - 9126.805 \\ F_4 = 7.391*t - 14575.909 \end{cases} \quad (3.82)$$

where $R^2 = 0.993$ and adjusted $R^2 = 0.992$, F-statistic = 2052.317, Prob(F-statistic) = 0.000, S.E. of regression = 8.644.

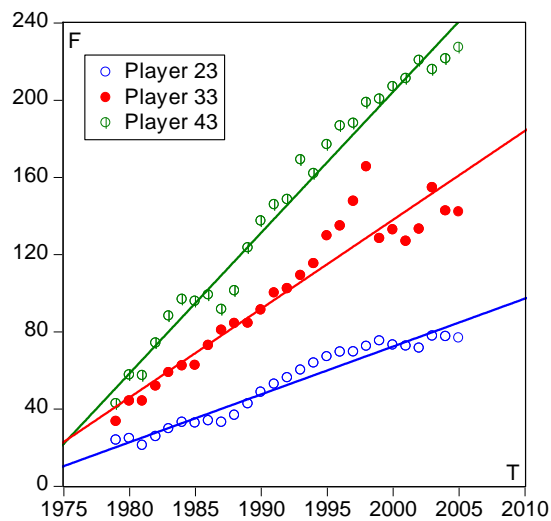


Figure 3.52: Linear regression of nitrogen fertilizer consumption ($\times 10^4$ tons) vs. time (Year)

Water quality of the Danjiangkou Reservoir is required to conform to the Chinese water quality standard of class II by 2010. That is to say, with reference to concentration of TN, it should range from 0.2 to 0.5mg/L by 2010. Suppose TN reduction follows a linear trend, and thus two controlling lines are designed to limit the TN concentration (C_s) in the Danjiangkou Reservoir from 2005 to 2010 (Fig. 3.53). Maximum line (C_{max}) and minimum line (C_{min}) are the upper threshold and lower threshold of TN concentrations in different years (t), respectively. These two lines can be expressed as Equations (3.83) and (3.84).

$$C_{max} = -0.127*t + 255.1 \tag{3.83}$$

$$C_{min} = -0.177*t + 355.3 \tag{3.84}$$

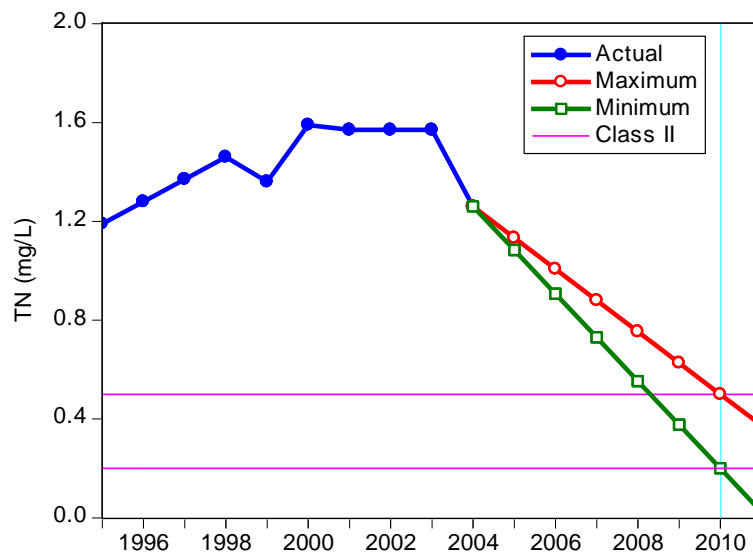


Figure 3.53: Controlling lines of TN concentration in the Danjiangkou Reservoir

A model of annual inflow of the Danjiangkou Reservoir (Q_f):

Based on the annual inflow ($\times 10^8 \text{ m}^3$) from 1931 to 1999 (Fig.3.54a), frequency filter type of full sample asymmetric (Fig. 3.54b) is used to establish the annual inflow model of the Danjiangkou Reservoir.

$$\begin{cases} Q_f = NC + CI \\ NC = G(NC) \\ CI = W(CI) \end{cases} \tag{3.85}$$

$$\begin{aligned} NC = & 6.908*NC(-1) - 21.803*NC(-2) + 40.958*NC(-3) \\ & -50.031*NC(-4) + 40.681*NC(-5) - 21.515*NC(-6) \\ & + 6.777*NC(-7) - 0.976*NC(-8) - 0.001*t + 1.859 \end{aligned} \tag{3.86}$$

where NC – non-cycle part of annual inflow with $R^2 = 1.00$ and adjusted $R^2 = 1.00$.

$$\begin{aligned}
 CI = & -4.886*CI(-1) - 15.40*CI(-2) - 38.369*CI(-3) \\
 & -81.728*CI(-4) - 155*CI(-5) - 267.624*CI(-6) \\
 & -426.791*CI(-7) - 634.965*CI(-8) - 887.470*CI(-9) \\
 & -1171.190*CI(-10) - 1464.685*CI(-11) - 1740.254*CI(-12) \\
 & -1967.870*CI(-13) - 2120.304*CI(-14) - 2177.983*CI(-15) \\
 & -2132.8*CI(-16) - 1989.876*CI(-17) - 1766.703*CI(-18) \\
 & -1489.920*CI(-19) - 1190.3458*CI(-20) - 897.625*CI(-21) \\
 & -635.716*CI(-22) - 419.96*CI(-23) - 256.386*CI(-24) \\
 & -142.767*CI(-25) - 71.094*CI(-26) - 30.685*CI(-27) \\
 & -10.882*CI(-28) - 2.865*CI(-29) - 0.435*CI(-30)
 \end{aligned}
 \tag{3.87}$$

where CI – cycle part of annual inflow with $R^2 = 0.998$ and adjusted $R^2 = 0.992$.

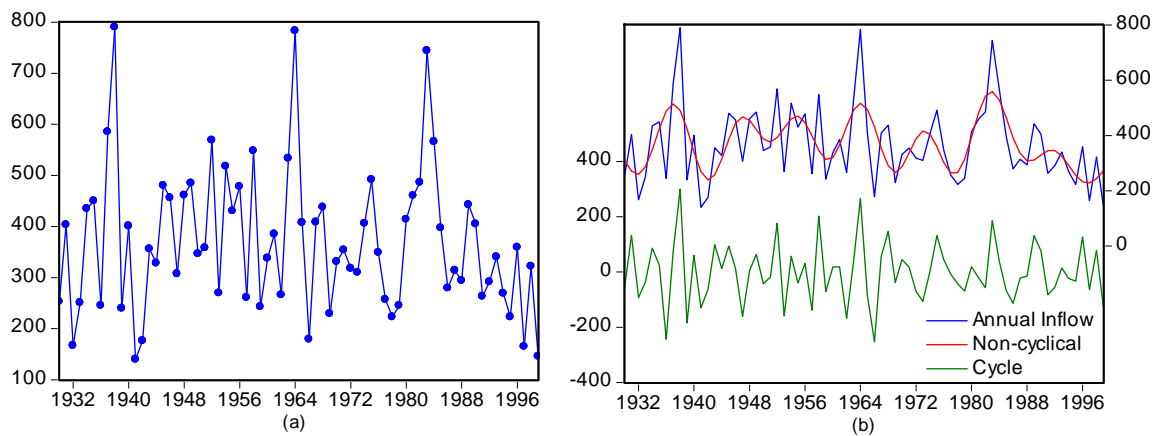


Figure 3.54: Annual inflow ($\times 10^8 \text{ m}^3$) of Danjiangkou Reservoir
 (a) situation from 1931 to 1999, (b) the model

In the simulation process, one problem is that the payoffs of the players are monetary values calculated in current (or nominal) prices. In details, the payoffs of player 1 and his sub-players 11, 12 and 13 are their benefits or the losses from 2010 to 2015. However, for the payoffs of players 2, 3 and 4 and their sub-players 21, 22 and 23, 31, 32 and 33 as well as 41, 42 and 43, they are their benefits or losses from 2005 to 2010. Therefore, the future values should be discounted so that they can be better compared with the present values. The future values are termed as “nominal values” and the present value as “comparable or real values”. In economics, Consumer Price Index (CPI) is one widely used deflator to kick out the inflation in prices and change the nominal values into comparable values. The discount formula can be expressed as:

$$V_R^k = \frac{I_d^k}{I_d^t} \times V_N^t \tag{3.88}$$

Where V_R^k – the comparable or real value of V in year k , V_N^t – the nominal value of V in year t , I_d – the Consumer Price Index, I_d^k – the Consumer Price Index in year k , I_d^t – the Consumer Price Index in year t .

A model of Consumer Price Index (CPI) of player 1 and his sub-players (Fig. 3.55) is expressed by:

$$I_d = 3.297 * t - 0.790 * I_d(-2) + 1.664 * I_d(-1) - 6521.667 \tag{3.89}$$

Where I_d – Consumer Price Index (CPI), t – time (year) with $R^2 = 0.997$ and adjusted $R^2 = 0.996$.

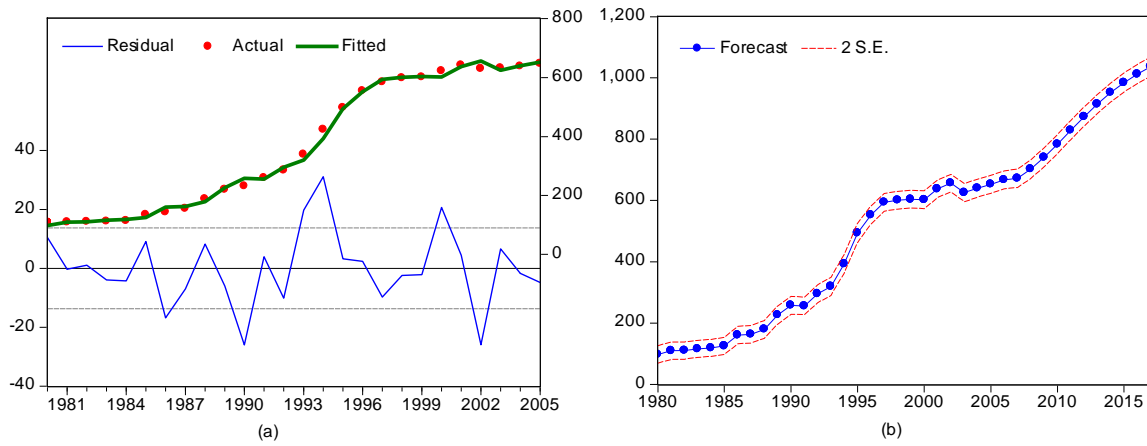


Figure 3.55: Consumer price index of player 1 and his sub-players
(a) VAR model, (b) the forecast

3.4 Design of scenarios

The future is uncertainty and it is even full of risks, and the uncertainty and risks comes from not only the uncertainty of some factors excluded in the models but also the uncertainty of some parameters or constrains in the models. Therefore, it is very necessary to make scenario analysis (or sensitive analysis) to assess the influences of driving forces on the future water resources, water consumption and water quality, which in turn influence game theory modeling framework and results (Fig. 3.56).

The previous modeling and simulating are made based on the past and current situations, and they are regarded as baseline scenario. The baseline scenario is regarded as the first

scenario (S1). The other three main scenarios are designed according to the possible changes of constrains and input variables in the future. The second scenario (S2) is very optimistic, in which socio-economy is high developed and environment is highly protected. The third one (S3) is a scenario of coordinated development, in which economic, social, environmental resource are co-ordinately developing through the industrial structure adjustment and the efficiency enhancement. The fourth one (S4) is a more pessimistic scenario, which will consider more about future potential risks. The descriptions of these main scenarios are showed in table 3.12.

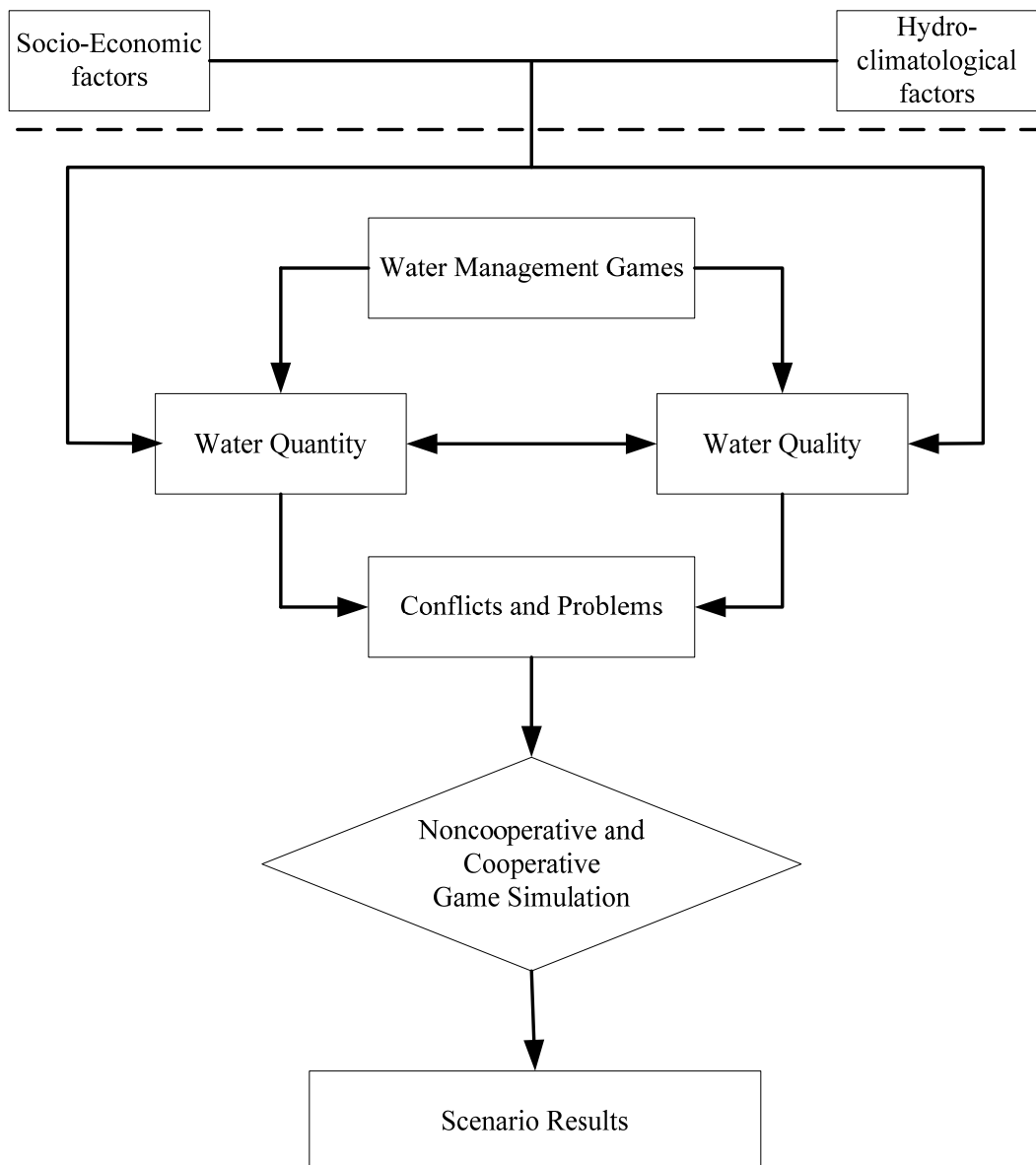


Figure 3.56: Sketch of influences of socio-economic and hydro-climatological factors to game modeling structure

Table 3.12: Descriptions of the main scenarios for all the games

Scenario	Description
S1	Baseline scenario, i.e. demographic changes, economic growth, scientific and technological advances, policies, environmental protection and resources development as well as hydro-climatology are just as usual.
S2	Population increasing rate is much lower than that in S1 due to the policy, economic growth rate is very high, scientific and technological advances much more fast, environmental protection are greatly attached, it meets wet years
S3	Population increasing rate and economic growth rate are slightly decreasing comparing with S1 due to coordinating economic development and environment and resource protections, scientific and technology is advancing, it is in moderate dry years
S4	Population increasing rate is increasing and economic growth rate is decreasing, scientific and technological advances is lower, environment problems are increasing more than S1, and it is in high dry years

Based on those descriptions of the main scenarios, the assumptions of scenarios are quantified in the table 3.13. Scenarios 2, 3 and 4 are designed according to scenario 1 (baseline).

Table 3.13: Assumption of the main scenarios for all players and sub-players

Main force (average annual change rate % on base of baseline)	S2	S3	S4
Demographic changes	-1.0	-0.3	+0.3
Industry added value	+3.0	-3.0	-6.0
Net income	+3.0	-3.0	-6.0
Agriculture added value	+6.0	+3.0	-3.0
Livestock and poultry	+6.0	+3.0	-3.0
Fertilizer consumptions	-6.0	-3.0	+3.0
Soil erosion	-6.0	-3.0	+3.0
Industry waste water discharge	-6.0	-3.0	+3.0
Urban domestic sewage discharge	-6.0	-3.0	+3.0
Reclaim water	+3.0	+2.0	+1.0
Industry waste water treatment	+2.0	+1.0	+0.5
Urban and rural sewage treatment	+12	+8.0	+5.0
Ecological water demand	+5.0	+2.0	-1.0
Ecological water use	× 4.0	× 3.0	× 0.5
Water resource (hydrological year %)	20	75	95
Water flow (hydrological year %)	10	75	95

4. Results and discussion

Water conflicts involved in Hanjiang River Basin have been modeled and simulated as five games in last chapter. Four scenarios have been designed in order to analyze the risks and uncertainties in the game simulation. This chapter presents and discusses the simulation and scenario results. The first part of this chapter interprets the modelling and simulation results, and the second part illustrates the scenario results. The last part discusses the simulation and scenario results.

4.1 Results of the simulation

Results of game 1:

Table 4.1 shows the equilibria results of water demand of sub-players 11, 12 and 13 in the non-cooperative game from 2010 to 2015. This non-cooperative simulation results confirm that player 11 will get water of $5.38-4.10 \times 10^8 \text{ m}^3$, the player 12 get $15.92-17.88 \times 10^8 \text{ m}^3$ and player 13 obtains $10.46-7.99 \times 10^8 \text{ m}^3$ from 2010 to 2015. The total water demand of these three players is $31.75-29.97 \times 10^8 \text{ m}^3$ from 2010 to 2015. Therefore, the total water displays a decreasing trend during this period of time.

Table 4.1: The water demand equilibrium of players 11, 12 and 13 in the non-cooperative game during 2010 to 2015 ($\times 10^8 \text{ m}^3$)

t	Q_{11}	Q_{12}	Q_{13}	Total
2010	5.38	15.92	10.46	31.76
2011	5.10	16.31	9.94	31.35
2012	4.83	16.71	9.43	30.97
2013	4.58	17.10	8.93	30.61
2014	4.33	17.49	8.45	30.27
2015	4.10	17.88	7.99	29.97

Table 4.2 presents the simulation results of water shares, which sub-players 11, 12 and 13 can get in a cooperative game from 2010 to 2015. The cooperative results explain that players 11, 12 and 13 can only get water of $4.02-3.06 \times 10^8 \text{ m}^3$, $11.89-13.33 \times 10^8 \text{ m}^3$ and $7.81-5.96 \times 10^8 \text{ m}^3$, respectively from 2010 to 2015. The total water share of those three players is decreasing from $31.76 \times 10^8 \text{ m}^3$ in 2010 to $29.97 \times 10^8 \text{ m}^3$ in 2015.

Table 4.2: Water Shares (Q_{ljk}) of players 11, 12 and 13 in the cooperative game ($\times 10^8 \text{ m}^3$)

t	Q_{11k}	Q_{12k}	Q_{13k}	Total
2010	4.02	11.89	7.81	23.73
2011	3.82	12.21	7.44	23.46
2012	3.62	12.52	7.06	23.20
2013	3.43	12.80	6.69	22.92
2014	3.24	13.08	6.32	22.63
2015	3.06	13.33	5.96	22.34

Comparing the cooperative results with the non-cooperative ones, water deficits of players 11, 12 and 13 can be obtained. Players 11, 12 and 13 have water deficits of $1.36\text{-}1.04 \times 10^8 \text{ m}^3$, $4.03\text{-}4.55 \times 10^8 \text{ m}^3$, $2.65\text{-}2.03 \times 10^8 \text{ m}^3$, respectively in cooperative game from 2010 to 2015. The total water shortage of them has a slight decrease from $8.03 \times 10^8 \text{ m}^3$ in 2010 to $7.63 \times 10^8 \text{ m}^3$ in 2015 (Table 4.3).

Table 4.3: Water deficit of players 11, 12 and 13 in the cooperative game ($\times 10^8 \text{ m}^3$)

t	Q_{11}	Q_{12}	Q_{13}	Total
2010	-1.36	-4.03	-2.65	-8.03
2011	-1.28	-4.10	-2.50	-7.89
2012	-1.21	-4.19	-2.37	-7.77
2013	-1.15	-4.30	-2.24	-7.69
2014	-1.09	-4.41	-2.13	-7.64
2015	-1.04	-4.55	-2.03	-7.63

The results of game 2:

Table 4.4 reveals the non-cooperative game simulation results from 2005 to 2010, where players 21, 22 and 23 produce nitrogen of 684.0-514 tons, 40131.7- 40466.3 tons, and 273586.4-290772.4 tons, respectively. Therefore, those three players will produce total nitrogen of $3.14\text{-}3.32 \times 10^5 \text{ m}^3$ tons from 2005 to 2010. The nitrogen production is increasing during this period of time.

Table 4.4: Nitrogen produced by players 21, 22 and 23 in the non-cooperative game (tons/a)

t	NP_{21}	NP_{22}	NP_{23}	Total
2005	694.0	40131.7	273586.4	314412.1
2006	634.2	40139.5	275665.6	316439.3
2007	601.7	40195.2	279338.8	320135.8
2008	570.9	40275.3	283116.7	323962.9
2009	541.7	40367.7	286994.6	327904.0
2010	514.0	40466.3	290772.4	331752.7

Table 4.5 presents that in order to meet the TN standard II, players 21, 22 and 23 should reduce nitrogen 163.2-356.2 tons, 9439.4-28040.0 tons and 64350.3-201482.3 tons, respectively from 2005 to 2010. The total nitrogen reduction is $7.4-23.0 \times 10^4$ m³ tons, and it increase more than three time during this period of time.

Table 4.5: Nitrogen reduced by players 21, 22 and 23 in the cooperative game (tons/a)

t	NP_{21}^-	NP_{22}^-	NP_{23}^-	Total
2005	163.2	9439.4	64350.3	73953.0
2006	182.3	11535.7	79223.8	90941.8
2007	286.5	19139.5	133010.7	152436.7
2008	269.4	19003.5	133585.7	152858.5
2009	271.5	20231.8	143838.1	164341.4
2010	356.2	28040.0	201482.3	229878.4

The results of game 3:

The simulation results of non-cooperative and cooperative games from 2005 to 2015 are presented in table 4.6 and 4.7. The results in table 4.6 explains the simulation results of nitrogen production of players 31, 32 and 33 in non-cooperative game from 2005 to 2010. These results prove that players 31, 32 and 33 will produce nitrogen of 379.2-730.6 tons, 15709.5-16714.4 tons and 66632.0-74001.1 tons, respectively, and the total nitrogen production of them are $8.2-9.1 \times 10^4$ m³ tons during this period of time. The nitrogen production in this game also shows an increasing trend.

Table 4.6: Nitrogen produced by players 31, 32 and 33 in the non-cooperative game (tons/a)

t	NP_{31}	NP_{32}	NP_{33}	Total
2005	379.2	15709.5	66632.0	82720.7
2006	467.7	15873.6	68232.0	84573.3
2007	543.8	16055.1	69751.5	86350.4
2008	606.1	16255.1	71198.2	88059.4
2009	668.3	16474.5	72602.2	89744.9
2010	730.6	16714.4	74001.1	91446.0

Table 4.7 proves the simulation results of nitrogen reduction of players 31, 32 and 33 in a cooperative game from 2005 to 2010. These results confirm that players 31, 32 and 33 should reduce nitrogen of 89.2-506.2 tons, 3695.0-11581.8 tons and 15672.5-51276.9 tons, respectively, in order to meet the TN standard II from 2005 to 2010. The total nitrogen reduction responsible for those three players is $1.9-6.3 \times 10^4$ m³ tons during this period of time.

Table 4.7: Nitrogen reduced by players 31, 32 and 33 in the cooperative game (tons/a)

t	NP_{31}^-	NP_{32}^-	NP_{33}^-	Total
2005	89.2	3695.0	15672.5	19456.8
2006	134.4	4561.9	19609.3	24305.6
2007	259.0	7644.8	33213.1	41116.9
2008	286.0	7669.8	33594.1	41549.9
2009	334.9	8256.8	36387.3	44979.0
2010	506.2	11581.8	51276.9	63364.9

The results of game 4:

Table 4.8 and table 4.9 present the non-cooperative and cooperative game simulation results, respectively in game 4 from 2005 to 2010. The results explain that players 41, 42 and 43 will produce nitrogen of 193.7-243.2 tons, 4764.5-4686.5 tons and 57621.9-76135.0 tons, respectively during this period of time. The total nitrogen production is creasing from $6.3 \times 10^4 \text{ m}^3$ tons to $8.1 \times 10^4 \text{ m}^3$ tons during 2005 to 2010.

Table 4.8: Nitrogen produced by players 41, 42 and 43 in the non-cooperative game (tons/a)

t	NP_{41}	NP_{42}	NP_{43}	Total
2005	193.7	4764.5	57621.9	62580.1
2006	203.8	4750.4	60562.8	65517.0
2007	213.7	4734	64212.5	69160.2
2008	223.5	4718.3	67959.0	72900.8
2009	233.4	4702.3	71948.2	76883.9
2010	243.2	4686.5	76135.0	81064.8

The cooperative results tell that players 41, 42 and 43 should reduce nitrogen of 45.6-165.8 tons, 1120.7-3247.4 tons and 13553.3-52755.2 tons, respectively to meet the standard from 2005 to 2010. Hence the total reduction should be $1.5\text{-}5.6 \times 10^4 \text{ m}^3$ tons during this period (Table 4.9).

Table 4.9: Nitrogen reduced by players 41, 42 and 43 in the cooperative game (tons/a)

t	NP_{41}^-	NP_{42}^-	NP_{43}^-	Total
2005	45.6	1120.7	13553.3	14719.5
2006	58.6	1365.2	17405.2	18829.0
2007	101.7	2254.2	30575.6	32931.5
2008	105.5	2226.3	32065.7	34397.5
2009	117.0	2356.7	36059.5	38533.2
2010	168.5	3247.4	52755.5	56171.5

The results of game 5:

a) Payoffs at current prices:

The game results of payoffs at current prices are presented in the matrix 4.1. In the matrix, the first column and the second column refer to the payoffs resulting from the simulations of non-cooperative and the cooperative games, respectively. In each column, the first, second, third and fourth numbers refer to the payoffs of players 1, 2, 3 and 4 respectively. The zeros are used (1) to keep the matrix symmetric, (2) to state no game played there, and (3) to display what the value look like if there were games.

Matrix 4.1: Payoff matrix of players 1, 2, 3 and 4 in the non-cooperative and cooperative games ($\times 10^8$ RMB at current prices)

t	V_1	V_2	V_3	V_4	U_1	U_2	U_3	U_4
2005	(0000.0	78.12	19.02	41.76)	(0000.0	-78.12	-19.02	-41.76)
2006	(0000.0	86.63	21.41	43.03)	(0000.0	-86.63	-21.41	-43.03)
2007	(0000.0	109.8	32.18	47.08)	(0000.0	-109.8	-32.18	-47.08)
2008	(0000.0	112.5	33.39	48.25)	(0000.0	-112.5	-33.39	-48.25)
2009	(0000.0	118.9	36.32	50.35)	(0000.0	-118.9	-36.32	-50.35)
2010	(-1981.2	139.0	46.38	56.53)	(1981.2	-139.0	-46.38	-56.53)
2011	(-2263.8	000.0	00.00	00.00)	(2263.8	000.0	00.00	00.00)
2012	(-2594.0	000.0	00.00	00.00)	(2594.0	000.0	00.00	00.00)
2013	(-2979.2	000.0	00.00	00.00)	(2979.2	000.0	00.00	00.00)
2014	(-3437.0	000.0	00.00	00.00)	(3437.0	000.0	00.00	00.00)
2015	(-3997.0	000.0	00.00	00.00)	(3997.0	000.0	00.00	00.00)

These results prove that the non-cooperative game will cost player 1 a total loss of 17.3×10^{11} RMB from year 2010 to 2015, but it yields players 2, 3 and 4 a benefit of 1.1×10^{11} RMB. However, comparing the overall costs and benefits, there is an overall loss of 16.2×10^{11} RMB when each player does not cooperate with the others. The cooperative game result proves that there is an overall benefit of 16.2×10^{11} RMB, though players 2, 3 and 4 lose 1.1×10^{11} RMB. Therefore, all the players will be better off if a side payment is made between them at the end of the cooperative game. Form these results, it is clearly seen that the players should cooperate with each other so as to maximize the overall benefits.

Tables 4.10-4.13 present the results losses of all the sub-players when players 1, 2, 3 and 4 are cooperative and non-cooperative. Table 4.10 shows that non-cooperation among play-

ers 1, 2, 3 and 4 will cost sub-players 11, 12 and 13 losses of $801.98-1535.38 \times 10^8$ RMB, $1489.08-3284.86 \times 10^8$ RMB and $29.66-34.85 \times 10^8$ RMB, respectively due to water deficits during 2010 to 2015.

Table 4.10: Losses of sub-players of 11, 12, and 13 in the non-cooperative game ($\times 10^8$ RMB at current prices)

t	V_{11}	V_{12}	V_{13}
2010	-801.98	-1489.08	-29.66
2011	-905.86	-1733.75	-30.50
2012	-1028.56	-2026.17	-31.43
2013	-1174.76	-2372.21	-32.44
2014	-1338.47	-2786.20	-33.56
2015	-1535.38	-3284.86	-34.85

On the contrary, the sub-players of 11, 12 and 13 will have no such losses if players 1, 2, 3 and 4 are cooperative, but cooperation imposes cost to sub-players of 21, 22, 23, 31, 32, 33, 41, 42 and 43. Table 4.11 gives an idea about those losses, in which the players 21, 22 and 23 will lose $0.15-0.32 \times 10^8$ RMB, $39.07-40.18 \times 10^8$ RMB and $38.89-98.50 \times 10^8$ RMB, respectively from 2005 to 2010.

Table 4.11: Losses of sub-players 21, 22 and 23 in the cooperative game ($\times 10^8$ RMB)

t	C_{21}	C_{22}	C_{23}
2005	-0.15	-39.07	-38.89
2006	-0.17	-39.06	-47.40
2007	-0.26	-39.76	-69.75
2008	-0.25	-39.54	-72.68
2009	-0.25	-39.52	-79.14
2010	-0.32	-40.18	-98.50

Table 4.12 reveals the simulation results of the losses of sub-players 31, 32 and 33 in this cooperative game. Players 31, 32 and 33 will lose $0.59-3.36 \times 10^8$ RMB, $11.46-16.98 \times 10^8$ RMB and $6.96-26.04 \times 10^8$ RMB, respectively from 2005 to 2010.

Table 4.12: Losses of sub-players 31, 32 and 33 in the cooperative game ($\times 10^8$ RMB)

t	C_{31}	C_{32}	C_{33}
2005	-0.59	-11.46	-6.96
2006	-0.89	-11.37	-9.15
2007	-1.72	-15.23	-15.22
2008	-1.90	-14.99	-16.50
2009	-2.22	-15.20	-18.90
2010	-3.36	-16.98	-26.04

Table 4.13 explains the simulation results of the losses of sub-players 41, 42 and 43 in this cooperative game. From this table, it is seen that players 41, 42 and 43 will lose $0.08-0.29 \times 10^8$ RMB, $38.21-38.41 \times 10^8$ RMB and $3.47-17.83 \times 10^8$ RMB, respectively from 2005 to 2010.

Table 4.13: Losses of sub-players 41, 42 and 43 in the cooperative game ($\times 10^8$ RMB)

t	C_{41}	C_{42}	C_{43}
2005	-0.08	-38.21	-3.47
2006	-0.10	-38.09	-4.84
2007	-0.18	-38.23	-8.67
2008	-0.18	-38.15	-9.92
2009	-0.20	-38.14	-12.01
2010	-0.29	-38.41	-17.83

b) The payoffs at comparable prices

Table 4.14 gives the Consumer Price Index (CPI), i.e. discount factor of future values. The numbers of the index in 2005 and 2006 are really values, while the numbers in the rest years in the table are the forecasting values. Based on those results, the payoffs of players 1 and his sub-players in the years of 2010, 2011, 2012, 2013, 2014 to 2015 have been transferred into the values in years of 2005, 2006, 2007, 2008, 2009 and 2010, respectively.

Table 4.14: Consumer Price Index (I_d) of player 1 and his sub-players from 2005 to 2016

t	I_d	t	I_d
2005	647.8	2011	829.0
2006	653.6	2012	873.4
2007	672.3	2013	914.8
2008	702.2	2014	952.1
2009	740.4	2015	984.6
2010	783.8	2016	1012.6

Matrix 4.2 presents the payoffs of players 1, 2, 3 and 4 at comparable prices. In the matrix, the first column and the second column refer to the payoffs resulting from the simulations of non-cooperative game and the cooperative game, respectively. In each column, the first, second, third and fourth numbers refer to payoffs of the players 1, 2, 3 and 4, respectively.

These results prove that the non-cooperative game will cost player 1 a total loss of 13.6×10^{11} RMB at comparable prices during 2010 to 2015, but it yields players 2, 3 and 4 a benefit of 1.1×10^{11} RMB. However, comparing the overall costs and benefits, there is an overall loss of 12.5×10^{11} RMB when each player does not cooperate with the others. The

cooperative game result shows that there is an overall benefit of 12.5×10^{11} RMB, though players 2, 3 and 4 lose 1.1×10^{11} RMB.

Matrix 4.2: Payoff matrix of players 1, 2, 3 and 4 in the non-cooperative and cooperative game ($\times 10^8$ RMB at comparable prices)

t	V'_1	V'_2	V'_3	V'_4	U'_1	U'_2	U'_3	U'_4
2005	-1637.4	78.12	19.02	41.76	1637.4	-78.12	-19.02	-41.76
2006	-1784.8	86.63	21.41	43.03	1784.8	-86.63	-21.41	-43.03
2007	-1996.7	109.8	32.18	47.08	1996.7	-109.8	-32.18	-47.08
2008	-2286.8	112.5	33.39	48.25	2286.8	-112.5	-33.39	-48.25
2009	-2665.0	118.9	36.32	50.35	2665.0	-118.9	-36.32	-50.35
2010	-3181.8	139.0	46.38	56.53	3181.8	-139.0	-46.38	-56.53

Table 4.15 explains the losses of all sub-players 11, 12 and 13 at comparable prices when players 1, 2, 3 and 4 are non-cooperative. The results explain that non-cooperation among players 1, 2, 3 and 4 will cost sub-players 11, 12 and 13 losses of $662.83-1222.25 \times 10^8$ RMB, $1230.70-2614.94 \times 10^8$ RMB and $24.51-27.74 \times 10^8$ RMB, at prices of years of 2005-2010, respectively due to water deficits during 2010 to 2015.

Table 4.15: Losses of sub-players of 11, 12, and 13 in the non-cooperative game ($\times 10^8$ RMB at comparable prices)

t	Price in year	V'_{11}	V'_{12}	V'_{13}
2010	2005	-662.83	-1230.70	-24.51
2011	2006	-714.20	-1366.92	-24.05
2012	2007	-791.73	-1559.65	-24.19
2013	2008	-901.75	-1820.91	-24.90
2014	2009	-1040.86	-2166.69	-26.10
2015	2010	-1222.25	-2614.94	-27.74

However, sub-players of 11, 12 and 13 can avoid those losses if players 1, 2, 3 and 4 are cooperative, but cooperation imposes cost to sub-players of 21, 22, 23, 31, 32, 33, 41, 42 and 43. The losses of sub-players of 21, 22, 23, 31, 32, 33, 41, 42 and 43 are $0.15-0.32 \times 10^8$ RMB, $39.07-40.18 \times 10^8$ RMB, $38.89-98.50 \times 10^8$ RMB, $0.59-3.36 \times 10^8$ RMB, $11.46-16.98 \times 10^8$ RMB, $6.96-26.04 \times 10^8$ RMB, $0.08-0.29 \times 10^8$ RMB, $38.21-38.41 \times 10^8$ RMB and $3.47-17.83 \times 10^8$ RMB, respectively from 2005 to 2010 (Tables 4.11-4.13).

4.2 Results of the scenarios

Scenarios results of the five games involved in the Hanjiang River Basin are illustrated in the following 5 sections.

4.2.1 Scenario results of game 1

Figures 4.1- 4.7 illustrate the comparison results of the four scenarios of game 1. Among them, figures 4.1 to 4.4 show water demand of sub-players of 11, 12 and 13 in the four different scenarios.

Figure 4.1a demonstrates that the added values of player 11 are $3016.4-5620.3 \times 10^8$ RMB, $3091.8-5760.8 \times 10^8$ RMB, $2925.9-5451.7 \times 10^8$ RMB and $2838.1-5288.2 \times 10^8$ RMB, respectively in the four scenarios from 2010 to 2015. In these four scenarios of added values, the water demands of the player 11 are $5.38-4.10 \times 10^8$ m³, $5.52-4.20 \times 10^8$ m³, $5.22-3.98 \times 10^8$ m³ and $5.06-3.86 \times 10^8$ m³, respectively from 2010 to 2015 (Fig. 4.1b).

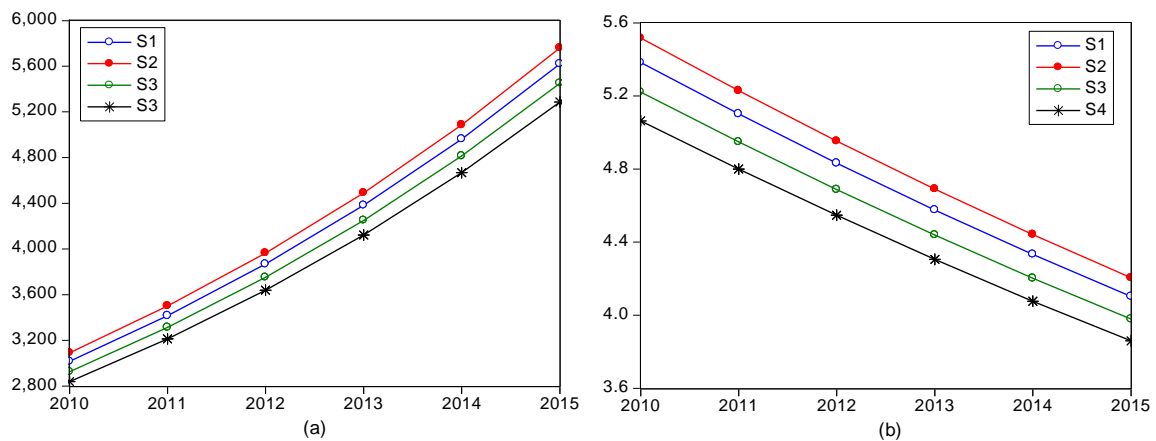


Figure 4.1: Scenarios of (a) added value (V_{11}) ($\times 10^8$ RMB) and (b) water demand (Q_{11}) ($\times 10^8$ m³) of player 11

From the results of four scenarios in figure 4.2a, it is clearly seen that the added values of player 12 are $5941.3-13905.7 \times 10^8$ RMB, $6119.6-14322.9 \times 10^8$ RMB, $5763.1-13488.6 \times 10^8$ RMB and $5590.2-13083.9 \times 10^8$ RMB, respectively from 2010 to 2015. Water demands of player 12 are $15.9-17.9 \times 10^8$ m³, $16.0-18.0 \times 10^8$ m³, $15.8-17.8 \times 10^8$ m³ and $15.8-17.7 \times 10^8$ m³, respectively in the four scenarios of added values (Fig. 4.2b).

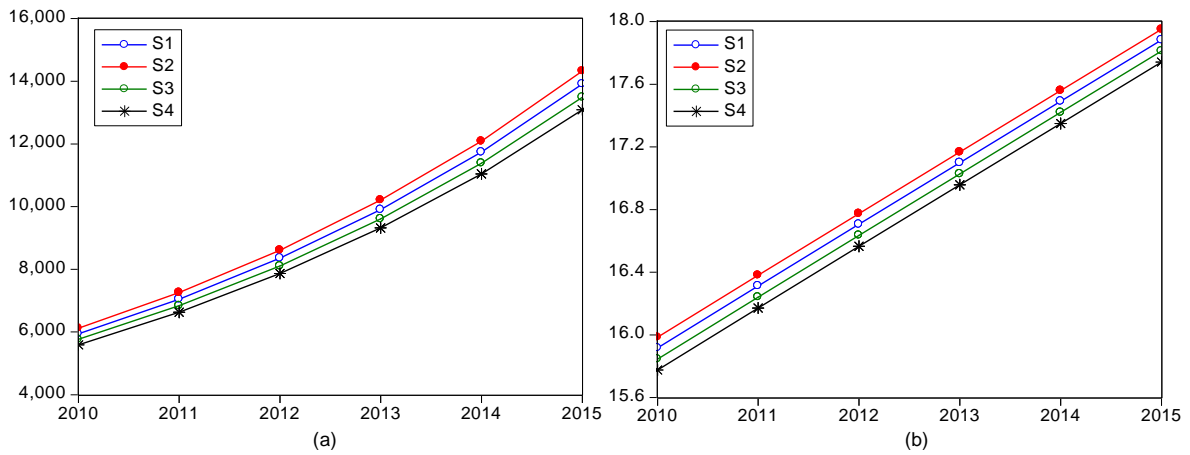


Figure 4.2: Scenarios of (a) added value (V_{12}) ($\times 10^8$ RMB) and (b) water demand (Q_{12}) ($\times 10^8$ m³) of player 12

Figure 4.3a and b prove the results of four population scenarios of player 12 and the water demands in these four scenarios from 2010 to 2015. The population is $1647.2-1823.9 \times 10^4$ persons, $1664.3-1805.6 \times 10^4$ persons, $1671.0-1812.9 \times 10^4$ persons and $1686.2-1829.4 \times 10^4$ persons, respectively in the four scenarios. Water demands are $15.3-16.3 \times 10^8$ m³, $15.2-16.3 \times 10^8$ m³, $15.3-16.3 \times 10^8$ m³ and $15.3-16.4 \times 10^8$ m³, respectively in these four population scenarios.

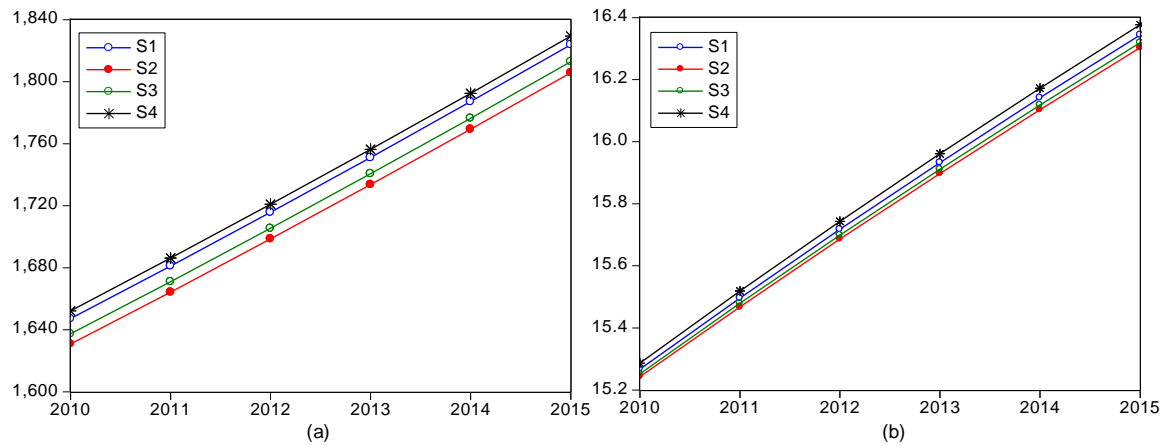


Figure 4.3: Scenarios of (a) population (L_{12}) ($\times 10^4$ persons) and (b) water demand (Q_{12}) ($\times 10^8$ m³) of player 12

Figure 4.4a and b illustrate the results of four added value scenarios of player 13 and the water demands in these four scenarios from 2010-2015. The added values of player 13 are $117.3-137.0 \times 10^8$ RMB, $124.4-145.3 \times 10^8$ RMB, $120.8-141.1 \times 10^8$ RMB and $113.8-132.9 \times 10^8$ RMB in these four scenarios. Water demands of player 13 are $10.5-8.0 \times 10^8$ m³, $11.1-8.5 \times 10^8$ m³, $10.8-8.2 \times 10^8$ m³ and $10.1-7.8 \times 10^8$ m³ in the four scenarios.

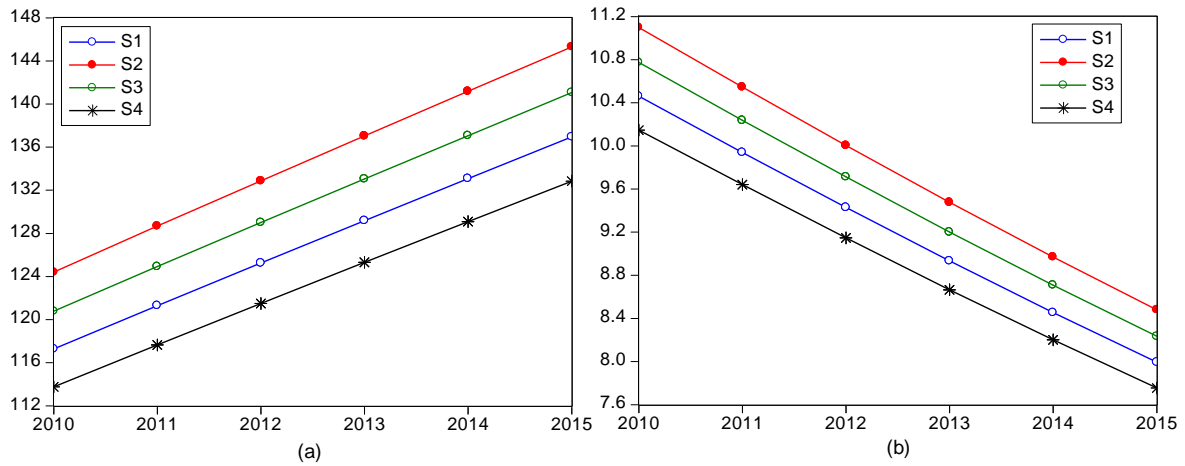


Figure 4.4: Scenarios of (a) added value (V_{13}) ($\times 10^8$ RMB) and (b) water demand (Q_{13}) ($\times 10^8$ m³) of player 13

Figures 4.5-4.7 reveal the scenario results of water supply in the four scenarios from 2010 to 2015. From the four scenarios of urban sewage discharge, it can see that player 1 discharges urban sewage of $11.3\text{-}13.6 \times 10^8$ m³, $10.6\text{-}12.8 \times 10^8$ m³, $10.9\text{-}13.2 \times 10^8$ m³ and $11.6\text{-}14.0 \times 10^8$ m³ (Fig. 4.5a). Reclaim water are $2.8\text{-}3.5 \times 10^8$ m³, $5.3\text{-}6.6 \times 10^8$ m³, $4.6\text{-}5.7 \times 10^8$ m³ and $3.9\text{-}4.8 \times 10^8$ m³, respectively in four water-reclaimed scenarios (Fig. 4.5b).

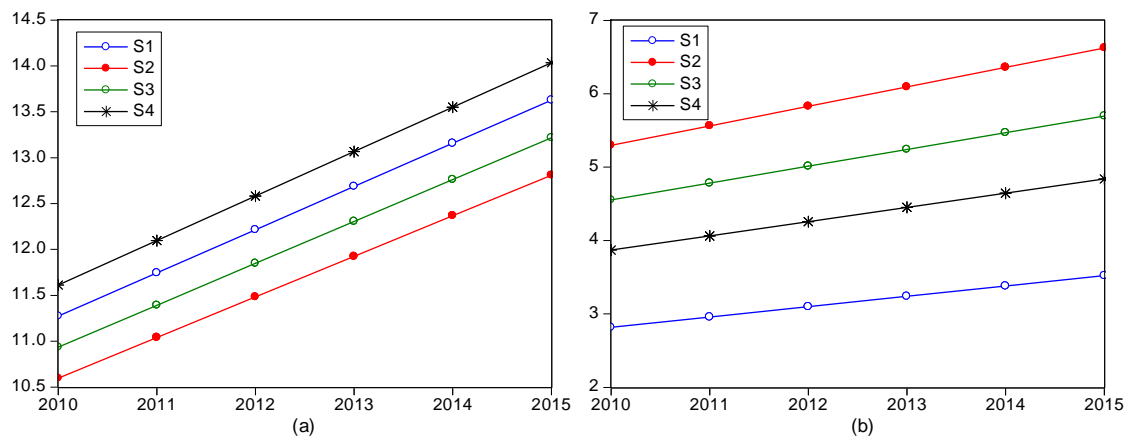


Figure 4.5: Scenarios of (a) urban sewage discharge (D_w) ($\times 10^8$ m³) and (b) reclaim water (R_1) ($\times 10^8$ m³) of player 1

Figure 4.6a and b demonstrate the scenario results of ecological based water use and water demand, respectively from 2010 to 2015. These results illustrate that ecological based water uses are $1.5\text{-}1.8 \times 10^8$ m³, $5.9\text{-}7.4 \times 10^8$ m³, $4.4\text{-}5.5 \times 10^8$ m³ and $0.7\text{-}0.9 \times 10^8$ m³, respectively in the four scenarios (Fig. 4.6a). Figure 4.6b shows the scenarios results of ecological based water demands from 2010 to 2015. The results confirm that ecological based

water demand is of $8.2-10.5 \times 10^8 \text{ m}^3$, $8.6-11.0 \times 10^8 \text{ m}^3$, $8.3-10.7 \times 10^8 \text{ m}^3$ and $8.1-10.3 \times 10^8 \text{ m}^3$, respectively in the four scenarios.

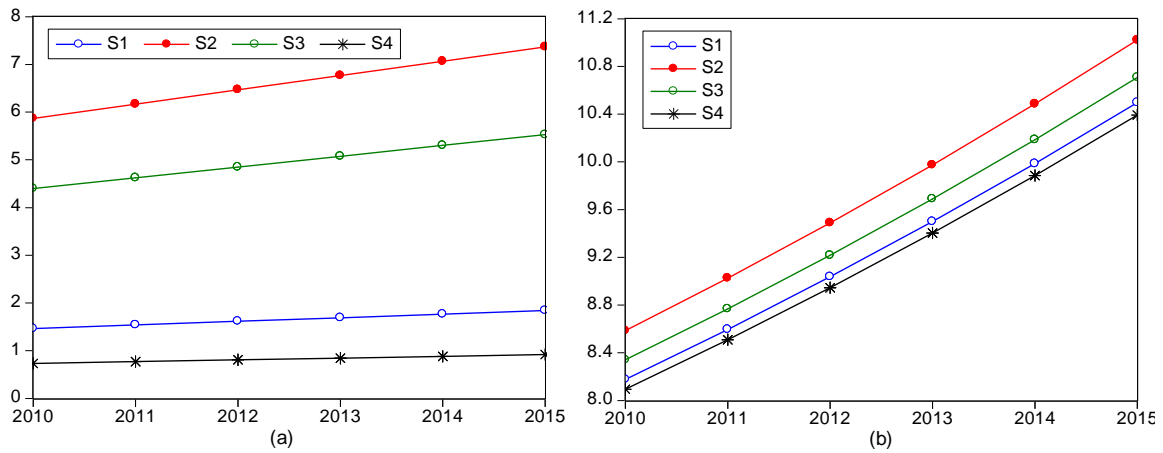


Figure 4.6: Scenarios of ecological based (a) water use (Q_{le}) and (b) water demand (Q_{leR}) ($\times 10^8 \text{ m}^3$) of player 1

Figure 4.7a and b explain the scenario results of total water demand and water supply of player 1 from 2010 to 2015. From the four scenarios, it sees that player 1 will demand water $39.9-40.5 \times 10^8 \text{ m}^3$, $41.2-41.7 \times 10^8 \text{ m}^3$, $40.2-40.7 \times 10^8 \text{ m}^3$ and $39.1-39.7 \times 10^8 \text{ m}^3$ (Fig. 4.7a), while water supply for player 1 is only $29.3-29.6 \times 10^8 \text{ m}^3$, $37.1-37.0 \times 10^8 \text{ m}^3$, $19.3-19.4 \times 10^8 \text{ m}^3$ and $17.4-18.1 \times 10^8 \text{ m}^3$, respectively in the four scenarios (Fig. 4.7b).

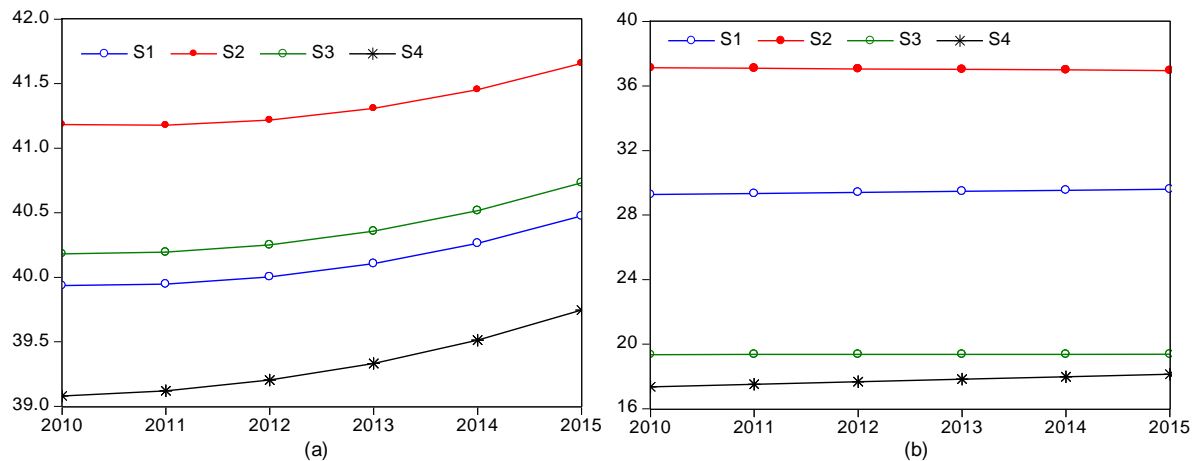


Figure 4.7: Scenarios of (a) total water demand (Q_I) and (b) water supply (W_I) ($\times 10^8 \text{ m}^3$) of player 1

Figures 4.8-4.10 illustrate the scenario results of water shares and water deficit of each sub-player from 2010 to 2015. In details, figure 4.8a explain that cooperation will give sub-player 11 water shares of $3.9-3.0 \times 10^8 \text{ m}^3$, $5.0-3.7 \times 10^8 \text{ m}^3$, $2.5-1.9 \times 10^8 \text{ m}^3$ and $2.2-1.8 \times 10^8$

m^3 , respectively in the four scenarios from 2010-2015. Scenarios results prove that sub-player 11 will face water deficits of $1.4-1.1 \times 10^8 m^3$, $0.5-0.4 \times 10^8 m^3$, $2.7-2.1 \times 10^8 m^3$ and $2.8-2.1 \times 10^8 m^3$, respectively in the four scenarios from 2010-2015 (Fig. 4.8 b).

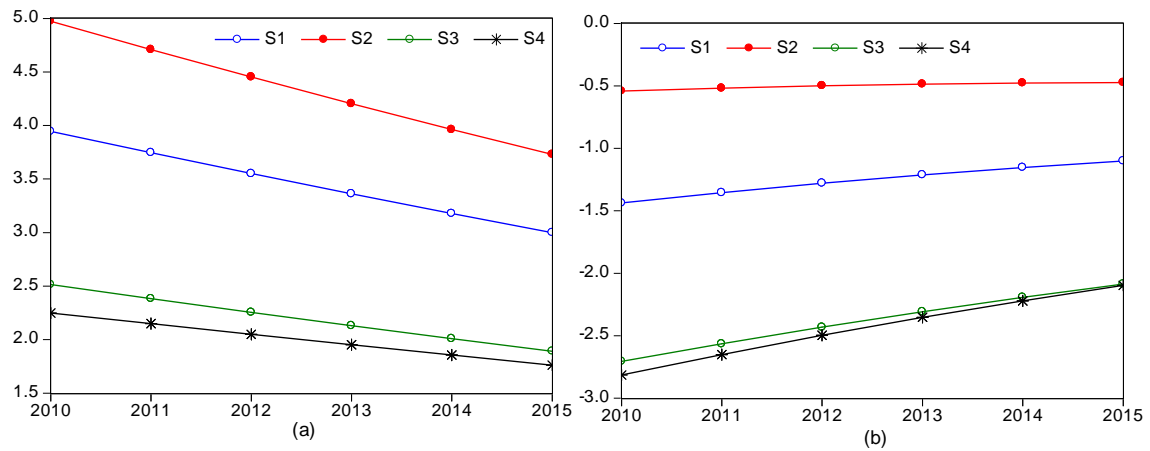


Figure 4.8: Scenarios of (a) water shares (Q_{11}) and (b) water deficit (W_{11}) ($\times 10^8 m^3$) of player 11 in the cooperative game

Figure 4.9a and b point up the scenario results of water shares and water deficits of player 12 in cooperative game from 2010 to 2015. Player 12 obtains $11.7-13.1 \times 10^8 m^3$, $14.4-15.9 \times 10^8 m^3$, $7.6-8.5 \times 10^8 m^3$ and $7.0-8.1 \times 10^8 m^3$, respectively in these four scenarios from 2010 to 2015 (Fig. 4.9a). However, player 12 has water deficits of $4.3-4.8 \times 10^8 m^3$, $1.6-2.0 \times 10^8 m^3$, $8.2-9.3 \times 10^8 m^3$ and $8.8-9.6 \times 10^8 m^3$, respectively in these four scenarios (Fig. 4.9b).

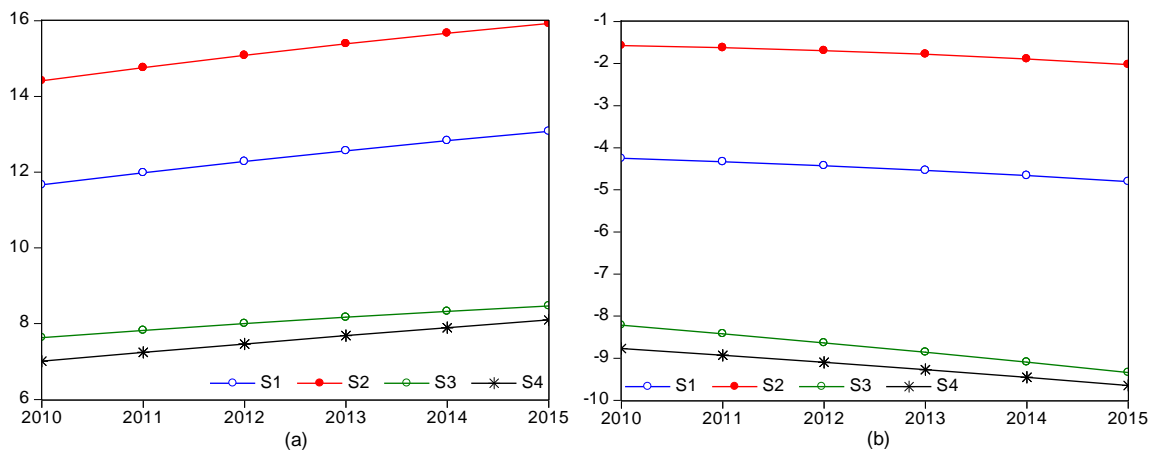


Figure 4.9: Scenarios of (a) water shares (Q_{12}) and (b) water deficit (W_{12}) ($\times 10^8 m^3$) of player 12 in the cooperative game

Figure 4.10a confirm that sub-player 13 obtain water shares of $7.7-5.8 \times 10^8 m^3$, $10.0-7.5 \times 10^8 m^3$, $5.2-3.9 \times 10^8 m^3$ and $4.5-3.5 \times 10^8 m^3$ in the cooperative game, respectively in

the four scenarios from 2010 to 2015. The scenario results prove that sub-player 13 will face water deficits of $2.8-2.1 \times 10^8 \text{ m}^3$, $1.1-1.0 \times 10^8 \text{ m}^3$, $5.5-4.3 \times 10^8 \text{ m}^3$ and $5.6-4.2 \times 10^8 \text{ m}^3$, respectively in the four scenarios from 2010-2015 (Fig. 4.10b).

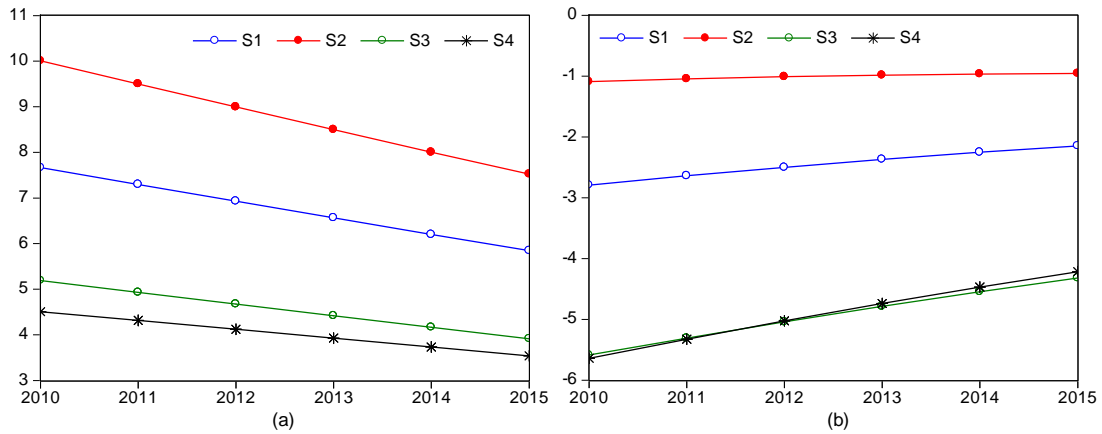


Figure 4.10: Scenarios of (a) water shares (Q_{13}) and (b) water deficit (W_{13}) ($\times 10^8 \text{ m}^3$) of player 13 in the cooperative game

4.2.2 Scenario results of game 2

The scenario results of game 2 are illustrated in figures 4.11-4.17. Figure 4.11a presents that player 23 has rural population of $751.0-744.4 \times 10^4$ persons, $743.5-737.0 \times 10^4$ persons, $748.7-742.2 \times 10^4$ persons and $753.2-746.6 \times 10^4$ persons, respectively in four rural population scenarios from 2005 to 2010. Figure 4.11b demonstrates that player 23 discharge $2557.5-2509.8$ tons, $2532.0-2484.7$ tons, $2549.9-2502.3$ tons and $2565.2-2517.3$ tons of nitrogen into the Danjiangkou Reservoir, respectively in these four rural population scenarios from 2005 to 2010.

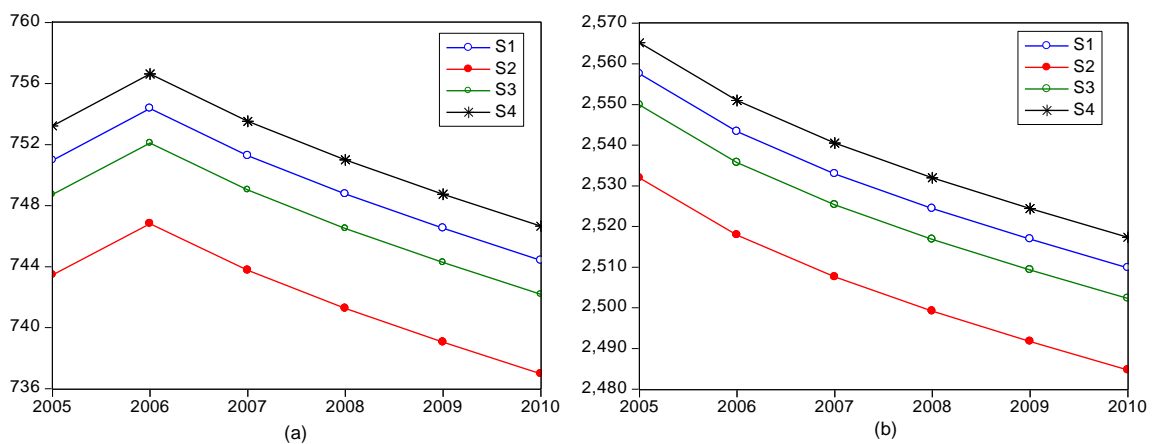


Figure 4.11: Scenarios of (a) rural population ($\times 10^4$ persons) and (b) nitrogen (tons) discharged into the reservoir by player 23

Figure 4.12a shows that player 22 has urban population of $155.6-177.4 \times 10^4$ persons, $154.0-175.6 \times 10^4$ persons, $155.1-176.8 \times 10^4$ persons and $156.1-177.9 \times 10^4$ persons, respectively in the four scenarios from 2005 to 2010. Figure 4.12b illustrates that player 22 discharges 6464.4-6229.2 tons, 5409.8-6166.9 tons, 5448.0-6210.5 tons and 5480.8-6247.9 tons of nitrogen into the Danjiangkou Reservoir, respectively in these four urban population scenarios from 2005 to 2010.

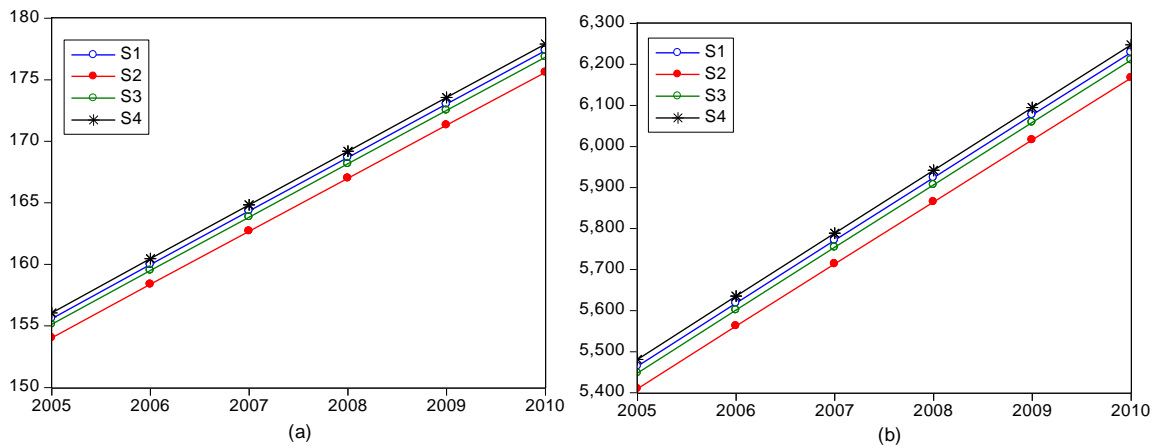


Figure 4.12: Scenarios of (a) urban population ($\times 10^4$ persons) and (b) nitrogen discharged into reservoir (tons) by player 22

The scenario results of soil erosion of player 23 are displayed in figure 4.13a. The sub-player 23 face soil erosion of 34253.6 km^2 , $32198.4-23630.5 \text{ km}^2$, $33226.0-28532.3 \text{ km}^2$ and $35281.2-40900.6 \text{ km}^2$, respectively in the four scenarios from 2005 to 2010. Figure 4.13b reveals that sub-player 23 discharge 5029.4 tons, 4727.6-3469.6 tons, 4585.8-3938.0 tons and 4723.4-5475.7 tons of nitrogen into the Danjiangkou Reservoir, respectively in these four urban population scenarios from 2005 to 2010.

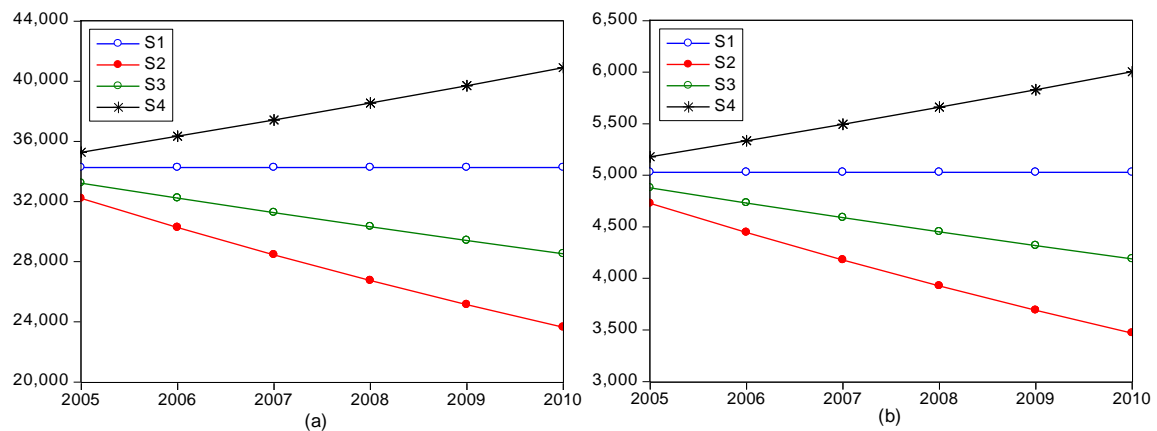


Figure 4.13: Scenarios of (a) soil erosion (km^2) and (b) nitrogen discharged into the reservoir (tons) by player 23

Figure 4.14a and b illustrate the four scenarios of nitrogen fertilizer consumptions of player 23 and nitrogen discharged into the Danjiangkou Reservoir by sub-player 23 in these four scenarios from 2005 to 2010. The four scenarios present that sub-player 23 consumes nitrogen fertilizer of $14.4-14.5 \times 10^4$ tons, $13.5-13.6 \times 10^4$ tons, $13.9-14.1 \times 10^4$ tons and $14.9-15.0 \times 10^4$ tons from 2005 to 2010 (Fig. 4.14). Nitrogen discharged into the Danjiangkou reservoir due to nitrogen fertilizer is 5320.7-5965.6 tons, 5001.4-5607.7 tons, 5161.1-5786.6 tons and 5480.3-6144.6 tons, respectively in the four scenarios.

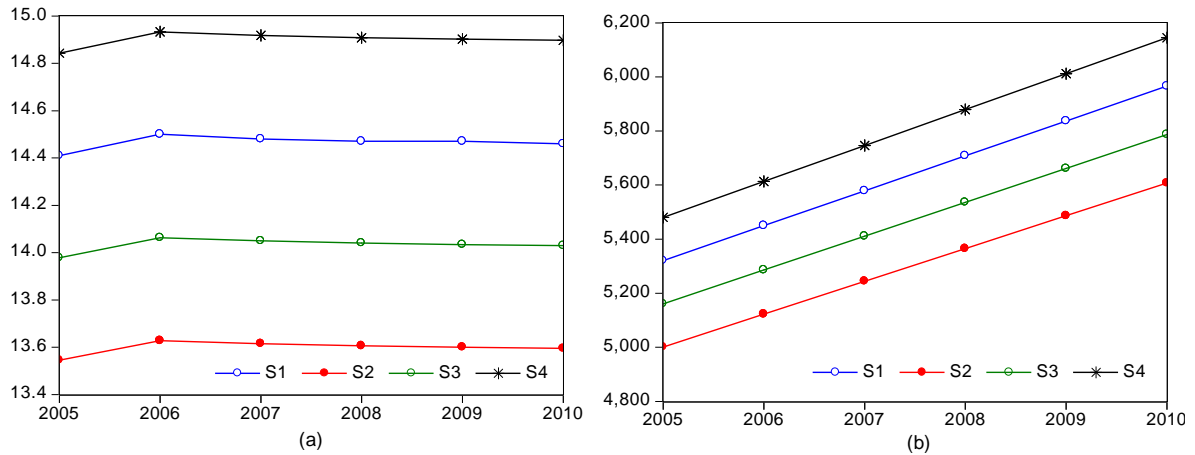


Figure 4.14: Scenarios of (a) nitrogen fertilizer consumption ($\times 10^4$ tons) and (b) nitrogen discharged into reservoir (tons) by player 23

Figure 4.15a and b prove the four scenarios of pig equivalences and nitrogen discharged into the Danjiangkou Reservoir in these animals scenarios from 2005 to 2010.

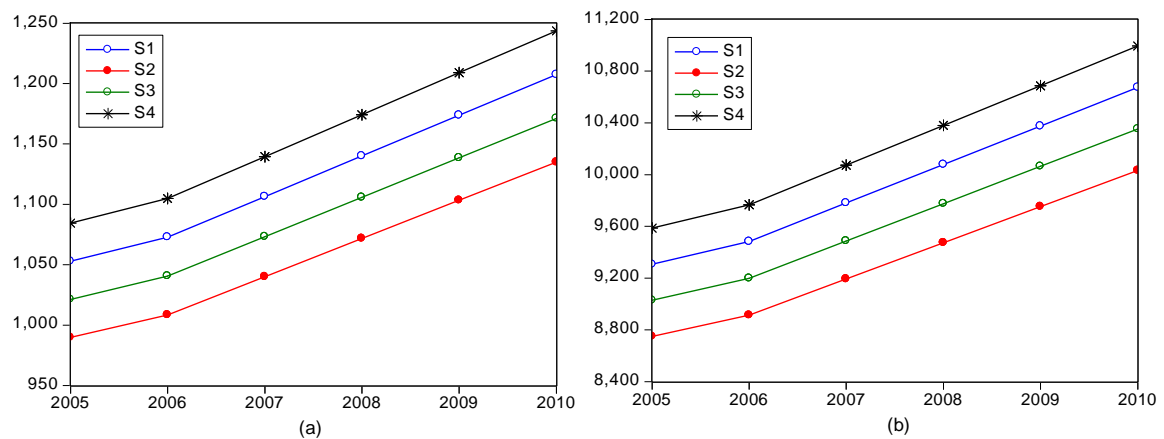


Figure 4.15: Scenarios of (a) pig equivalences ($\times 10^4$ units) and (b) nitrogen discharged into reservoir (tons) by player 23

Those four scenarios present that sub-player 23 has pig equivalences of $1052.9-1207.5 \times 10^4$ units, $989.8-1135.0 \times 10^4$ units, $1021.4-1171.2 \times 10^4$ units and $1084.5-1243.7 \times 10^4$ units. Ni-

trogen discharged into the Danjiangkou Reservoir by sub-player 23 is 9307.6-10673.6 tons, 8749.2-10033.2 tons, 9028.4-10353.4 tons and 9586.9-10993.8 tons, respectively in these four animal scenarios.

Figures 4.16a and b demonstrate the nitrogen discharged into the Danjiangkou Reservoir by rural domestic life and animal husbandry in four treatment scenarios from 2005 to 2010. Four scenarios of nitrogen produced by rural domestic life discharged into the Reservoir are 2557.5-2509.8 tons, 2228.1-2186.5 tons, 2345.9-2302.1 tons and 2436.9-2391.5 tons, respectively. Four scenarios of nitrogen production from animal husbandry into the Reservoir are 9307.6-10673.6 tons, 8190.7-9392.7 tons, 8563.0-9819.7 tons and 8842.2-10139.9 tons, respectively.

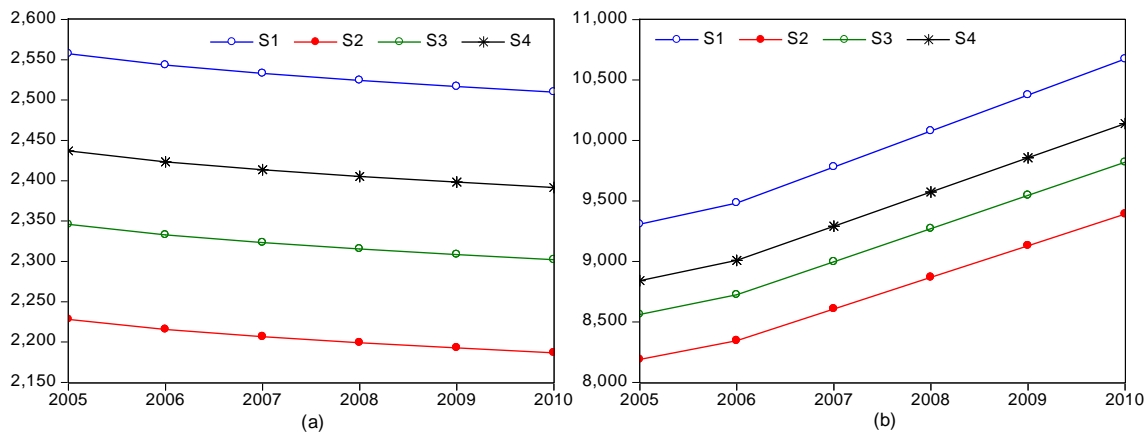


Figure 4.16: Scenarios of nitrogen (tons) discharged into reservoir from (a) rural domestic life, and (b) animal husbandry by player 23 in four treatment scenarios

Figure 4.17 illustrates the nitrogen discharge of player 22 and player 21 into the reservoir from urban domestic life and industrial waste water, respectively in four treatment scenarios.

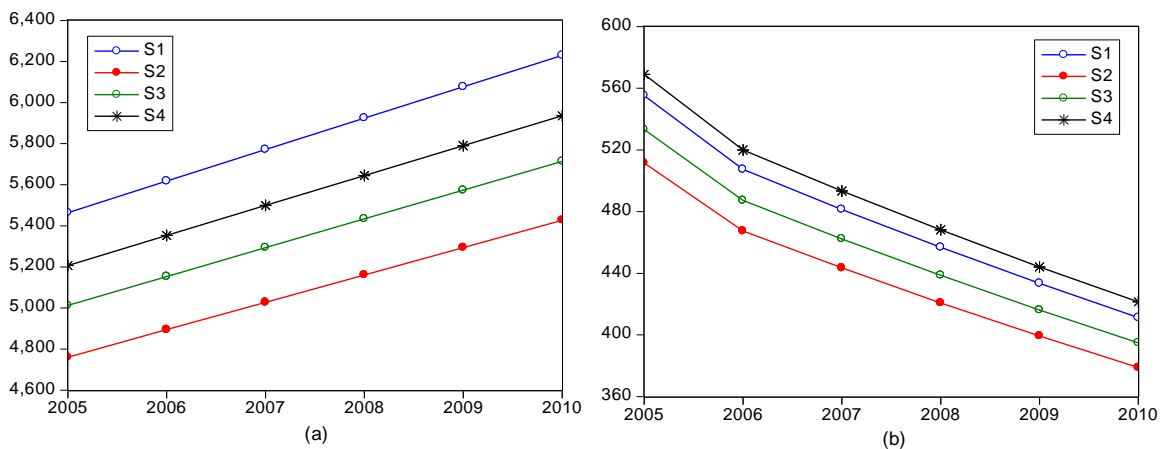


Figure 4.17: Scenarios of nitrogen (tons) discharged into reservoir from (a) urban domestic life by player 22 and (b) industrial waste water by player 21 in four treatment scenarios

Those scenario results show that sub-player 22 discharge from urban domestic life 5464.2-6229.2 tons, 4760.0-5426.9 tons, 5012.2-5713.6 tons and 5206.8-5935.5 tons of nitrogen into the Reservoir. Nitrogen from industry waste water discharged by 21 into the Reservoir by sub-player 23 are 555.2-411.2 tons, 511.5-378.8 tons, 533.2-394.9 tons and 569.0-421.4 tons, respectively in four treatment scenarios.

Figure 4.18 demonstrates the scenarios results of the nitrogen discharged into the Dangjiangkou Reservoir by sub-players 21, 22 and 23 from 2005 to 2010. The results prove that sub-players 21 discharges into the Dangjiangkou Reservoir nitrogen of 555.2-411.2 tons, 544.1-403.0 tons, 549.7-407.1 tons, and 522.4-409.1 tons, respectively. Sub-play 22 discharges into the Dangjiangkou Reservoir nitrogen of 8022.0-8739.0 tons, 7059.3-7690.3 tons, 7380.2-8039.9 tons and 7620.9-8302.0 tons respectively. Sub-player 23 discharges into the Dangjiangkou Reservoir nitrogen of 19657.7-21668.6 tons, 17428.4-17906.5 tons, 18345.7-19501.1 tons and 19768.1-22594.1 tons, respectively.

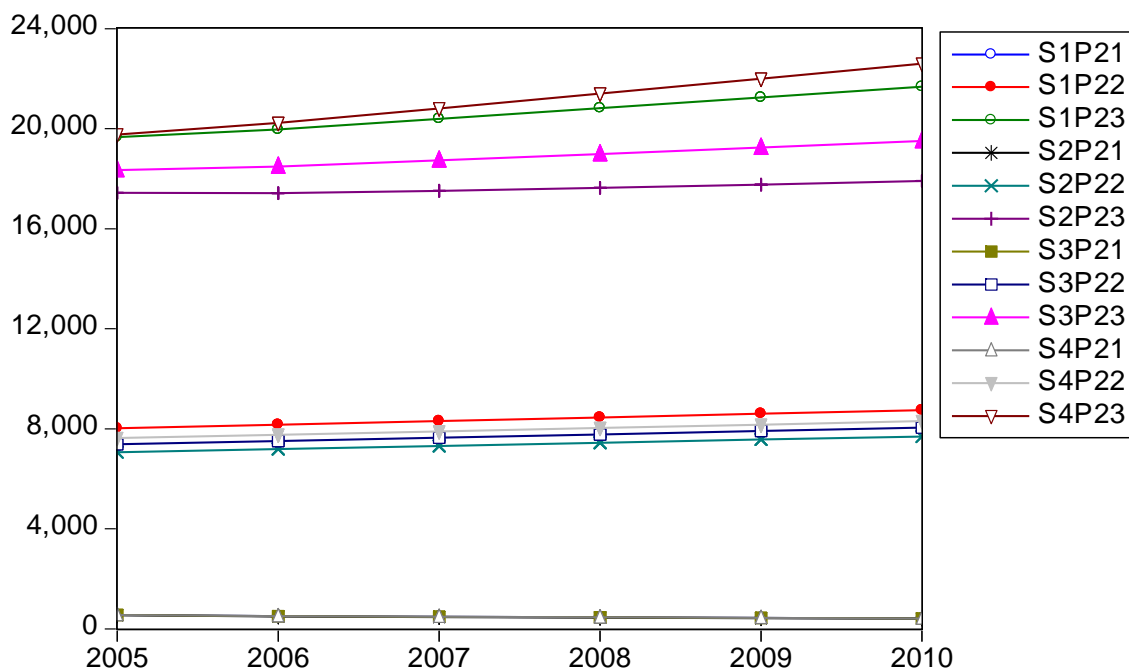


Figure 4.18: Nitrogen (tons) discharged into the reservoir by players 21, 22 and 23 (P21, P22 and P23) in scenarios 1, 2, 3 and 4 (S1, S2, S3 and S4)

4.2.3 Scenario results of game 3

Figures 4.19-4.26 illustrate the scenario results of game 3. The situation of game 3 is similar with game 2. Figure 4.19a shows that sub-player 33 has rural population of 224.1-

206.3×10⁴ persons, 221.9-204.3×10⁴ persons, 223.5-205.7×10⁴ persons and 224.8-206.9×10⁴ persons, respectively in the four scenarios from 2005 to 2010. Figure 4.19b explains that the nitrogen discharged into the Danjiangkou Reservoir by sub-player 33 is 850.0-782.6 tons, 841.5-774.8 tons, 847.5-780.2 tons and 852.6-784.9 tons, respectively in these four rural population scenarios from 2005 to 2010.

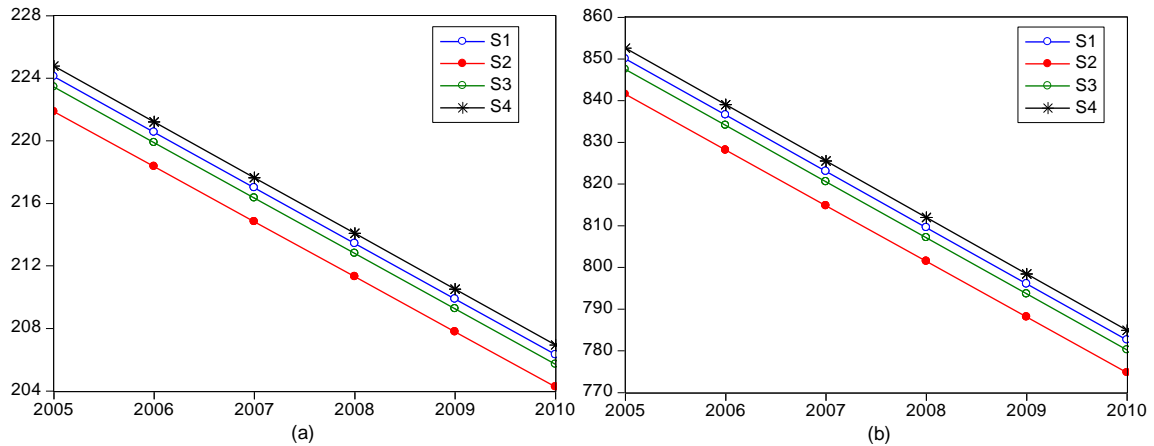


Figure 4.19: Scenarios of (a) rural population (×10⁴ persons) and (b) nitrogen discharged into reservoir (tons) by player 33

Figure 4.20a confirms that sub- player 32 owns urban population of 133.7-174.4×10⁴ persons, 132.4-172.7×10⁴ persons, 133.3-173.9×10⁴ persons and 134.1-174.9×10⁴ persons, respectively in the four scenarios from 2005 to 2010. Figure 4.20b is evidence for that nitrogen discharged into the Danjiangkou Reservoir by sub-player 32 is 5284.1-6891.1 tons, 5231.2-6822.2 tons, 5268.2-6870.4 tons and 5299.9-6911.8 tons, respectively in these four urban population scenarios from 2005 to 2010.

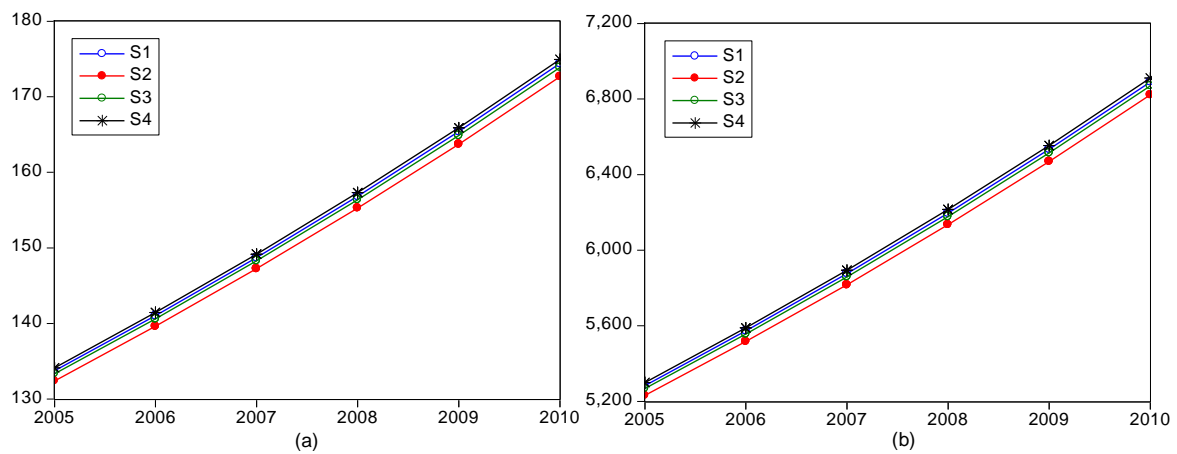


Figure 4.20: Scenarios of (a) urban population (×10⁴ persons) and (b) nitrogen discharged into the reservoir (tons) by player 32

The scenario results of soil erosion of sub-player 33 are illustrated in figure 4.21a. The sub-player 33 has soil erosion of 10922.4 km², 10267.1-7535.0 km², 10594.7-9098.0 km² and 11250.1-13041.9 km², respectively in the four scenarios from 2005 to 2010. Figure 4.21b explains that nitrogen discharged into the Danjiangkou Reservoir by sub-player 33 is 1790.1 tons, 1682.8-1235.0 tons, 1736.5-1491.2 tons and 1843.9-2137.6 tons, respectively in these four urban population scenarios from 2005 to 2010.

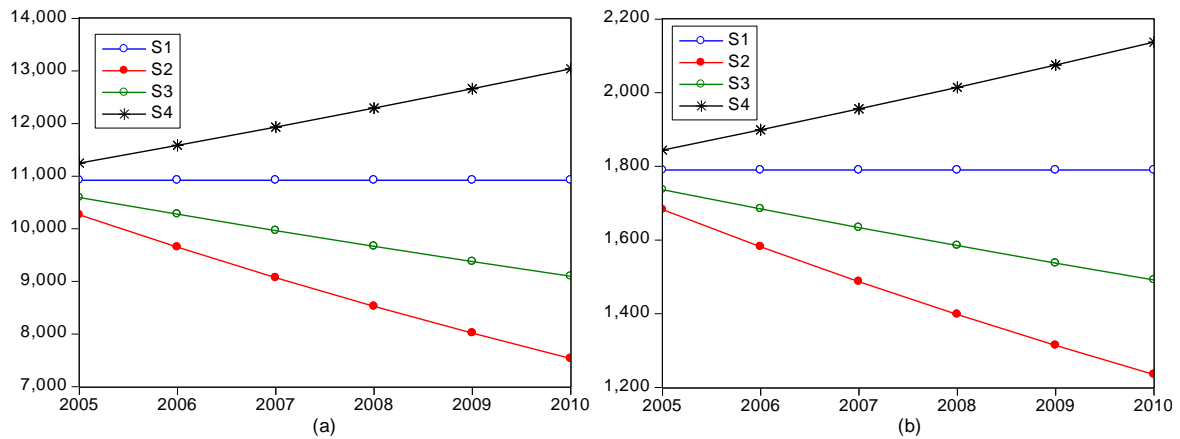


Figure 4.21: Scenarios of (a) soil erosion (km²) and (b) nitrogen discharged into the reservoir (tons) by player 33

Figure 4.22a and b demonstrate the four nitrogen fertilizer consumptions of player 33 and nitrogen discharge into the Danjiangkou reservoir by sub-player 33 in the four scenarios from 2005 to 2010. In those scenarios, sub-player 33 consumes nitrogen fertilizer of 6.5-6.9×10⁴ tons, 6.1-6.5×10⁴ tons, 6.3-6.7×10⁴ tons and 6.7-7.1×10⁴ tons. Sub-player 33 discharges into the Reservoir nitrogen: 11150.4-11107.7 tons, 10481.4-10441.3 tons, 10815.9-10774.5 tons and 11485.0-11441.0 tons, respectively.

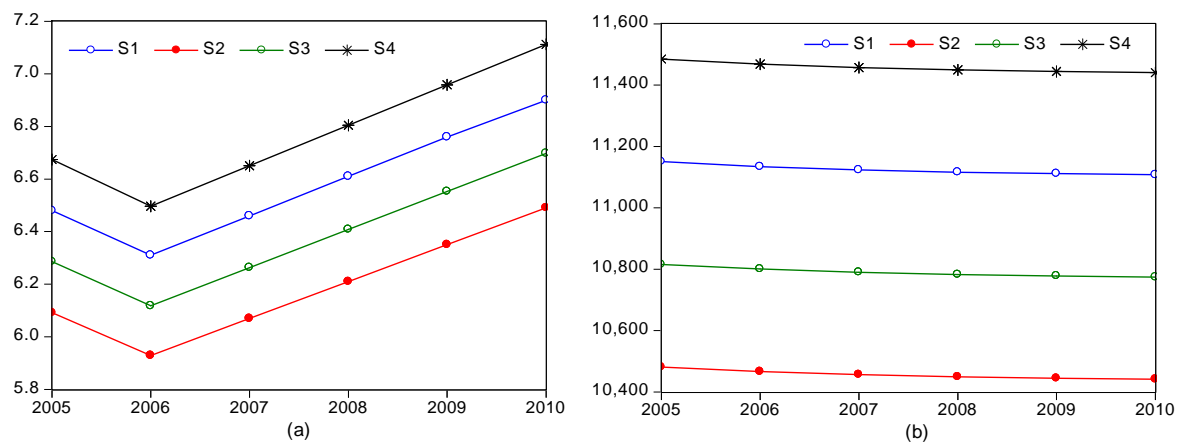


Figure 4.22: Scenarios of (a) nitrogen fertilizer (×10⁴ tons) and (b) nitrogen discharged into the reservoir (tons) by player 33

Figure 4.23a and b confirm the results of pig equivalences and the related nitrogen discharged into the Danjiangkou Reservoir by sub-player 33 in these scenarios from 2005 to 2010. In the four scenarios, sub-player 33 has pig equivalences of $310.3\text{-}333.7 \times 10^4$ units, $292.1\text{-}313.7 \times 10^4$ units, $301.4\text{-}323.7 \times 10^4$ units and $320.2\text{-}343.7 \times 10^4$ units, respectively. Nitrogen discharged into the Danjiangkou Reservoir by this sub-player is 3089.8-3318.7 tons, 2904.4-3119.6 tons, 2997.1-3219.1 tons and 3182.5-3418.2 tons, respectively.

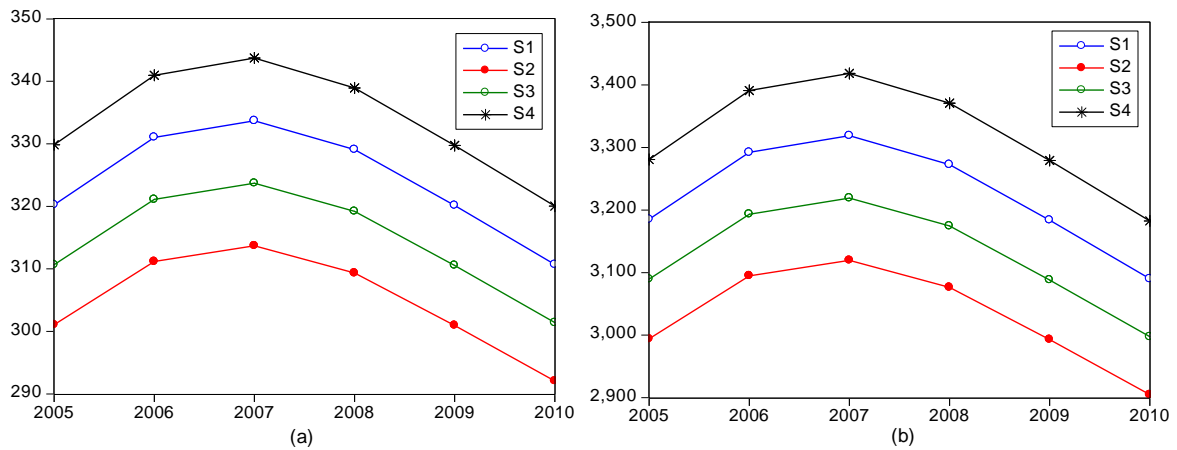


Figure 4.23: Scenarios of (a) pig equivalences ($\times 10^4$ units) and (b) nitrogen discharged into the reservoir (tons) by player 33

Figure 4.24a and b prove nitrogen from rural domestic life and animal husbandry discharged into the Danjiangkou Reservoir by sub-player 33 in four treatment scenarios from 2005 to 2010. Nitrogen from rural domestic life discharged into the Reservoir by this sub-player is 850.0-782.6 tons, 740.5-681.8 tons, 779.7-717.8 tons and 810.0-745.7 tons, respectively. Nitrogen from animal husbandry discharged into the Reservoir are 3318.7-3089.8 tons, 2920.4-2719.0 tons, 3053.2-2842.6 tons and 3152.7-2935.3 tons, respectively.

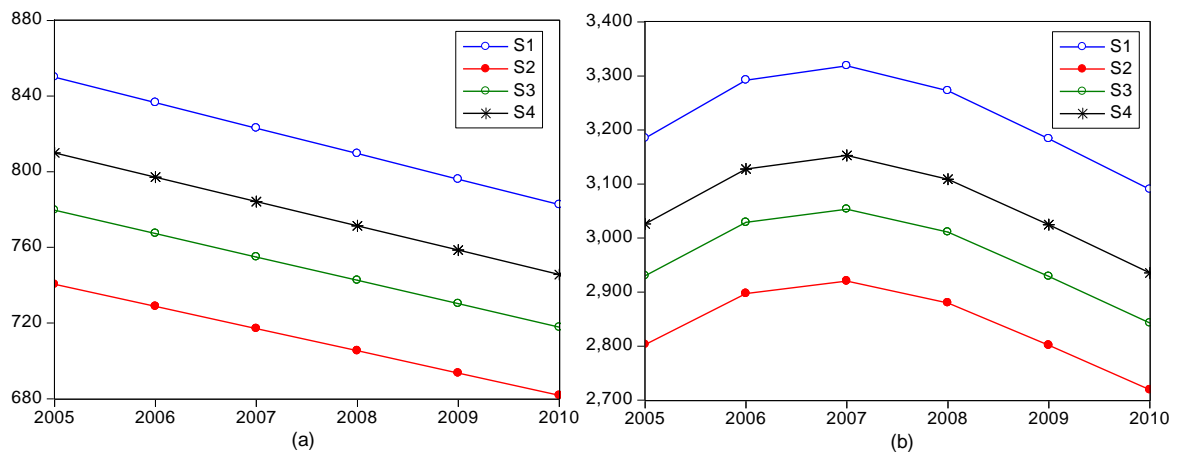


Figure 4.24: Scenarios of nitrogen (tons) discharged into reservoir from (a) rural domestic life and (b) animal husbandry by player 33 in four treatment scenarios

Figure 4.25a and b illustrate the nitrogen discharged by sub-player 32 and sub-player 31 into the reservoir in the four treatment scenarios from 2005 to 2010. Nitrogen discharged by sub-player 32 into the Danjiangkou Reservoir is 5284.1-6891.1 tons, 4603.5-6003.5 tons, 4846.8-6320.8 tons and 5034.9-6566.2 tons, respectively. Nitrogen discharged sub-player 31 into the Danjiangkou Reservoir is 341.3-657.5 tons, 314.4-605.7 tons, 327.7-631.4 tons and 349.7-673.8 tons, respectively.

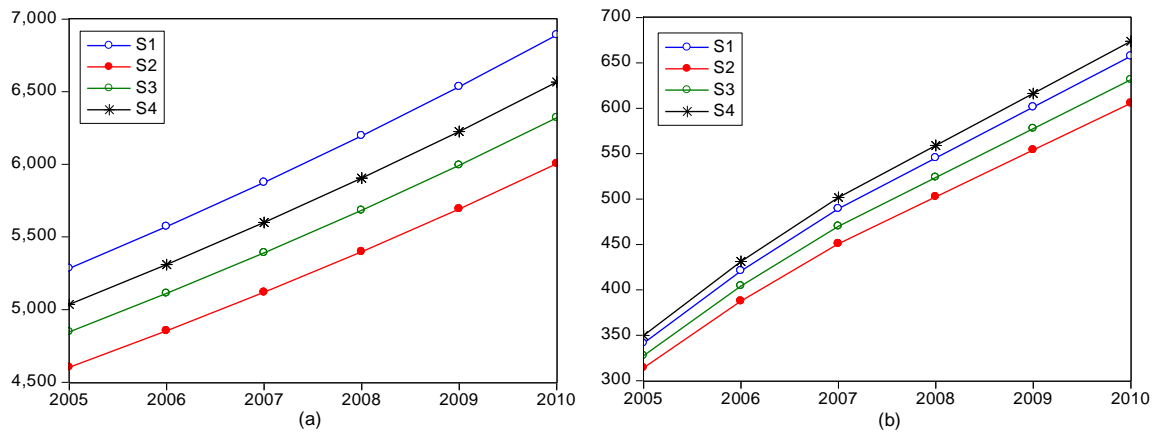


Figure 4.25: Scenarios of nitrogen (tons) discharged into reservoir from (a) urban domestic life by player 32, (b) industry waste water by player 31 in the four waste treatment scenarios

In order to compare the scenario results from 2005 to 2010, nitrogen discharged by sub-players 31, 32 and 33 into the Dangjiangkou Reservoir are illustrated in Figure 4.26.

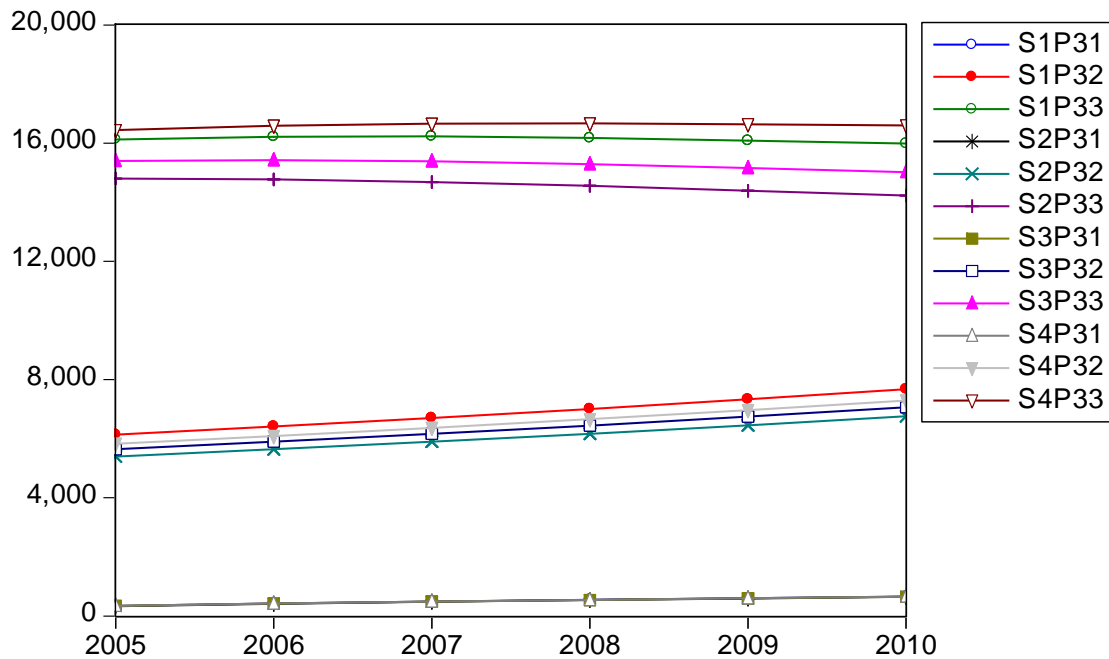


Figure 4.26: Nitrogen (tons) discharged into the reservoir by player 31, 32 and 33 (P31, P32 and P33) in scenarios 1, 2, 3 and 4 (S1, S2, S3 and S4)

The results verify that sub-players 31 discharges into the Dangjiangkou Reservoir nitrogen of 341.3-657.5 tons, 334.4-644.3 tons, 337.8-650.9 tons and 339.5-654.2 tons in scenario 1 (S1), scenario 2 (S2), scenario 3 (S3) and scenario 4 (S4), respectively from 2005 to 2010. Sub-player 32 discharges into the Reservoir nitrogen of 6134.1-7673.7 tons, 5398.0-6752.8 tons, 5643.4-7059.8 tons and 5827.4-7290.0 tons, respectively in the four scenarios from 2005 to 2010. For sub-player 33, he discharges into the Reservoir nitrogen of 16125.5-15987.7 tons, 14798.7-14232.2 tons, 15394.6-15023.0 tons and 16667.0-16602.0 tons, respectively in the four scenarios in the same time interval.

4.2.4 Scenario results of game 4

Figures 4.27-4.32 give an idea about scenario results of game 4. The situation of game 4 is very similar with game 2 and 3. Figure 4.27a presents the four rural population scenarios of the sub-player 43 from 2005 to 2010. Sub-player 43 has rural population of $82.7-68.0 \times 10^4$ persons, $81.9-67.3 \times 10^4$ persons, $82.5-67.7 \times 10^4$ persons and $83.0-68.2 \times 10^4$ persons, respectively in the four scenarios from 2005 to 2010. Figure 4.27b illustrates that nitrogen discharged into the Danjiangkou Reservoir by sub-player 43 is 313.8-257.7 tons, 310.6-255.1 tons, 312.8-256.9 tons and 314.7-258.5 tons, respectively in these four rural population scenarios from 2005 to 2010.

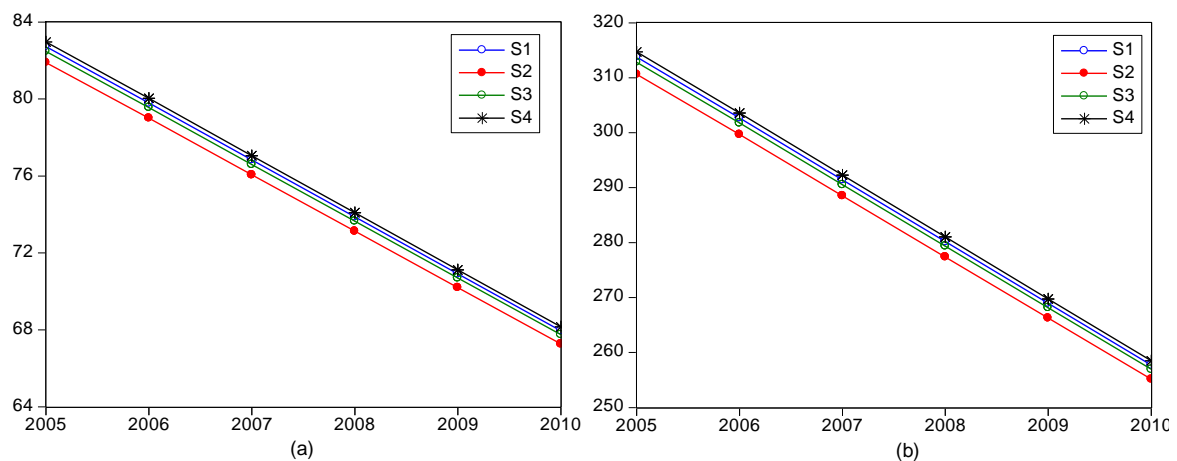


Figure 4.27: Scenarios of (a) rural population ($\times 10^4$ persons) and (b) nitrogen discharged into reservoir (tons) by player 43

Figure 4.28a explains the four urban population scenarios of sub-player 42 from 2005 to 2010. The four scenarios show that this sub-player owns urban population of $25.8-38.1 \times 10^4$ persons, $25.6-38.4 \times 10^4$ persons, $25.7-38.7 \times 10^4$ persons and $25.9-38.9 \times 10^4$ persons, respectively from 2005 to 2010. Figure 4.28b illustrates that nitrogen discharged into

the Danjiangkou Reservoir by this sub-player is 1019.8-1533.3 tons, 1009.6-1517.9 tons, 1016.7-1528.7 tons and 1022.8-1537.9 tons, respectively in these four urban population scenarios from 2005 to 2010.

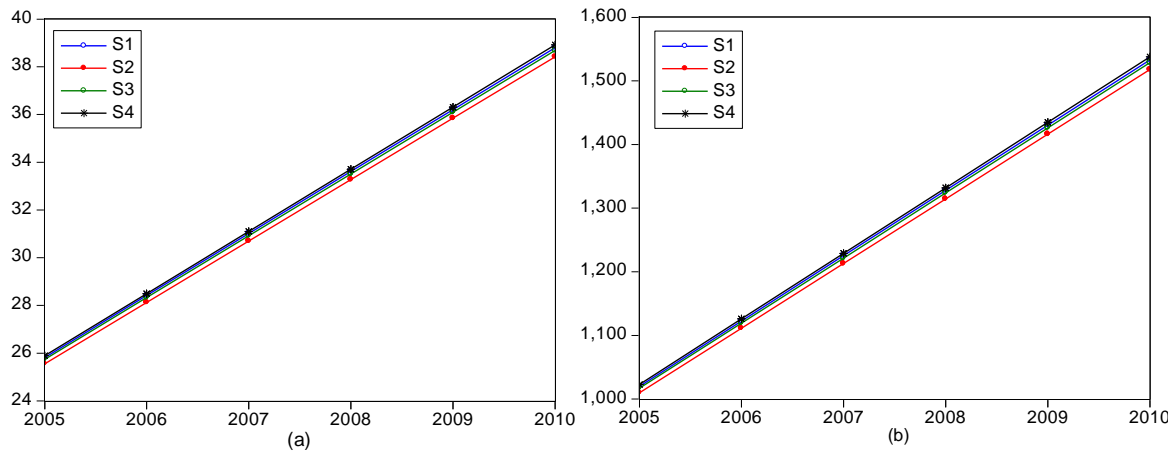


Figure 4.28: Scenarios of (a) urban population ($\times 10^4$ persons) and (b) nitrogen discharged into the reservoir (tons) by player 42

The scenario results of soil erosion of sub-player 43 are displayed in figure 4.29a. Sub-player 43 has soil erosion of 3230.7 km², 3036.8-2228.8 km², 3133.8-2691.1 km² and 3327.6-3857.6 km², respectively in the four scenarios from 2005 to 2010. Figure 4.29b explains that nitrogen discharged by this sub-player into the Danjiangkou Reservoir is 529.5 tons, 497.7-365.3 tons, 513.6-441.1 tons and 545.4-632.3 tons, respectively in these four soil erosion scenarios from 2005 to 2010.

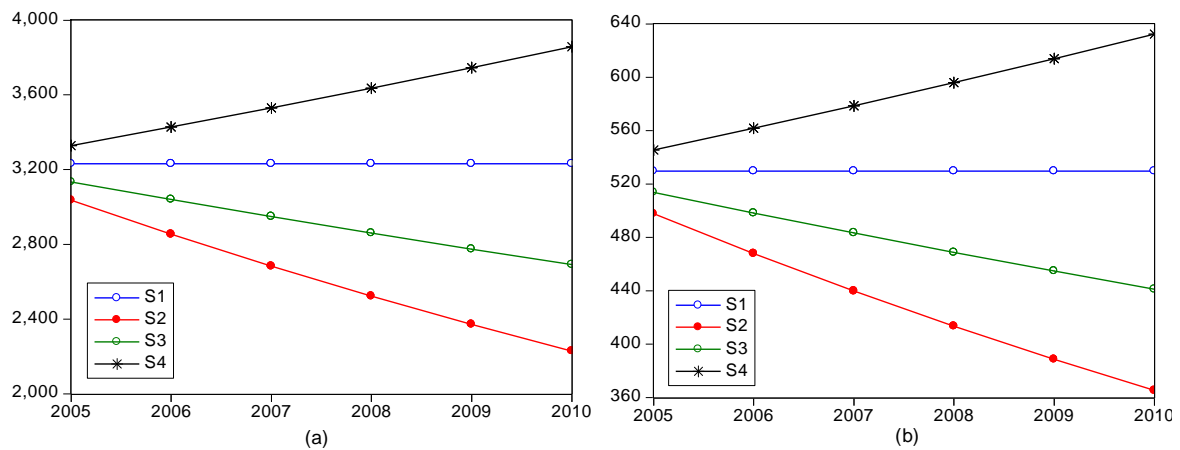


Figure 4.29: Scenarios of (a) soil erosion (km²) and (b) nitrogen discharged into the reservoir (tons) by player 43

Figure 4.30a and b illustrate the four scenarios of nitrogen fertilizer consumptions of sub-player 43 and nitrogen discharge into the Danjiangkou Reservoir from 2005 to 2010. The

scenario results prove that this sub-player consume nitrogen fertilizer of $2.1-2.8 \times 10^4$ tons, $1.9-2.6 \times 10^4$ tons, $2.0-2.7 \times 10^4$ tons and $2.2-2.9 \times 10^4$ tons, respectively from 2005 to 2010. Nitrogen discharged into the Reservoir by this sub-player is 1811.8-2470.1 tons, 1703.1-2321.9 tons, 1757.4-2396.0 tons and 1866.2-2544.2 tons, respectively in the four scenarios of nitrogen fertilizer consumptions from 2005 to 2010.

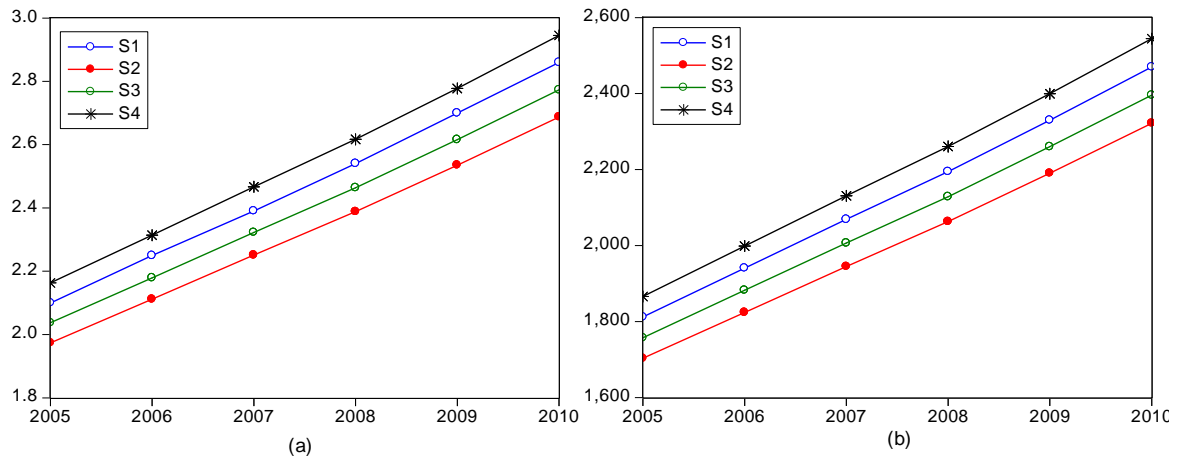


Figure 4.30: Scenarios of (a) nitrogen fertilizer ($\times 10^4$ tons) and (b) nitrogen discharged into the reservoir (tons) by player 43

Figure 4.31a and b show the four scenarios of pig equivalences and nitrogen produced from these animals by player 43 into Danjiangkou Reservoir in these scenarios from 2005 to 2010. The four scenarios of pig equivalences are $313.4-408.3 \times 10^4$ units, $294.6-383.8 \times 10^4$ units, $304.0-396.0 \times 10^4$ units and $322.8-420.5 \times 10^4$ units. Nitrogen into Danjiangkou Reservoir is 3116.5-4060.3 tons, 2929.5-3816.7 tons, 3023.0-3938.5 tons and 3210.0-4182.1 tons, respectively in those scenarios.

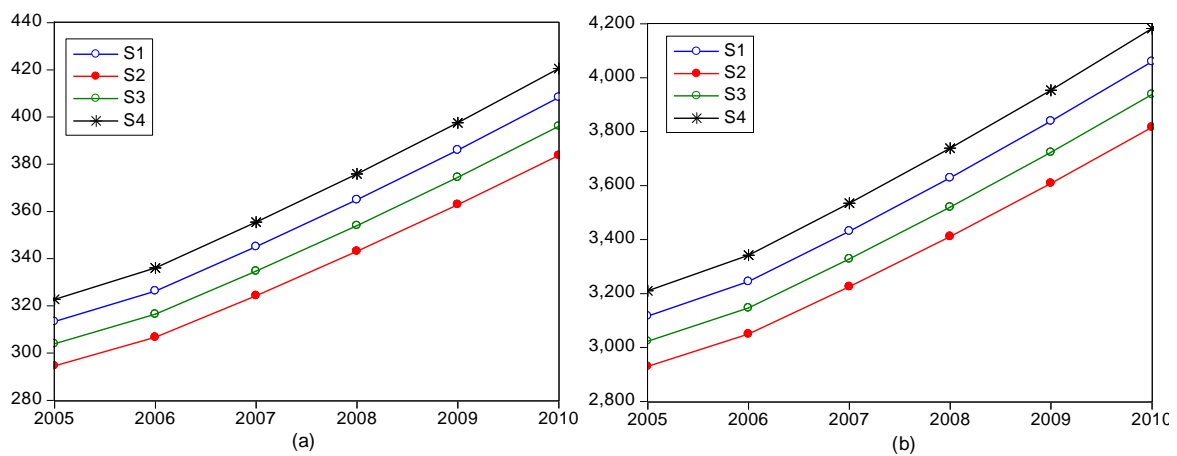


Figure 4.31: Scenarios of (a) pig equivalences ($\times 10^4$ units) and (b) nitrogen discharged into the reservoir (tons) by player 43

Figure 4.32a and b shows the scenario results of nitrogen from rural domestic life and animal husbandry discharged into the Reservoir by sub-player 43 in four treatment scenarios from 2005 to 2010. Nitrogen from rural domestic life discharged into the Reservoir is 313.8-257.7 tons, 273.3-224.5 tons, 287.8-236.4 tons and 300.0-245.6 tons, respectively. Nitrogen from animal husbandry discharged into the Reservoir is 3116.5-4060.3 tons, 2742.5-3573.1 tons, 2867.2-3735.5 tons and 2960.7-3857.3 tons, respectively.

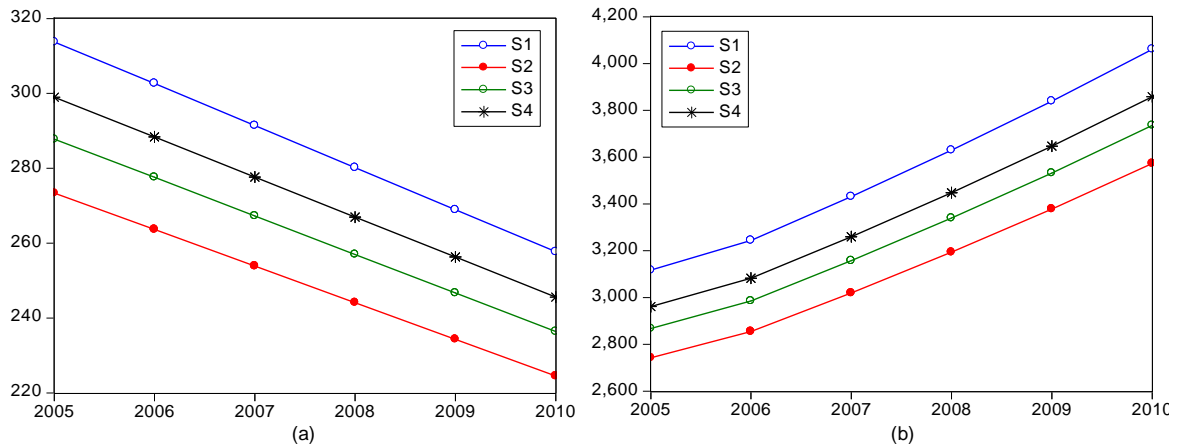


Figure 4.32: Scenarios of nitrogen (tons) discharged into reservoir by (a) rural domestic life and (b) animal husbandry by player 43 in four treatment scenarios

Figure 4.33a and b illustrate the nitrogen discharge from urban domestic sewage of player 42 and industry waste water of player 41 into the Reservoir in four treatment scenarios from 2005 to 2010. Nitrogen discharged from urban domestic life into the Reservoir is 1019.8-1533.3 tons, 888.4-1335.8 tons, 935.4-1406.4 tons and 971.7-1461.0 tons, respectively. Nitrogen discharged from industry waste water into the Reservoir is 174.3-218.9 tons, 160.6-201.7 tons, 167.4-210.2 tons and 178.7-224.3 tons, respectively.

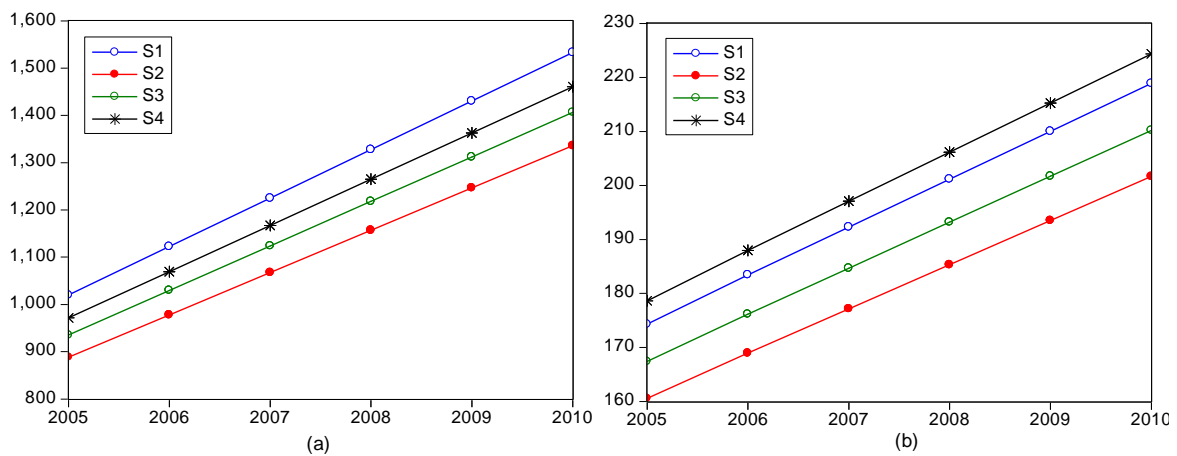


Figure 4.33: Scenarios of nitrogen (tons) discharged into reservoir from (a) urban domestic life by player 42, and (b) industry waste water by player 41 in four treatment scenarios

Figure 4.34 proves the scenario results of the nitrogen discharged into the Dangjiangkou Reservoir by sub-players 41, 42 and 43 of from 2005 to 2010. The results explain that sub-player 41 discharges into Dangjiangkou Reservoir nitrogen of 174.3-218.9 tons, 170.8-214.5 tons, 172.6-216.7 tons and 173.5-217.8 tons, respectively in scenario 1 (S1), scenario 2 (S2), scenario 3 (S3) and scenario 4 (S4), respectively from 2005 to 2010. Sub-player 42 discharges into the Reservoir nitrogen of 1333.5-1791.0 tons, 1173.5-1576.1 tons, 1226.8-1647.7 tons and 1266.8-1701.4 tons, respectively in the four scenarios from 2005 to 2010. For sub-player 43, he discharges into the Reservoir nitrogen of 5457.8-7059.9 tons, 4778.8-6045.9 tons, 5052.2-6460.5 tons and 5461.0-7149.5 tons, respectively in the four scenarios during the same period of time.

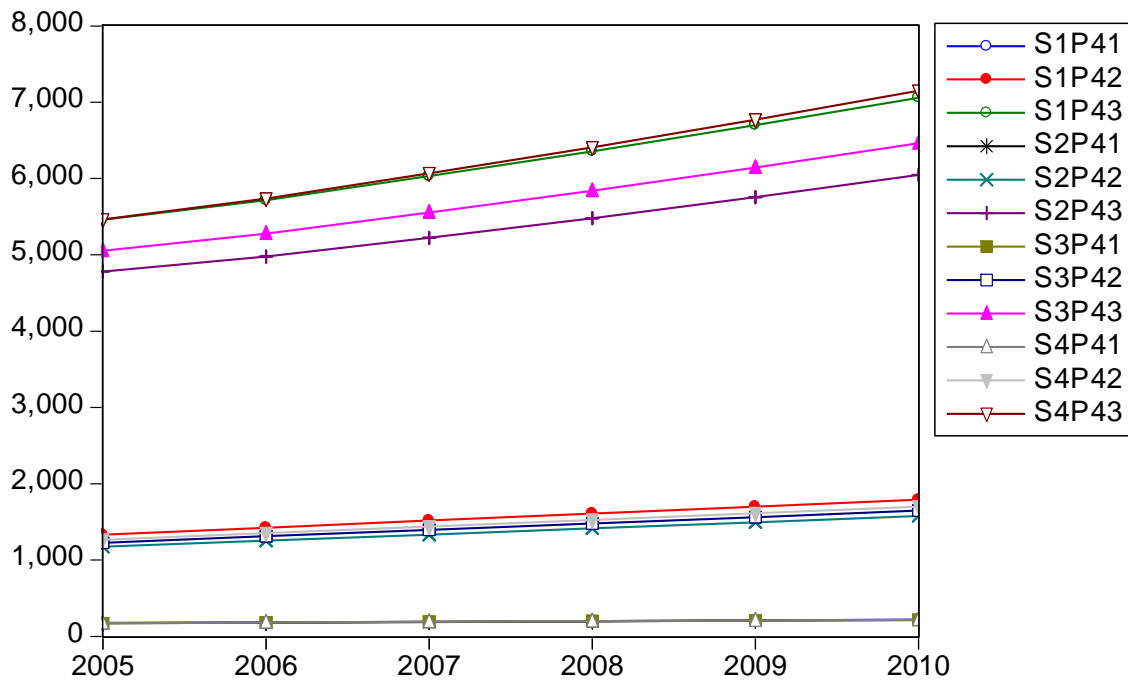


Figure 4.34: Nitrogen (tons) discharged into the reservoir by players 41, 42 and 43 (P41, P42 and P43) in scenarios 1, 2, 3 and 4 (S1, S2, S3 and S4)

4.2.5 Scenario results of game 5

Figure 4.35 illustrates the scenario results of player 1. Player 1 faces water deficits of $10.6-10.9 \times 10^8 \text{ m}^3$, $3.1-3.8 \times 10^8 \text{ m}^3$, $20.8-21.4 \times 10^8 \text{ m}^3$ and $21.7-21.6 \times 10^8 \text{ m}^3$, in scenario 1 (S1), scenario 2(S2), Scenario 3(S3) and scenario 4 (S4), respectively from 2010 to 2015. The results reveal that player 1 will face extreme water shortage in scenarios 3 and 4.

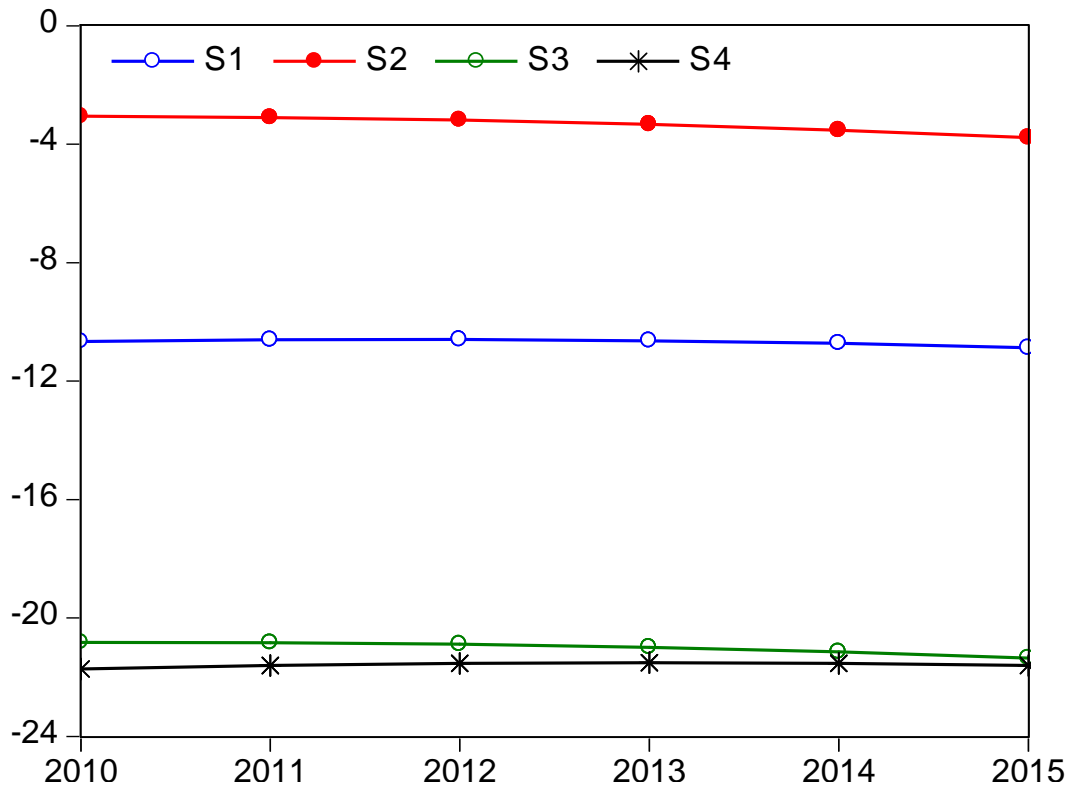


Figure 4.35: Water deficit ($\times 10^8$ m³) of player 1 in four scenarios

Figure 4.36 reveals the scenario results of nitrogen discharged into reservoir by players 2, 3, and 4 (P1, P2, P3 and P4) in scenarios 1, 2, 3 and 4 (S1, S2, S3 and S4) from 2005 to 2010.

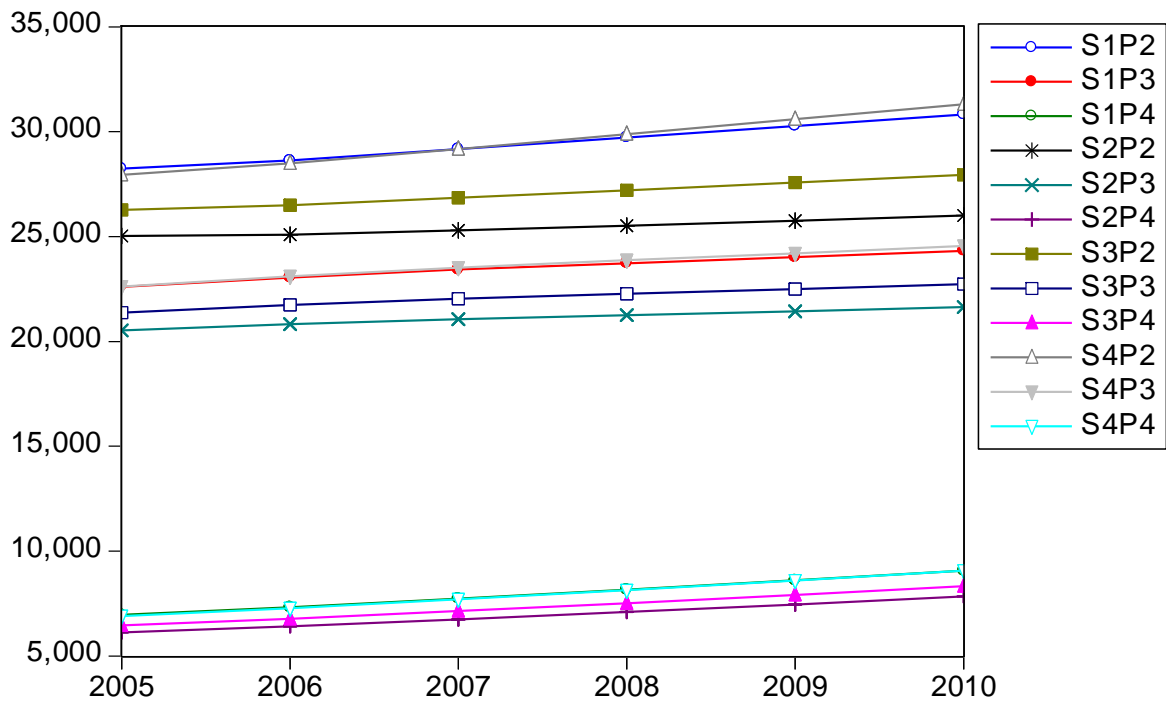


Figure 4.36: Scenarios of nitrogen (tons) discharged into the Reservoir by the players 2, 3 and 4

The results explain that player 2 discharges into the Dangjiangkou Reservoir nitrogen of 28234.9-30818.8 tons, 25031.8-26000.0 tons, 26275.6-27948.1 tons, and 27941.4-31305.2 tons in scenario 1 (S1), scenario 2 (S2), scenario 2 (S3) and scenario 4 (S4), respectively from 2005 to 2010. Player 3 discharges into the Reservoir nitrogen of 22600.9-24318.9 tons, 20531.2-21629.3 tons, 21375.8-22733.7 tons and 22612.2-24546.1 tons, respectively in the different scenarios from 2005 to 2010. Player 4 discharges into the Reservoir nitrogen of 6965.6-9069.8 tons, 6123.1-7836.5 tons, 6451.6-8324.9 tons and 6901.3-9068.7 tons, respectively in the different scenarios from 2005 to 2010.

Different nitrogen reduction amount of players 2, 3, 4 in the four scenarios are illustrated in figure 4.37. In scenario 1 (S1), players 2, 3 and 4 will reduce nitrogen of 6633.0-21355.8 tons, 5309.4-16581.8 tons, 1636.4-6284.9 tons, respectively from 2005 to 2010. In scenario 2 (S2), players 2, 3 and 4 will reduce nitrogen of 2938.8-13500.4 tons, 2447.5-11231.1 tons, 783.9-4069.1 tons, respectively from 2006 to 2010. In scenario 3 (S3), players 2, 3 and 4 will reduce nitrogen of 11799.7-21719.7 tons, 9599.4-17667.4 tons, and 2897.3-6469.7 tons, respectively from 2005 to 2010. In scenario 4 (S4), players 2, 3 and 4 will reduce nitrogen of 18742.5-27281.1 tons, 15167.8-21390.9 tons, 4629.3-7903.0 tons, respectively from 2005 to 2010.

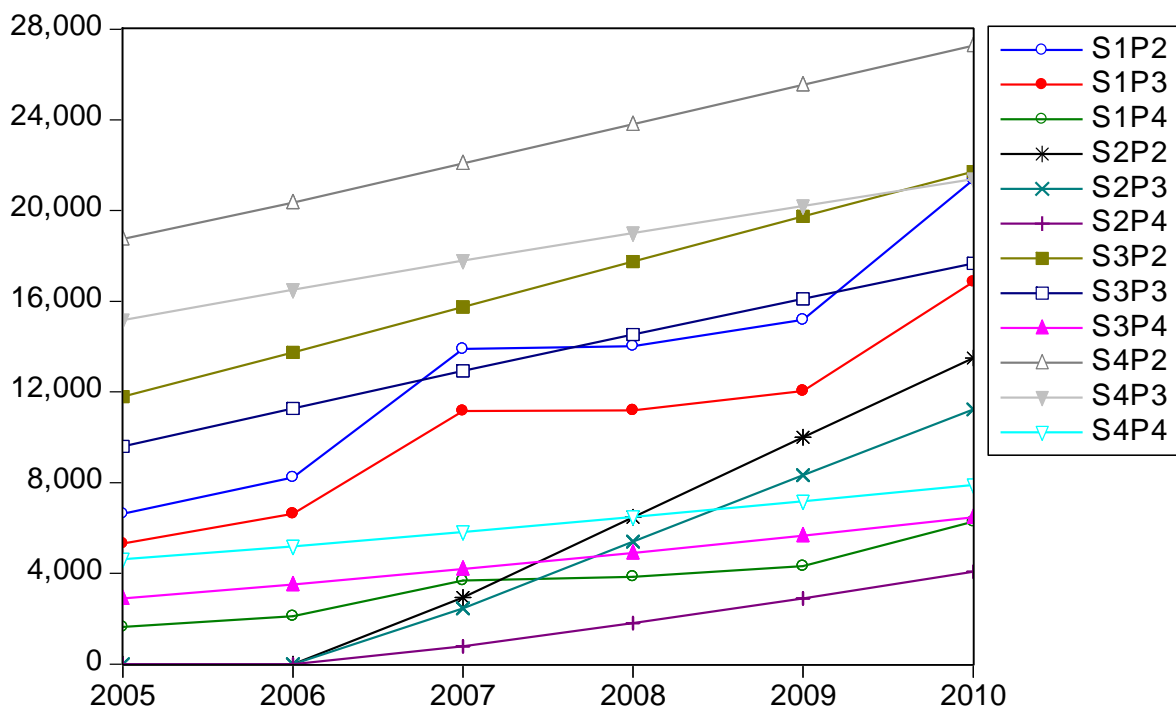


Figure 4.37: Scenarios of nitrogen (tons) reduction of players 2, 3 and 4

4.3 Discussion

Generally speaking, the simulation results prove that cooperative games bring the players a collective benefit, although some sub-players will be worse-off. However, each player will be better off if a side payment is made from the beneficial players to the worse-off players. The scenario results illustrate that the structure of the game simulation are not so stable, and there are uncertainties and risks in the simulation models due to changes of driving forces in the future.

4.3.1 Discussion of the simulation results

(1) Discussion of the results of game 1

The non-cooperation game simulation results interpret that water demand of sub-player 11 and 13 will be decreased from $5.38 \times 10^8 \text{ m}^3$ to $4.10 \times 10^8 \text{ m}^3$ and from $10.46 \times 10^8 \text{ m}^3$ to $7.99 \times 10^8 \text{ m}^3$ due to efficient use of water from 2010 to 2015. However, sub-player 12 will demand much more water from $15.98 \times 10^8 \text{ m}^3$ in 2010 to 17.88 in 2015 (Table 4.1). The growth of water demand of sub-player 12 is mainly because of the growth population and increase of Per capita net income. In the cooperative game, sub-players of 11, 12 and 13 group together to consider the water quota for urban ecology and share the scarce water among them. In this case, each of them certainly obtains less water than that in non-cooperative game. For example, sub-player can get $5.38 \times 10^8 \text{ m}^3$ of water for consumption in 2010 in non-cooperative game, but he can only get $4.02 \times 10^8 \text{ m}^3$ of water in the same year in the cooperative game (Table 4.2). Therefore, cooperation between sub-players 11, 12 and 13 makes them worse off. Sub-player 12 will be the biggest loser of the three players, and sub-player 13 is the second (Table 4.3). This is the reason why each player does not want to cooperate with others, and why they overtake ground water and ecological based water and compete for water.

Although they can get much more water for consumption in non-cooperation than that in cooperation, the non-cooperation will severely destroy the environment. In a long run, water will gradually become much more scarcity, and this causes the problem of "The Tragedy of Commons". From the society point of view, this game forms a prisoners' dilemma game. However, this prisoners' dilemma game is quite different from the one widely cited in the literature. The prisoners' dilemma game can be solved by designing a mechanism, which can drive the players to reach collective rationality by changing the game rules (Wei

and Gnauck, 2007d). However, this prisoners' dilemma game cannot be solved by just changing the rules due to severe resources shortage. In order to stress the specialty of this kind of game, it would rather name it as "Resource deficit dilemma game" or "Prisoners' dilemma game in case of resource deficit" than "Prisoners' dilemma game".

(2) Discussion of the results of games 2, 3 and 4

Those three games are TN reduction games. From the results of non-cooperative game simulation, it sees that the nitrogen productions of sub-player 21 is decreased and this is mainly because of the increase of industry waste treatment rate due to government policy of limiting industrial waste discharge (Wei, 2007). However, the nitrogen production of sub-players 22, 23, 32, 33, 42 and 43 are still increasing mainly due to their low rate of waste treatment and relatively undeveloped economy if the current policy holds constant (Tables 4.4, 4.6, 4.8). The cooperative game simulation results of games 2, 3 and 4 confirm that sub-players 23, 33 and 43 are the largest polluters in each game, respectively. The second largest polluters are sub-players 22, 32 and 42 in each game, respectively. Considering all those games, the largest polluter is sub-player 23, the second one sub-player 22, and the last one sub-player 41 (Tables 4.4-4.9).

Those three games also belong to prisoners' dilemma games. Every player has no incentive to reduce pollutants, because he can save cost by free-riding others' achievement. At the end, the deterioration of water body will increase, which in turn harm the players. However, cooperation will make the players full of risks and uncertainties.

(3) Discussion of the results of game 5

In game 5, payoffs of player 1 and his sub-players 11, 12 and 13 are calculated at current prices (Matrix 4.1 and Table 4.10) and at comparable prices (Matrix 4.2 and Table 4.15), respectively. The payoffs at current prices include inflation, and the comparison results of payoffs at current prices usually lack reliability and stringency. The Consumer Price Index (CPI) is used to discount the payoffs of player 1 and his sub-players from 2010 to 2015 into the values from 2005 to 2010, respectively (Table 4.14). CPI is a good indicator of inflation, which is widely used to transfer the values at current prices into values at constant or comparable price(s). Those simulation results prove that non-cooperation will cost losses to player 1 and his sub-players, while cooperation will bring losses to players 2, 3 and 4 as well their sub-players. However, cooperation will produce much larger benefits to the society than non-cooperation. Therefore, at the end of game, if players 1 and his sub-

players transfer part of their benefits to cover the losses of other players, every player and sub-player better off in cooperative game.

4.3.2 Discussion of the scenario results

Games of 1, 2, 3 and 4 are games of prisoners' dilemma, and game 5 is an assurance game. From an aspect of the game models structure itself, there will be risk and uncertainty if the coalition between all the players is not stable in the cooperative game. Full cooperation will make all players collective better off, but individual players will face risk if some players take free-riding strategies or cooperate one time and do not cooperate another times. In the game of prisoners' dilemma, every individual player will face highest risk because he will get the lowest payoffs if he cooperates. In the assurance game, the collective payoff is still not the social optimum because the cooperative results are still not assured. In this connection, the coalitions in the game simulation are not stable. In addition, the results of future are usually various due to the uncertain changes of external driving forces in the future. Four scenarios were designed in order to analyze the risks and uncertainties in the game simulation and try to find out which drive force is the main factor influences the game structure.

(1) Discussion of the scenario results of game 1

Scenario results of added value and water demand prove that players 11 (industry), 12 (domestic life) and 13 (agriculture) demand much more water in the economic developed scenario than that in undeveloped scenarios. This confirms that faster economic development will increase water demand of those three players (Fig. 4.1, Fig. 4.2 and Fig.4.4). However, in each of the four scenarios, water demand of players 11 and 13 are decreasing with economic development (Fig. 4.1b and Fig. 4.4b), and this is mainly because industrial and agricultural water consumption usually becomes more efficient with economic growth and also because governmental polices reduce industry water consumption in this sever water scarce area. For player 12 (household), the growth of net income will push water demand to increase if others hold constant in each of the four scenarios (Fig. 4.2b). The four population scenarios reveal that population growth is not sensitive to domestic water demands of player 12 (Fig. 4.3). Comparing the scenario results of those three players, it illustrates that water demand of player 13 is very sensitive to the economic development, while the sensitivity of domestic water demand is lower to the economic development.

With the technological development, more urban water sewage will be reclaimed into fresh water (Fig. 4.5b). With the enhancement of environmental and ecological protection awareness of people, the ecological based water demand and water use will be increased. However, the scenario results display that ecological based water demand is much less than ecological based water consumptions (Fig. 4.6). Therefore, it is clearly seen that ecology has a severe water deficit. In the scenario of high water supply, water demand is also very high (Fig. 4.7). The scenario results of water demand and water supply confirm that player 12 will face the most severe problem of water deficits, and players 13 and 11 are the second and third in the cooperative game (Fig. 4.8-4.10). In summary, with the technological development of reclaim water, water supply increases. However, due to the increases of ecological water use and demand, water supply to players of 11, 12 and 13 still cannot meet their water demand even in optimistic scenario 2.

(2) Discussion of the scenario results of games 2, 3 and 4

The games 2, 3 and 4 are nitrogen reduction games, and the scenario results are discussed together due to their similarities. The rural population decreases in the four scenarios, due to urbanization and much more people move to cities (Fig. 4.11a, Fig. 4.19a and Fig. 4.27a). In the highest rural population growth rate scenario, the nitrogen discharged into the Danjiangkou Reservoir by players 23, 33 and 43 is also the biggest, and vice-versa (Fig. 4.11b, Fig. 4.19b and Fig. 4.27a). Just opposite to rural population, the urban population keeps increasing (Fig. 4.12a, Fig. 4.20a and Fig. 4.28a). In each scenario, the urban population growth results in the increase of nitrogen discharge into the Reservoir. In the scenario of higher rate urban population growth, much larger the nitrogen discharge is (Fig. 4.12b, Fig. 4.20b and Fig. 4.28b). The nitrogen discharge is decreased with the reduction of soil erosion area (Fig. 4.13, Fig. 4.21 and Fig. 4.29). In the four scenarios of nitrogen fertilizer consumption, more nitrogen fertilizer consumption causes more nitrogen discharged into the reservoir. In each of those scenarios, nitrogen fertilizer consumption of player 23 becomes very stable. However, nitrogen discharge from consumption of nitrogen fertilizer of player 23 is still keeping increasing for a certain period of time (Fig. 4.14). The nitrogen fertilizer consumption of player 33 still maintains increasing, but nitrogen from consumption of nitrogen fertilizer of player 33 has a trend of slow decrease (Fig. 4.23b) in each scenario. For player 43, the consumption of nitrogen fertilizer and its related nitrogen discharged into the reservoir are both increasing (Fig. 4.30). The number of domestic animals and poultry of player 23 and 43 keep on increasing, and thus the nitrogen is also maintain-

ing to grow. The scenario of highest growth of animal husbandry causes the highest nitrogen discharge if others keep constant (Fig. 4.15 and Fig. 4.30). As for player 33, the scenario results confirm that the numbers of animals and poultry and their related nitrogen discharge into the Reservoir increase during 2005 to 2007, and then they decrease. In the four waste treatment scenarios, the highest rate of waste water treatment will bring the lowest nitrogen discharged into the reservoir (Fig. 4.16, Fig. 4.17 and Fig. 4.32). In each scenario, nitrogen from rural domestic life of players 23, 33 and 43 into the reservoir is decreased (Fig. 4.16a, 4.24a and 4.32a) due to increasing rate of waste treatment in this field. With reference to the industrial nitrogen discharge, the discharge of player 21 is decreasing (Fig. 4.17b), but the discharge of player 31 and 41 is still maintaining increase (Fig. 4.25b and Fig. 4.33b). However, nitrogen discharge from urban domestic life still keep increasing in each scenario, and this is mainly because the waste treatment rates of urban sewage are still very low (Fig. 4.16a, Fig. 4.25a and 4.33a). Player 23, (agriculture) is the main nitrogen pollutant source of the Reservoir, and the second is player 22 (domestic life) (Fig. 4.18).

The scenarios of games 2, 3 and 4 confirm that animal husbandry growth, nitrogen fertilizer consumption, soil erosion and rural population growth are the first, second, third and fourth main nitrogen populates sources, respectively in those three games. In the four scenarios of each game, animal husbandry is the most sensitive driving force to nitrogen discharge into the reservoir.

(3) Discussion of the scenario results of game 5

With reference to the water polluters in the four scenarios, player 2 is the main polluters (Fig. 4.36), and he has responsibility to reduce much more nitrogen discharge than the players 3 and 4 (Fig.4.37). However, it will impose much more cost on player 2 to reduce more nitrogen discharge. Therefore, player 2 maybe free rides others' achievements of nitrogen reduction most time, and thus the risk of non-cooperation will probably come from this player. As for the scenarios, scenario 4 is the highest risk scenario, in which deteriorations of water quality will be increased due to more nitrogen emitting in the reservoir.

4.3.3 Evaluation of the results

The models are selected based on the statistical and econometric standards and test, such as goodness of fit (R^2 and adjust- R^2), F test, t test, test of 4 Gauss-Markov conditions and

disturbance term assumption, etc. However, in practice, whether the results are believable also depends on the quality and forecasting abilities of the models. The common approach to evaluate the simulation results is to split T observations in the data set into T_1 observations to be used for estimation, and the rest T_2 for testing and evaluations. T_2 is the last observation taken from every data set in this study, so the horizon of prediction of errors is one year. Based on this method, the evaluation results of the game models are demonstrated in tables 4.16-4.18. In those tables, the observation is the real value of each variable in each different year, and the forecast is the value that each model predicted. The residual is the difference between the forecast and observation. The error is the ratio of residual to the observation.

The evaluation results of simulation of the game 1 and its sub-games are given in the table 4.16. From these results, it is seen that the minimum simulation error is 0.14% and the maximum is 5.11%. Table 4.17 proves the evaluation results of simulation of games 2, 3 and 4 and its sub-games. The minimum error of simulation results is 0.22% and the maximum error is 16.51%. In summary, the results of simulation errors are classification in table 4.18. The table reveals that the maximum error is 16.5% and minimum is 0.14%. These results demonstrate the models used in game simulation have good predicting abilities and the simulation results have high practical values.

Table 4.16: Comparisons of the observations and forecasts in game 1 and its sub-games

T2	Variable	Observation	Forecast	Residual	Error (%)
2005	D_w	8.82	9.03	0.21	2.41
2005	Q_{1eR}	6.27	6.25	-0.02	0.32
2006	Q_{11}	6.39	6.71	0.32	5.01
2006	Q_{12}	14.30	14.20	-0.10	0.70
2006	Q_{13}	12.90	12.48	-0.42	3.26
2006	V_{11}	1848.50	1851.07	2.57	0.14
2006	V_{12}	2876.60	2956.21	79.61	2.77
2006	V_{13}	98.00	99.68	1.68	1.72
2006	β_{11}	289.28	292.76	3.48	1.20
2006	β_{12}	201.16	208.03	6.87	3.42
2006	β_{13}	7.60	7.99	0.39	5.11
2006	I_d	653.6	666.9	13.3	2.03

Table 4.17: The comparisons of observations and forecasts in games 2, 3 and 4 and their sub-games

T2	Variable	Observation	Forecast	Residual	Error (%)
2000	O_f	232.76	249.40	-16.64	7.15
2005	\ddot{W}_{21}	3272.00	3164.18	-107.82	3.30
2005	\ddot{W}_{31}	12582.00	14658.96	2076.96	16.51
2005	\ddot{W}_{41}	1668.33	1672.03	3.70	0.22
2005	L_{22U}	155.59	156.42	0.83	0.53
2005	L_{22R}	758.57	748.54	-10.03	1.32
2005	L_{32U}	136.76	133.74	-3.02	2.21
2005	L_{32R}	218.04	224.11	6.07	2.78
2005	L_{42U}	25.81	23.53	-2.28	8.84
2005	L_{42R}	82.72	85.73	3.01	3.64
2005	\ddot{W}_{22U}	2281.78	2519.75	237.96	10.43
2005	\ddot{W}_{32U}	7978.56	8622.63	644.07	8.07
2005	\ddot{W}_{42U}	1199.02	1102.13	-96.88	8.08
2005	\ddot{W}_{22R}	2281.78	2519.75	237.96	10.43
2005	\ddot{W}_{32R}	7978.56	8622.63	644.07	8.07
2005	\ddot{W}_{42R}	1199.02	1102.13	-96.88	8.08
2005	\ddot{O}_{23}	1052.90	1062.76	9.86	0.94
2005	\ddot{O}_{33}	309.78	320.26	10.48	3.38
2005	\ddot{O}_{34}	313.38	308.43	-4.95	1.58
2005	F_{23}	14.41	14.52	0.11	0.76
2005	F_{33}	6.48	6.16	-0.32	4.94
2005	F_{43}	2.10	2.14	0.04	1.85
2005	V_{23}	435.77	423.40	-12.37	2.84
2005	V_{33}	1082.13	1109.69	27.56	2.55
2005	V_{43}	1892.01	1846.62	-45.39	2.40

Table 4.18: Errors classification and analysis

Errors (%)	Max.	Min.	Obs.
[0, 5.0)	4.94	0.14	26
[5.0, 10)	8.84	5.01	7
[10, 15)	10.43	10.43	2
[15, 20)	16.64	16.51	2
All	16.51	0.14	37

As for water supply, water demand and water shortage, the general results are consistence with the study of Li and Xiu (2004) and CWRPI (2005), although there are differences in the specific forecasting values between this research and their researches. All those results turn out that the player 1 and his sub-players have water deficit even in high technology developed scenarios. Comparing with their specific forecasting results, the results of this research are more reliable, because their results were deduced based on socio-economic data prior to 1997. As for the TN pollution reduction results, so far no study has made such detailed analysis and forecast. In this connection, the scenario results also have very high practical values for decision makers to make policies and planning on water quantity dis-

tribution, water quality protection, water pricing as well as ecological loss compensation for the South to North Water Transfer projects.

However, due to lacking of long time series data of the evaporation and water price, the scenarios have not included the effects of climate change on water supply, water deficits and TN concentration and the price elasticity of water demand. It is also very necessary to make a future study on those aspects in the future.

5. Conclusions

Water is essential for the existence of human and all other species. However, degradation of water quality and scarcity of water quantity are two severe problems in developing countries. Water resource management is vital and complex because it usually involves water conflicts of multi-stakeholders with contradictory interests, goals and strategies. The overall objective and principles of water management are to promote the coordinated development of water in order to maximize economic, social and environmental welfare in equitable, efficient and sustainable manners. There are different policy instruments which can be used to solve water conflicts. Dinar et al. (1997) and Wang et al. (2003) analyze four basic institutional mechanisms for water allocation, i.e. public allocation, user-based allocation, marginal cost pricing, and water market allocation. Bonnie and D'estree (2000) and Mostert (1998) present four methods - litigation, market transactions, political deal-making and alternative dispute resolution techniques - to resolve water conflicts. Water markets approach is one frequently cited in the literature, but water market is hard to establish a real water market in most countries. In the absence of market and exclusive property rights, conflicts between the multi-actors on competing uses over water are still unavoidable.

The overall objective of this research is to develop a practical game theoretical modeling and simulating approaches to solve the water conflicts and promote the maximization of the collective welfares from a socio-economic and environmental perspective. In order to realize the objective, conflicts are regarded as the main course of the research. It includes defining the conflicts and conflicts bodies, translating the conflicts in games, analyzing the conflicts, and finding solution to solve the conflicts. Non-cooperative and cooperative game methods are used separately to model and simulate water conflicts. Non-cooperative modeling approach is used to analyze why players do what they are doing. Cooperative approach is used to analyze how they can do better. The aim to analyze non-cooperative game is to find better solution for cooperation.

Game is a metaphor of the rational behaviors of multi-actors in an interacting or interdependent situation, such as cooperating or coalition, conflicting, competing, coexisting, etc. Game theory is the study of the strategies and equilibrium of the actors, and to analyze how the players can do better. Game theory was originally applied into the cost distribution in joint water resource projects. It has been applied to solve the cost distribution of water resource projects, allocation of waste, water rights and water amount, transboundary pollution, analysis of water police and so on. However, so far most game theoretic models have not solved the water problems where there exist conflicts of both quality and quantity.

Like other sciences, game theory itself is comprised of a collection of models. It is usually divided broadly two approaches, either non-cooperative approach or cooperative approach. The non-cooperative game models can be divided into two kinds, namely strategic games and extensive games. Strategic (or normal) games are usually applied to model the static (or simultaneous-move) games, and an extensive game is usually used to model dynamic games, such as dynamic games. Some game models are widely used in the literature, and these games include zero-sum game, prisoners' dilemma game, chicken game, assurance game as well as driving force game. Generally speaking, all the environmental (or water) resource games are classified into the three kinds, namely HH game (the games in the society of human beings), HN game (games between homo sapience and the nature) and NN games (the games in nature).

Those modeling approaches consists of defining the conflicts and formulating these conflicts as a game, setting up game model, analyzing the game model, solving the game as well as interpreting the results. The games can be defined either by the types of activities or fields (industry, agriculture, domestic life and nature, etc.) or the regions in which activities take place. The non-cooperative and cooperative game theoretic models are developed for water resource management in a river basin scale. With reference to the establishment of these models, the main steps are to decompose the river system, define the game and how each player to optimize water quantity and water quality respectively in order to maximize his or her payoff. The essence of non-cooperative game theoretic model is that every player maximizes net benefits, i.e. the values produced by using per unit water minus the cost to reduce the waste. Similarly the cooperative game theoretic model is that all the players maximize the collective net benefits, and find method to share the benefits or cost fairly. The main types of data used for the game the game theoretic models include socio-economic data, climatological, hydrological data water quality data as natural resource data.

Water resource in China is much unevenly distributed in time and space, and water shortage has been a long-time and widespread problem in Northern regions of China. In order to mitigate the existing crisis of water resources, the engineers in the country proposed the South to North Water Transfer (SNWT) Projects. Middle Route Project (MRP) will divert water from the Danjiangkou Reservoir in the Hanjiang River Basin. The conflicts involved in the Hanjiang River Basin are defined mainly by water transfer activities. Firstly water transfer sets a higher standard on water quality in the Danjiangkou Reservoir, which will raise local cost to reduce pollutants. Secondly, a substantial amount of water diverted will cause a reduction of runoff and water level, and thus it will change the ecological condition in the downstream of the river. The conflicts on water quality and quantity involved in the Hanjiang River Basin are modeled as a game or a set of games. As an illustrative example, the cities of Hanzhong, Ankang, and Shangluo of Shaanxi province, Shiyan city of Hubei province and counties of Xixia and Xichuan of He'nan province and Beijing municipality are modeled as four players' game. This game is composed of four sub-games including water seizing game and three pollutants reducing games. In each sub-game, industry, domestic life and agriculture are regarded as three sub-players. In the game simulating process, players in each game and sub-game make both non-cooperation and cooperation. Comparing the results of non-cooperative and cooperative games, the main results are obtained.

Water seizing game causes a prisoners' dilemma. The results of the simulation of water seizing game turn out that non-cooperation will bring each player the water they need. However, this will greatly damaged the ecology and environment by seizing water from ecology, which in turn will influence the economic development and the life of local people. Cooperative game will share more water to ecology, but industry, domestic life and agriculture will face serious water deficits. The results of cooperative game in game 1 show that player 11 (industry), player 12 (domestic life) and player 13 (agriculture) will respectively suffer water deficits of 104-136 million m³, 403-455 million m³, and 263-265 million m³ during 2010 to 2015.

The games of reducing nitrogen pollutants are also games of prisoners' dilemma, in which reducing pollutants are beneficial to players but players have no incentive to do that. The simulating results of games 2, 3 and 4 demonstrate that non-cooperation cannot improve the water quality in the Danjiangkou Reservoir to the standard level due to the free riding problems; cooperation will improve the water quality to the standard while extra costs will

impose to the players. The results of cooperative game in game 2 explain that players 21, 22, 23 should reduce nitrogen 163.2-356.2 tons, 9439.4-28040.0 tons and 64350.3-201482.3 tons, respectively from 2005 to 2010. The results of cooperative game in game 3 reveal that players 31, 32 and 33 should reduce nitrogen of 89.2-506.2 tons, 3695.0-11581.8 tons and 15672.5-51276.9 tons, respectively from 2005 to 2010. The results of cooperative game in game 4 prove that players 41, 42 and 43 reduce nitrogen of 45.6-165.8 tons, 1120.7-3247.4 tons and 13553.3-52755.2 tons, respectively from 2005 to 2010

The game 5 is the first level game, and this game is a chicken game. These results demonstrate that the non-cooperative game will cost player 1 losses of 13.6×10^{11} RMB at comparable prices from year 2010 to 2015, but it yields players 2, 3 and 4 a total benefits of 1.1×10^{11} RMB. For sub-players 11, 12 and 13, non-cooperation will bring them losses of 66.28-122.23 billion RMB, 123.07-261.494 billion RMB and 2.45-2.77 billion RMB at comparable prices, respectively due to water deficits during 2010 to 2015. However, in cooperation game, players 21, 22 and 23 will lose 15.0-32.0 million RMB, 3.91-4.02 billion RMB and 3.89-9.85 billion RMB, respectively from 2005 to 2010. Players 31, 32 and 33 will lose 0.059-0.34 billion RMB, 1.15-1.7 billion RMB and 0.70-2.60 billion RMB, respectively, and the players 41, 42 and 43 will lose 0.008-0.029 billion RMB, 3.82-3.84 billion RMB and 0.35-1.78 billion RMB, respectively. Comparing the overall costs and benefits, there is an overall loss of 12.6×10^{11} RMB when each player does not cooperate with the others. The cooperative game results confirm that there is an overall benefit of 12.6×10^{11} RMB, though players 2, 3 and 4 lose 1.1×10^{11} RMB. Therefore, all the players will be better off if a side payment is made between them at the end of the cooperative game.

The simulation estimation explains that the maximum error is 16.5% and minimum is 0.14%. Therefore, the models used in game simulation have good predicting abilities and the games results have high practical values. The scenario results of game 1 reveal that technological development and the increase of water reclaiming rate in the future, water supply will increase. However, due to the increases of ecological based water use and demand in the future, water supply to players 11, 12 and 13 still cannot meet their water demand even in the optimistic scenario. In the four scenarios, sub-player 12 will face the most severe water deficits, and player 13 and player 11 are the second and third respectively. The scenario results of games 2, 3 and 4 prove that animal husbandry growth, nitrogen fertilizer consumption, soil erosion and rural population growth are the first, second,

third and fourth big nitrogen populates sources, respectively. In each scenario, animal husbandry growth is the most sensitive driving forces and sub-players 23, 33 and 43 are the main nitrogen polluters, and the seconds are sub-players 22, 32 and 42 in games 2, 3 and 4, respectively. The scenario results of game 5 demonstrate that player 1 and his sub-players will face the highest risk in scenario 4 (S4), and they will cost greatest losses if they do not cooperative with other players in scenario 4. The results also confirm that player 2 is the largest polluters, and the risk of non-cooperation most probably comes from him, and this risk will be very high in scenario 4.

In conclusion, the game theoretic simulation results illustrate that cooperation brings some players or sub-players losses, but it will produce much more collective benefits and each players or sub-players will be better off if a side payment is made from the beneficial players to the losers. This game theoretical modeling and simulating approach not only facilitates a clear comparison of the different water users, but is also beneficial to water decision makers. These game results will benefit for the water users, administration and water supply companies.

In this research there are still some limitations and numbers of assumptions:

- Some players have not been included in the simulation process, which are Tianjin municipality, Hebei province, the water receiving part of Henan province and the middle and low reaches of the Hanjiang River of Hubei province;
- The stabilities of coalition has been analyzed, but the risks and uncertainties resulting from the instabilities has not been estimated;
- Some pollutant sources of nitrogen in the Danjiangkou Reservoir are not included in this research, such as the trash, finishing industry, air pollution, pesticide, shipping and the internal sources of reservoir;
- It analyzes and forecasts the minimum water demand of urban ecology, and the minimum water demand of river has not been considered;
- The ecological based economic losses resulting from water shortage has not been estimated. Therefore, the losses of industry, domestic life and agriculture have not been compared with the ecological based economic losses;
- The benefits of reducing pollutants and losses of not reducing to local people have not considered in this research;

- In the scenarios analysis, whether climate change, such as precipitation change, global warming will affect the water supply and demand and water quality in the future has not been included in this paper;
- The price elasticity of water demand to all the players has not been included into the scenario analysis;
- Only the 20% wet, 75% and 95% hydrological years has been studied, and other situations are not included.

In order to improve applicability of the methodology and the simulation and models, it is very necessary to make the following researches in the future:

- Including all other players into the simulation process;
- Estimating the risks and uncertainties resulting from the instabilities of coalition;
- Considering other pollutants sources of the River Basin in order to provide a much more appropriate methods for all players to share the quota to reduce pollutant sources;
- Developing a model of real ecological based water demand as the constraints of water supply;
- Estimating the economic losses of ecology resulting from water shortage in order to compare the economic losses of industry, domestic life, agriculture with the economic losses of ecology;
- Studying and estimating the benefits of reducing pollutants and the losses of not reducing pollutants to local people;
- Studying the overall interrelationships between climate change and water and air temperature, water supply and water demand as well as water quality, and how they in turn influence the game structure;
- Studying the price elasticity of water demand to different players;
- Defining more scenarios and analyzing the cross scenarios in order to avoid the future risks and uncertainties and plan a more ideal future;
- Applying game theoretic simulation to other lines of South-to- North Water Transfer Projects and other river basins.

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