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Hydrological Energy Analysis of Yangtze River Basin, China

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Hydrological Energy Analysis of Yangtze River Basin, China

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Abstract

In this project, an Energy model from Thomson Reuters HBV-TR similar as the HBV model from Swedish Meteorological and Hydrological Institute (SMHI) is used in Yangtze River Basin for energy inflow simulation. Yangtze River is the biggest river in China and the area of whole river basin is about 1.8 million square kilometers covering more than one fifth of whole China area. At the same time Yangtze River basin has huge hydro-energy at 268 000 MW in theory and 197 000 MW exploitable. Meteorological data, installed capacity data and hydropower production data of Yangtze River Basin are collected for model calibration. The project study area is divided into three subareas according to their precipitation, temperature and geological conditions. And HBV-TR model is used on each of them. The calibration results cannot be judged by normal criteria due to the difficulty of lacking data. However, by using other supplementary means, some reasonable calibration results are obtained. In study area, the peak value of energy flow appears in summer time during June to September following the same pace of precipitation. In Upper area, the average annual energy inflow is around 8—20 GWh when this number in Middle area and Lower area is 200—300 GWh and 400—850 GWh respectively.

Keywords: Yangtze River Basin, Energy inflow, HBV-TR, Calibration

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Abbreviations

MW: Megawatt

MWh: Megawatt hours

GWh: Gigawatt hours

Acronyms

SMHI: Swedish Meteorological and Hydrological Institute

GSOD: Global Summary of the Day

EPA: United States Environmental Protection Agency

HBHP: Hu Bei hydropower

CJW: Chang Jiang (Yangtze River) web

SPIN: State Power Information Network

21CMA: 21th Century Meteorological Amateurs

WHU: Wu Han University

NCDC: National Climate Data Center

Hudong: Hudongpedia

1. Introduction

1.1 Background

Nowadays, with the arising of severe environment pollution and resources shortage problems, people over the world are becoming more and more eager to find out some renewable and clean energy. The position of conventional thermal power energy which is facing the problem of running out of fossil fuel and other environmental related issues would hopefully gradually be taken over by renewable and clean energy. Hydropower which to some extent is able to fulfill this desire due to its own properties like completely clean without any pollution, always available as long as having water, higher energy efficiency about 80% comparing with only 30% to 50% thermal efficiency in thermal power and much lower cost etc.(Guo, 2006)

However hydropower is not perfect without any limitation. One vital factor is water which is significantly influenced by precipitation and temperature. Under this situation, in order to more sufficiently use hydropower, obtaining acknowledgement of how much potential energy is available in advance by using rainfall-runoff model would be of great importance.

For this reason, a study of hydro-energy in Yangtze River Basin is carried out. The study area of this project is the middle and upstream area of Yangtze River basin located in China which is number one both in water resource reserve and exploitable water energy all around the world. But the developing degree is just around 25.3% by 2010 which is much lower than most developed countries. But this China's develop degree number will hopefully increase to 70.3% by 2020 (Jun Lue, 2009).

1.2 Methodology

Literature study of basic information of project study area, data type, knowledge of HBV model and calibration result analysis was taken during autumn semester in 2011 and thesis work in 2012.

Based on the tributary distributed condition, the border of this project study area is made according to visual inspection ended at Three Gorges Dam. And within the study area, three subareas are divided according to the meteorological condition, geological condition and also data manipulation perspective.

In this thesis project, an Energy model from Thomson Reuters HBV-TR similar as the HBV model from Swedish Meteorological and Hydrological Institute (SMHI) is utilized for hydro-energy inflow computation and calibration. The target value data in the model is hydropower production, which is supposed to be calibrated against unit in GWh, comes from the Chinese Energy Year Book from 1995 to 2010. But this production data needs correction because of the increasing of installed capacity in each subarea unit in MW. This installed capacity data comes from web and some relevant approximations. After correction, the production unit in GWh is used for target value in the model with low resolution in each year due to classification policy. So the target value for each day in one year stays same without dynamic change.

Calibration input data including precipitation and temperature are obtained from Global Summary of the Day (GSOD) with daily resolution from 1981 to 2011. More than 200 stations are available in Yangtze River Basin. After collection, 56 qualified stations are selected for the input data with more than 95% data available and appropriate locations.

After calibration in the HBV-TR model, due to lack of long time series and high resolution target data, calibration graph result, numerical result, snow pack graph and runoff graph are used for rationality of model results.

1.3 Objective

The main objective of this thesis project is to analyze the hydro-energy inflow in the study area of Yangtze River Basin ended at Three Gorges hydropower station by using HBV-TR model.

1.4 The scope of the study

As this degree project will be carried out from energy perspective instead of building hydrology model, some details about hydrology are neglected. Due to lack long time series and high resolution data, the target value data in model calibration is obtained after relative approximations and simplifications.

2. Study Area background

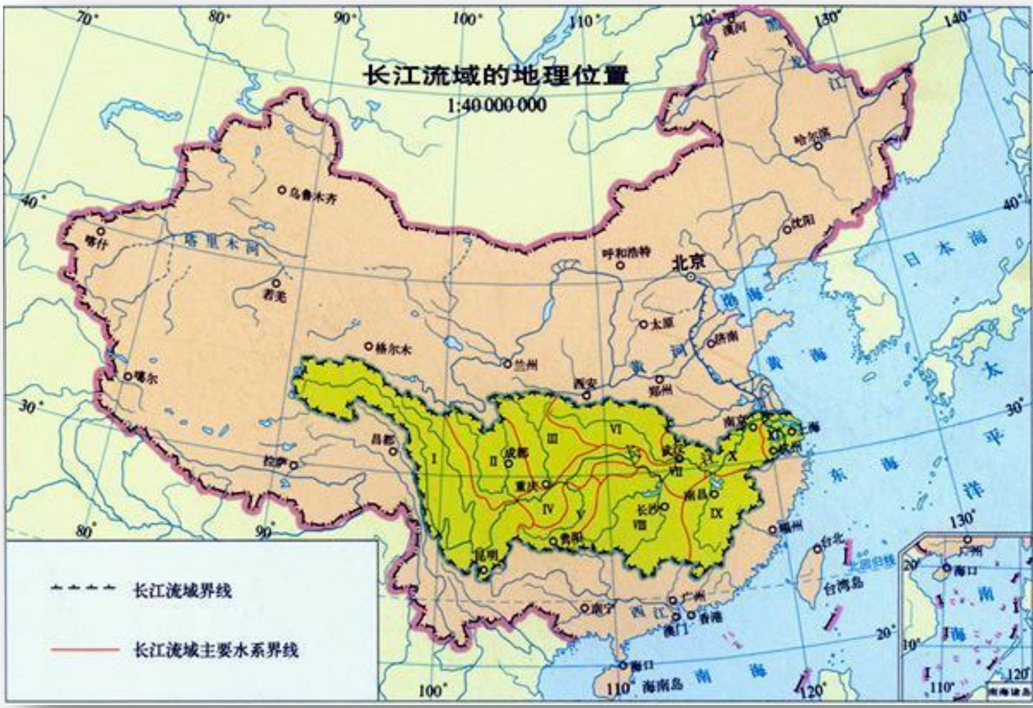


Figure 2.1 Geographical position of Yangtze River Basin. (Source: Hudong, 2005)

Yangtze River is the biggest river in China and third in the world. It is originally from the main peak of Tang Gula mountain in Tibet plateau. The main stream of Yangtze River is about 6300 km which goes through about 11 administrative provinces in China. At the same time, tributaries spread radially in north and south directions which can be seen in figure 2.1.

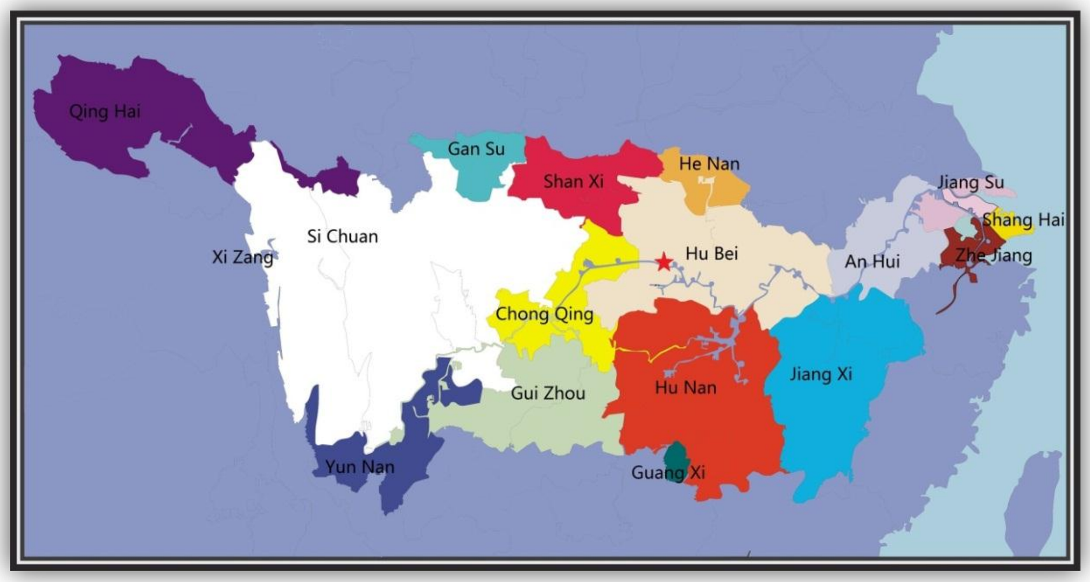


Figure 2.2 Yangtze River Basin

However, not all territory of these provinces belongs to Yangtze River Basin. The basin area is shown in figure 2.2 which is around 1.8 million square kilometers covering more than one fifth of whole China area. Yangtze River basin is located in the eastern part of Eurasia continent, subtropical area which is dominated by monsoon climate. Precipitation in this area is quite uneven which decreases gradually from southeast to northwest with an average of 1067mm. Mountain area has more precipitation than plain area while windward slope more than leeward slope. Due to the rich precipitation, Yangtze River basin has huge hydro-energy that is theoretically about 268 000 MW, and 197 000 MW of it is exploitable which is around 53.4% of the total national hydro-energy which can also be seen in figure 2.3. (Zhang and Chen, 2004)

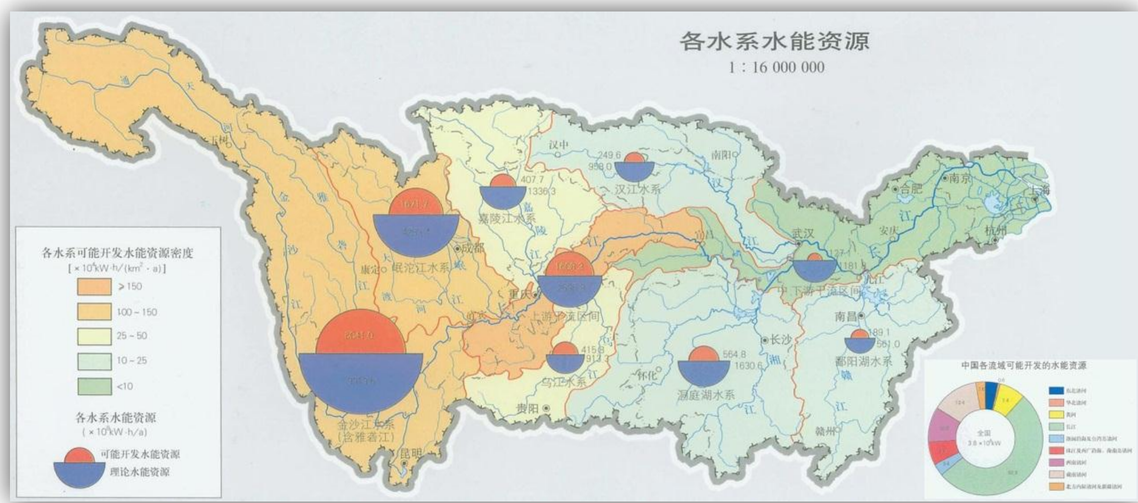


Figure 2.3 Hydro-Energy in each River system in Yangtze River Basin. (Source: CJW, 2005)

From figure 2.3, obviously, the upstream area has great potential of hydro energy. Reason for this is partly because of the precipitation and partly because of the topography. In upstream area, most of the basin is consisted of plateau and mountain. And the big elevation difference brings great hydro-energy to Yangtze River.

2.1 Study Area and Subareas

2.1.1 Study area definition

The study area of this project is the watershed area of Three Gorges hydropower station. Watershed is defined by United States Environmental Protection Agency (EPA) as: the area of land where all of the water that is under it or drains off of it goes into the same place.

Figure 2.4 Yangtze River Systems. (Source: HBHP, 2008)

According to figure2.4, as can be seen, the Three Gorges Dam is at the yellow point upon the mainstream of Yangtze River and the closest big tributaries in upstream are marked out with black color. The tributary on the north of mainstream flows from almost northwest to southeast when the south tributary goes from southwest to northeast. So the conclusion is that their basins areas are supposed to spread in the similar direction respectively.

So the borders of the watershed area of Three Gorges Dam should start from the dam to northwest and southwest respectively and include all the tributaries which water will finally flow to Three Gorges.

Not all the tributaries but just some big ones are shown in figure 2.4. After making borders, there might be thousands of small rivers and lakes which are also supposed to be in the watershed area missed. However, as said in project scope part, these hydrology details can be neglected.

The study area is shown in figure2.5, the left side of Yangtze River Basin ended at two black border lines.

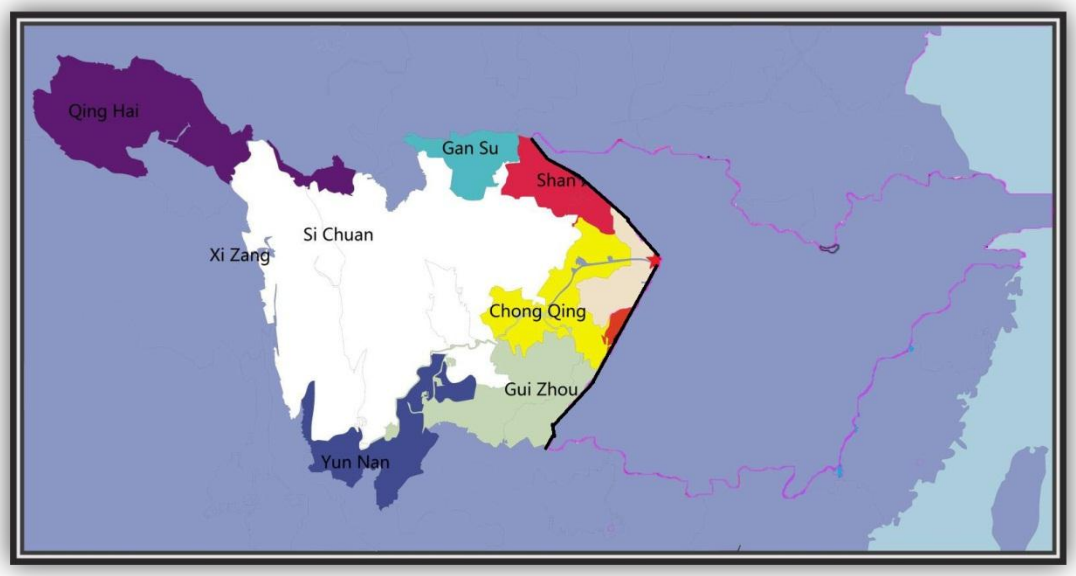


Figure 2.5 Study Area. (Colorful area ended at two black border lines)

Next step is to divide the study area into subareas according to their meteorology and topography conditions.

This study area is consisted of several different administrative provinces. And all the energy and power statistic data accumulated are based on each province unit. Considering this, using administrative borders for subareas will be helpful in further data manipulation.

2.1.2 Topography

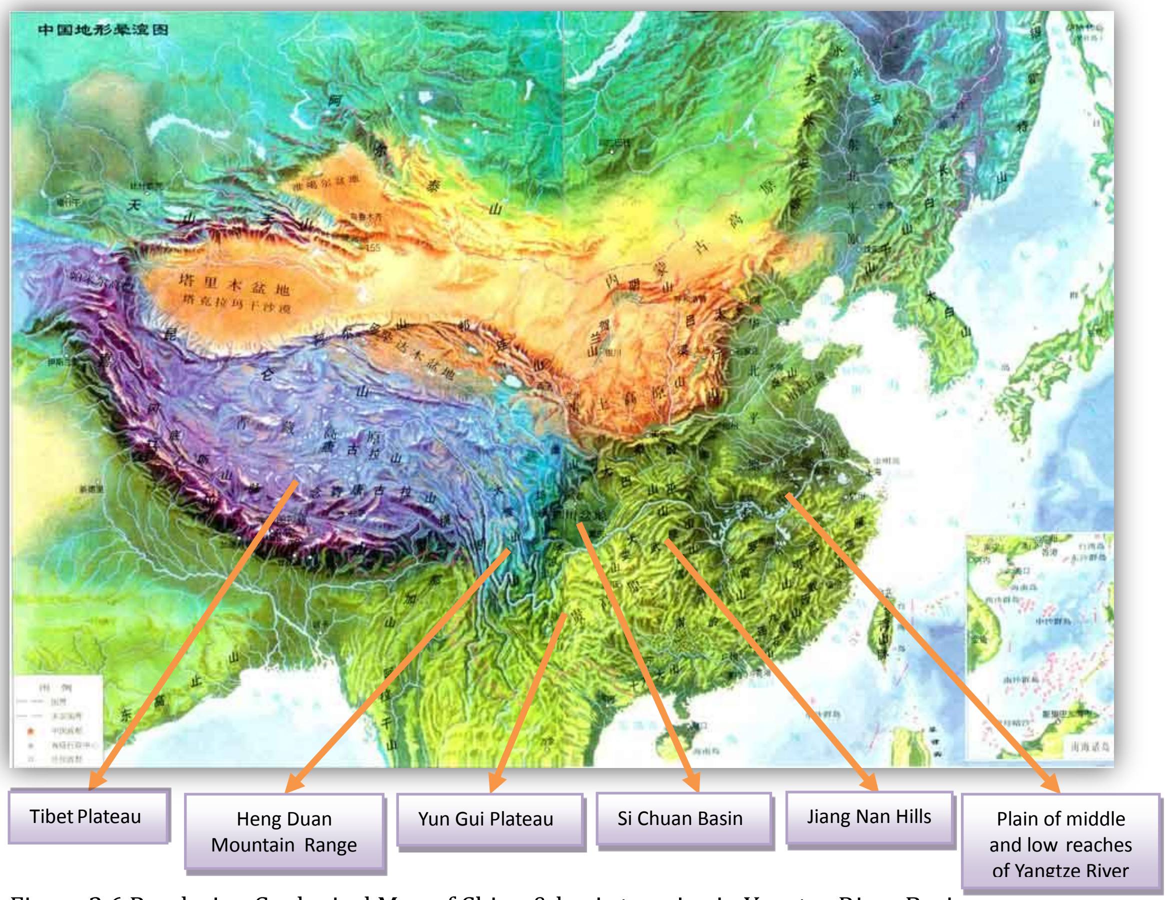


Figure 2.6 Rendering Geological Map of China & basic terrains in Yangtze River Basin. (Source: 21CMA, 2009)

Among all the regions in Yangtze River basin, these are several terrains included—plateau, mountain, basin, hills and plain which can be seen in figure 2.6.

First the plateau part, there are two plateau areas in Yangtze River Basin, Tibet plateau and Yun Gui plateau. Tibet plateau is the highest and largest plateau globally with an area of 2.5 million km^2. Because of its high average elevation above 4000m, sometimes it is also called "the Roof of the World" (Peregrine and Melvin, 2001)

The other Plateau is Yun Gui Plateau which locates in southwestern China. It is consisted of two parts, one is the plateau area with an average elevation about 2000m in northern Yun Nan province and some mountain peaks around 3700m. The other part is rolling hills, deep river-carved gorges, and mountains marked with geologic faults in western Gui Zhou Province (Encyclopædia Britannica, 2012).

After plateaus, it is Heng Duan mountain range area bordering Tibet plateau to the west and Si Chuan Basin to the east. Most of the mountains run north to south. In the southwest part of the mountain area, there are three big rivers including Yangtze River flowing in the valleys formed by mountains ranges. (Fan, Bräuning, Cao and Zhu, 2009)

Si Chuan Basin, located on the east side of Heng Duan Mountain, consisted of low hills and alluvial plains. Yangtze River flows through the southern part of Si Chuan Basin.

Next to Si Chuan Basin on the east side and south to main stream of Yangtze river it is the Jiang Nan hills which have low mountains, small hills and basins cross over most of which have elevation between 200m—600m. Water in this area flow through many tributaries to Dong Ting lake and Po Yang lake and heads north to Yangtze River because of the tilting north topography character. (Baidu, 2012)

The plain area in the midstream and downstream area is around 50 000 km^2 and most area's elevation is less than 45m. (Encyclopædia Britannica, 2012)

The land view of Yangtze River Basin is shown in figure 2.7.

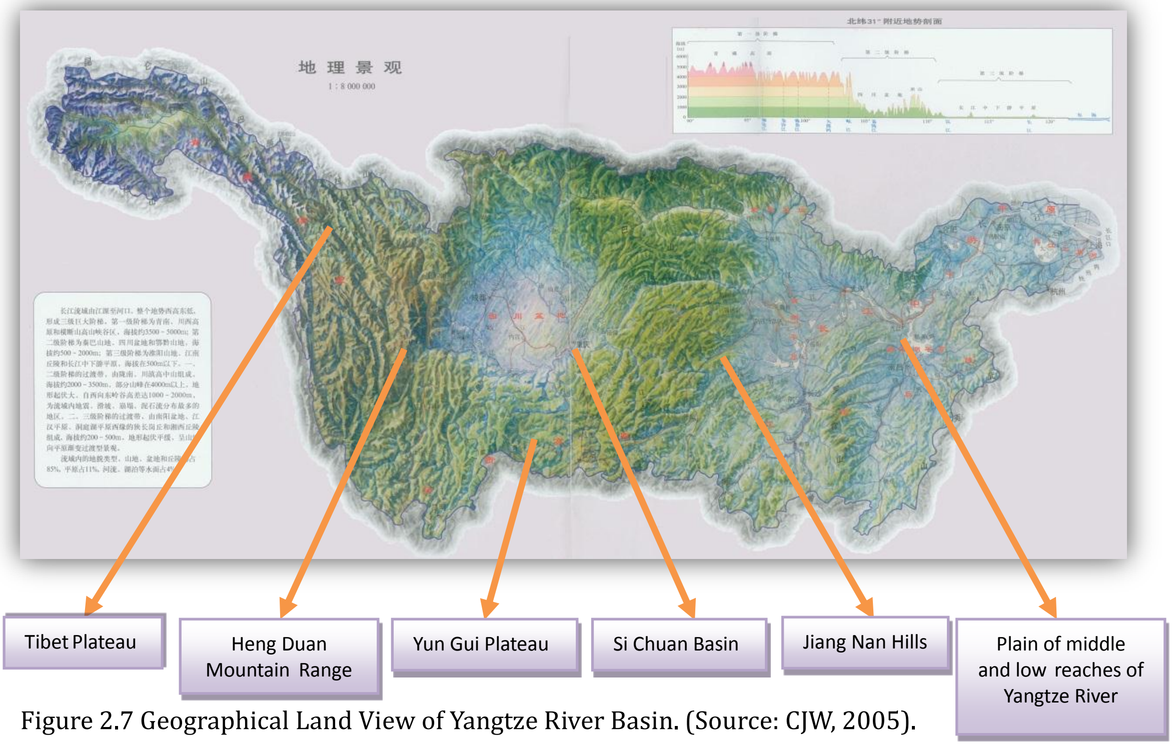


Figure 2.7 Geographical Land View of Yangtze River Basin. (Source: CJW, 2005).

2.1.2 Precipitation

As can be seen in figure 2.8, the huge Yangtze River Basin area has big diversity in precipitation situation the same as its topography situation. At the same time, this diversity shows gradually increased precipitation amount from upstream area to downstream area.

The annually average precipitation in Yangtze River Basin is about 1067mm. Due to its huge area and complicated topography, the precipitation spreads extremely uneven.

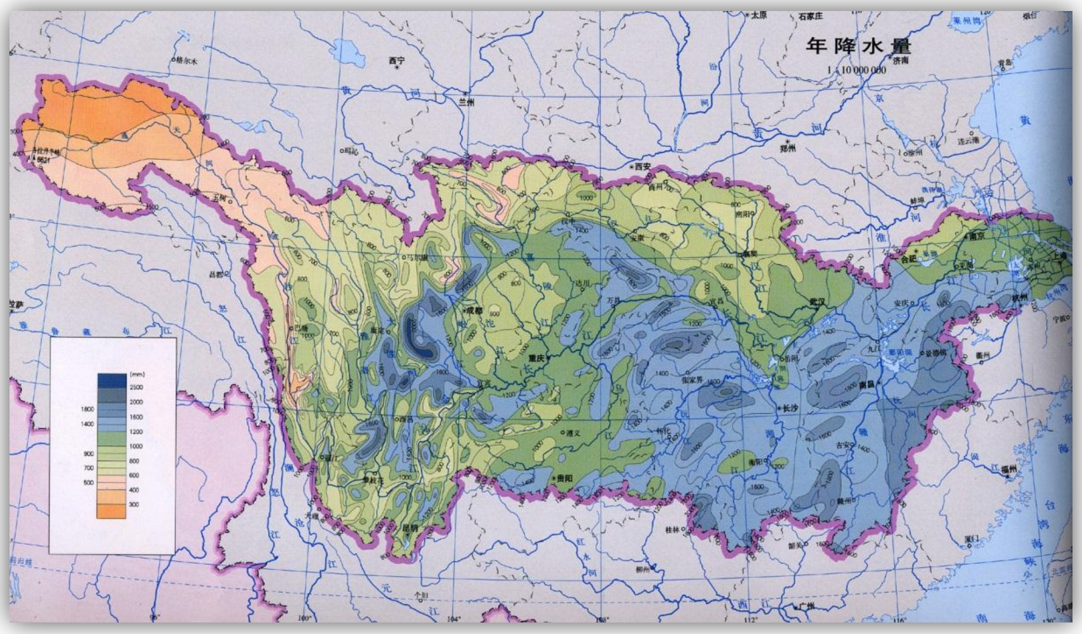


Figure 2.8 Annual Precipitation in Yangtze River Basin. (Source: Library of WHU, 2001)

The orange color part in figure2.8 belonging to Qing Hai province is the origin part of Yangtze River. It has a small precipitation less than 400mm per year. However, most of the basin area stays inside the humid zone which has high precipitation around 800mm—1600mm. In the west and the edge of east part of Si Chuan Basin, Jiang Xi province, Hu Bei province and Hu Nan province, this number can beyond 1600mm. And in some semi-humid zone which including the west plateau area of Si Chuan province, Qing Hai province, some part of Gan Su province, there will be 400mm—800mm of precipitation for the whole year.

Precipitation in different seasons also varies. The driest time is December and January and in spring time from March to May precipitation will increase every month. From June to July, in middle stream and downstream area of Yangtze River, heavy rainfall will appear reaching more than 200mm per month. In August, the rainfall area will move upwards and due to this reason west area of Si Chuan Basin will have more than 200mm rainfall. In autumn season from September to November, precipitation in the whole river basin area will decrease month by month. The heaviest precipitation time, probably lasting 4 months, will take the majority of whole year's precipitation. The ratio in downstream area is 50%--60% when in upstream will come to 60%--80% from June to September among which July and August will take over 40%. (Zhang and Chen, 2004)

2.1.3 Temperature

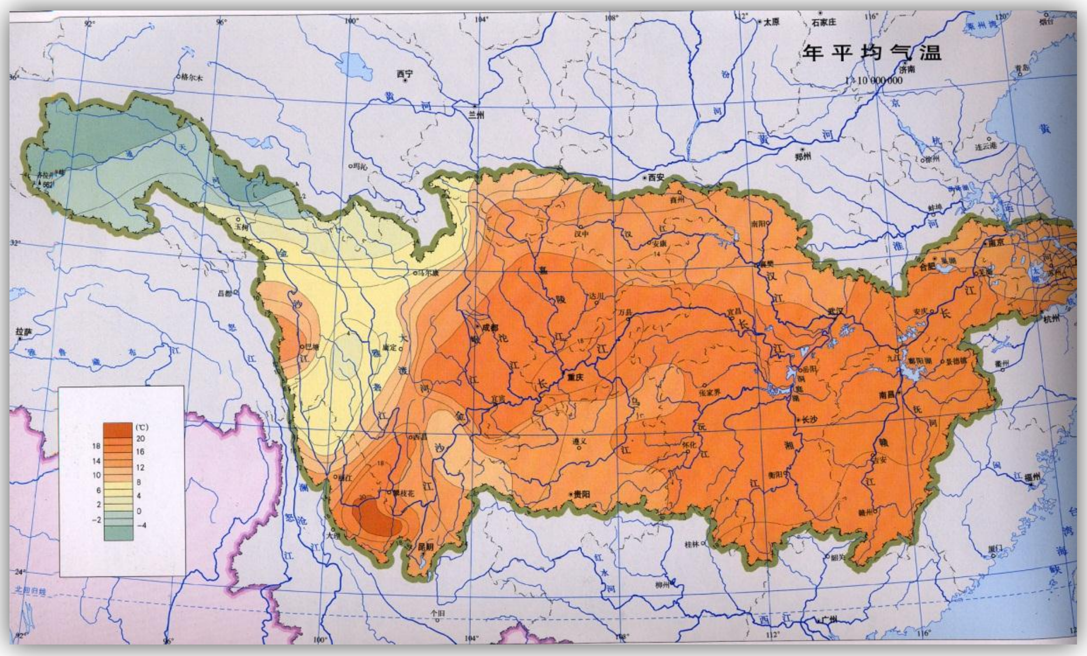


Figure 2.9 Annual Temperature in Yangtze River Basin. (Source: Library of WHU, 2001)

The annual average temperature map of Yangtze River Basin is shown in figure 2.9. It can be seen that, the average temperature spreads in similar way as its precipitation situation. It increases from upstream area to downstream area gradually. If combine with topography map figure 2.7, it is obviously seen that in Tibet plateau, Yun Gui plateau and Heng Duan mountain range, the temperature of these areas are much lower than other areas, only around - 4℃—0℃ because of high elevation above 3000 meters. And from Si Chuan Basin on topography map to the downstream direction, the average temperature in this area seems to be similar around 16℃—20℃. And temperature in southern side of Yangtze River is higher than northern side.

In midstream and downstream area, the average temperature lies between 16 ℃ to 18 ℃. The highest temperature occurs in Hu Nan province and southern part of Hu Bei province with more than 18 ℃. Yangtze River delta area together with midstream and downstream area of Han River, which is one big tributary of Yangtze, has approximately 16 ℃. The temperature of Si Chuan Basin is much higher than upstream areas having the similar longitude at about 16 to 18 ℃ due to its special topographical structure.

2.1.4 Subarea

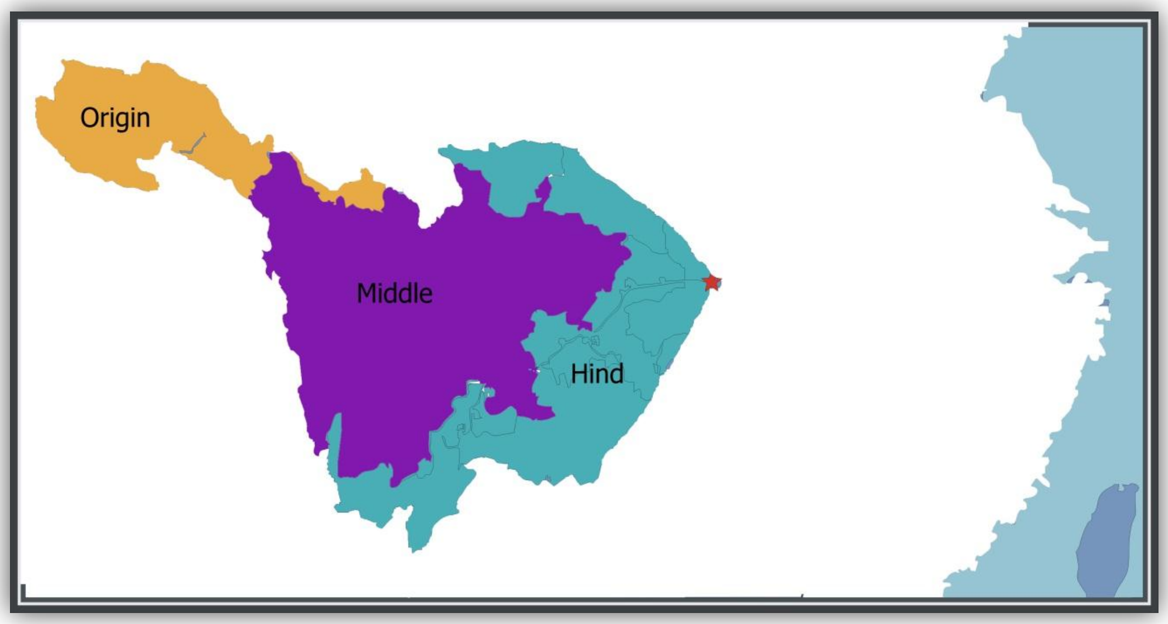


Figure 2.10 Subareas in Study area. Upper, Middle and Hind.

After climate and topography study, study area is divided into three parts—Upper, Middle and Lower respectively, which can be seen in figure 2.10.

Table 2-1 Basic meteorological and area size of regions in Study Area

Region Involved	Temperature (° C)	Precipitation(mm)	Involved Area(km2)
Hu Bei	15—17	800—1600	46475
Chong Qing	18.2	1200—1900	82400
Shan Xi	8—16	676.4	36150
Gan Su	0—14	280.6	54528
Gui Zhou	10—20	1191	84560
Yun Nan	14.6—16.9	600—2300	76640
Qing Hai	-5.9—8.7	17.6—247.1	180300
Tibet	-5.6—20	363	60000
Si Chuan			485400

According to the border made, there are several administrative provinces included in study area—Qing Hai, Tibet, Gan Su, Si Chuan, Shan Xi, Gui Zhou, Yun Nan, Chong Qing and Hu Bei. Table 2-1 shows some basic information of these regions like annual precipitation, temperature and area in study area.

The precipitation and temperature data of Si Chuan province are not listed because of its huge area size with more varieties.

First, it is the plateau area on west with annual average precipitation around 600mm—700mm and 4 ℃—12 ℃ for annual average temperature. Obvious dry and wet season exist there. Total rainfall in wet season from June to September is 70% to 90% of the whole year's precipitation when precipitation in dry season from November to January is less than 10mm in each month. On southwest mountain area, most parts have higher average temperature about 12 ℃—20 ℃ and precipitation around 800mm—1000mm per year among which wet season occupies 85% to 90%. In Si Chuan Basin area, precipitation is about 800mm—1800mm which is much heavier than other parts of Si Chuan province. And the climate there is more moderate with a temperature range from 12 ℃—20 ℃. (Zhang, Wei and Zhou, 2010; Zhang and Chen, 2004)

Under this situation, from figure 2.7, 2.8 and 2.9 and discussion before it can be known that Si Chuan province is a special region which is a combination of big difference in temperature, precipitation and topography. The best way for model would no doubt be dividing this region into sub-regions which have similar characters. However, as mentioned before, the data of installed capacity and production are collected in province unit. So it is better to make the whole Si Chuan province an subarea for data manipulation.

Si Chuan province borders Tibet to the west. And in study area there is only a small piece of Tibet is included. And there is no hydropower station on those tributaries located in Tibet according to the hydropower station list found from State Power Information Network (SPIN) (http://www.sp.com.cn/). So Si Chuan and Tibet are divided into Middle subarea.

Qing Hai province has similar situation with Si Chuan province. But it is not that complex in meteorological and topographical condition as Si Chuan province. This province is the origin place of Yangtze River. Comparing with other parts of the river basin, it has lower temperature, lower precipitation which can be seen from table 2-1 and this entire region involved in study area is located on Tibet plateau according to figure2.7. So Qing Hai province alone is selected as the Upper subarea. And this subarea is just a small part of Qing Hai province.

When it comes to Lower subarea shown in figure 2.10, the situation seems more complicated. This area is extended in north and south and consisted of several provinces as can be seen from figure 2.5 and 2.10. And in this subarea, only Chong Qing municipality is entirely involved. All other provinces are just partly inside. They are Hu Bei, Shan Xi, Gan Su, Gui Zhou and Yun Nan. Their basic meteorological information and area sizes involved in the study area are listed in table 2-1.

Because the border of the study area is made by hand, the areas of each region involved in study area comes from visual inspection. Actually, from figure 2.7, 2.8 and 2.9, it feels like putting Gan Su and Yun Nan into middle subarea will be more reasonable because they share common elevation according to Google Earth. In north part of Si Chuan and Gan Su, elevation there is more than 1000 meters when in south part of Si Chuan and Yun Nan, it is about 2000 meters. At the same time, temperature and precipitation in boundary places are also similar. But the main reason for not dividing them into the Middle area is for data manipulation. Gan Su and Yun Nan involved in the study area are just part of each entire province and there are quite a few of hydropower stations inside. But whole Si Chuan province is inside the study area. Not putting Gan Su and Yun Nan into Middle area will give less approximation and higher accuracy in data. In this project case, data would anyway not be good enough for high precision calibration. But it still deserves trying to make it better.

2.2 Data Collection and Analysis

After dividing the subareas in study area, next step is to build up model for each of them.

There are some basic input and target data for the HBV-TR model. They are Qobs—the calibration target data; observed energy inflow has GWh as its unit. Tobs and Pobs—temperature and precipitation input data which units are centigrade and millimeter respectively.

2.2.1 Data Collection

Before this idea of doing China project, Thomson Reuters does not have much information about China Hydropower market. So, all the data and information about hydrology, hydropower, energy and related fields would be interesting. So at the beginning, collecting data in all these fields is the main task which lasts about two months. But some important data are still missing, like daily flow data and daily power generation data and so on which are pretty important for the calibration part. Due to this lacking data condition, the calibration part will not take a lot of time.

Data related to this project are mainly from internet. Meteorological data from Global Summary of the Day (GSOD) of National Climate Data Center (NCDC), annually hydro-production for each province in Yangtze River Basin from 1995—2009 from China Energy Year Book and installed capacity of different regions from 1997 to 2003. Others data and information are also important because they can offer some basic knowledge and some previous work done by others which would help to make the calibration results reasonable.

Before building up the model, the raw data needs to be manipulated in order to be used in the HBV-TR model.

2.2.2 Meteorological data

In order to have calibrations input data in HBV-TR model, the raw meteorological data from GSOD needs to be parsed in proper ways.

Most of the meteorological station raw data from GSOD are available from 1942. However, before 1973, most stations' data are not complete; some stations even have no data. In this project, 30 years' data back to 1981 is required. So the first criterion is to find out those stations which data are complete from 1981 to 2011. Second, they are supposed to be representatives of Yangtze River Basin's meteorological condition. Basically, the stations located inside the basin area would be perfect. Sometimes those stations located in the vicinity area but have similarities in meteorological conditions with the region inside the basin can also be used. Regarding this, some stations not too far from the basin borders would also be

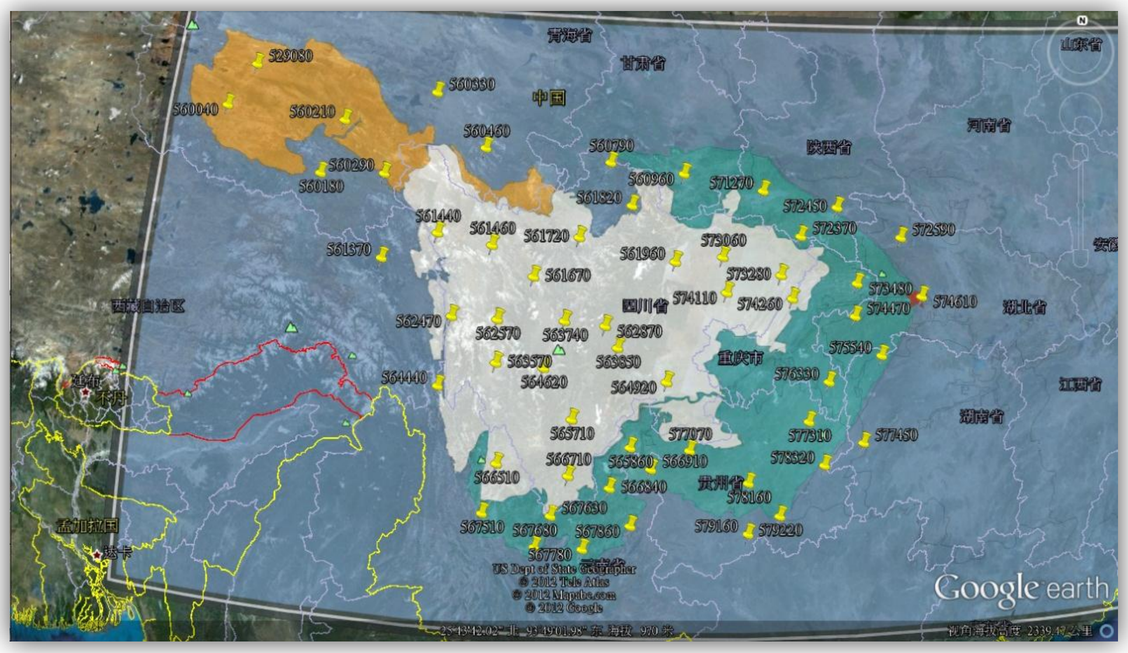


Figure 2.11 Meteorological stations used in model shown in Google Earth.

considered. In order to see these stations, Google Earth is used for help. In the raw data file from GSOD, the longitude and latitude are included and free software called csv2kml which is available at (http://www.tchartdev.com/csv2kml.htm) is used to convert the original coordinates into a KML file which can be open in Google Earth as a point layer shown in figure 2.11.

After selection, there are 56 qualified stations related to the study area are picked out. These stations have data from 1981 to 2011 in which more than 95% of both temperature and precipitation are available.

These 56 stations' data are extracted into text files as Pobs and Tobs where the precipitation and temperature are daily based and have millimeter and centigrade as their units respectively.

The other part of data is the target value data which also needs some manipulation before using in the model. In this step, the target data will be parsed based each subarea.

2.2.3 Middle (Sichuan & Tibet)

Table 2-2 Target Data used in Middle area

	Production (GWh)	Installed Capacity(MW)	Growth Number	Corrected Production	Daily Production(GWh)
1995	25978.8				
1996	26880.0				
1997	24684.0	6082.40	4.6857	115661	317
1998	25268.0	7705.90	3.6985	93453	256
1999	26040.0	10416.90	2.7359	71244	195
2000	31511.0	11008.30	2.5890	81581	223
2001	42236.0	11531.50	2.4715	104386	286
2002	40985.0	11854.60	2.4041	98533	270
2003	48015.0	12341.50	2.3093	110880	304
2004	62057.0	16000.00	1.7813	110539	302
2005	65335.0	18500.00	1.5405	100651	276
2006	78465.0	21000.00	1.3571	106488	293
2007	81413.0	23500.00	1.2128	98735	271
2008	98086.0	26000.00	1.0962	107518	294
2009	106541.0	28500.00	1.0000	106541	292
2010		31000.00			

By searching the internet resource, installed capacity of Si Chuan from 1997—2003 and 2010 are obtained but 2004—2009 are missing. The assumption here is made that for installed capacity from 2004 to 2009, the growth in each year will be same around 2500 MW from 2003 to 2010. After filling the installed capacity column showed in table 2-2, calculation of the growth rate will be possible by setting the installed capacity in 2009 as reference.

In order to use meteorological data to calibrate against the power production, the calculated hydropower production for each year should base on same installed capacity because the precipitation does not increase with the soaring of installed capacity. Then, the production times the rate of each year from 1997 to 2009 will give out corrected productions which should be similar fluctuated in certain range in every year. Due to lacking daily production data, in this case, input production data for HBV-TR model is just the value of the corrected production divided by number of days in each year from 1997 to 2009. It means that the daily power production of every year will be the same without dynamic change as shown in figure 2.12.

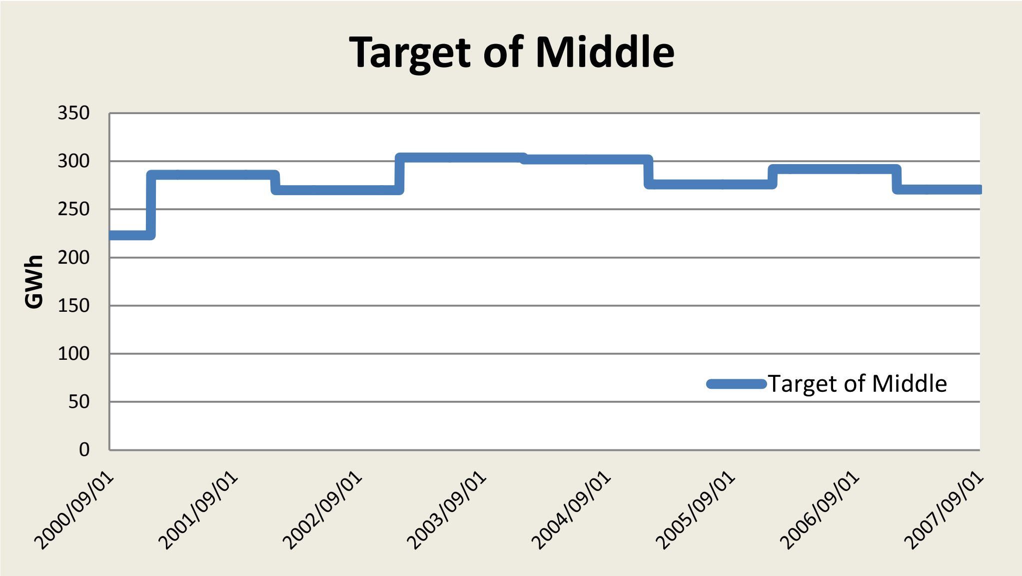


Figure 2.12 Target Value Curve of Middle Area.

2.2.4 Lower (Hu Bei, Shan Xi, Chong Qing, Yun Nan, Gui Zhou & Gan Su)

In this subarea, two biggest problems are lacking installed capacity data and dealing with the combination of 5 not complete administrative regions and one municipality city.

In Hu Bei province, there is no installed capacity data for 2004 and other regions after 2003 are totally blank. However, the data list of hydropower stations in each province found in SPIN is updated in January 6th, 2008. So in this case, the assumption is that this station list including all the stations in all those provinces and the data in this list are updated by the end of 2007. Now, installed capacity of 2007 can be obtained from the data list and same estimation as has been done in Middle area will find out each year's installed capacity shown in table 2-4 and the original data of production in each region is shown in table 2-3.

Table 2-3 Hydropower Production of each Administrative Region from 1997—2009

	Hubei	Guizhou	Yunnan	Shan Xi	Gansu	Chong Qing
	GWh	**GWh**	**GWh**	**GWh**	**GWh**	**GWh**
1997	24526.0	11084.0	16763.0	2247.0	8248.0	31.4
1998	26221.0	11989.0	16998.0	3120.0	9257.0	40.1
1999	22501.0	13354.0	18491.0	1968.0	11747.0	32.3
2000	28140.0	18344.0	19653.0	3480.0	10254.0	38.2
2001	27512.0	22196.0	21648.0	14914.0	11797.0	40.7
2002	27258.0	22153.0	20924.0	2592.0	10574.0	37.5
2003	38064.0	20825.0	28090.0	4675.0	10807.0	46.2
2004	69724.0	22605.0	29983.0	4249.0	11942.0	93.5
2005	81365.0	21335.0	34919.0	5054.0	16557.0	67.3
2006	75606.0	22596.0	35572.0	3988.0	17045.0	56.4
2007	93770.0	34062.0	43095.0	5545.0	18908.0	83.8
2008	127247.0	39404.0	64728.0	6423.0	18872.0	171.6
2009	120592.0	40088.0	62280.0	7459.0	25021.0	165.7

Table 2-4 Hydropower Installed capacity in each Administrative Region from 1997—2009

	Hu Bei	Gui Zhou	Yun Nan	Shan Xi	Gan Su	Chong Qing
	MW	**MW**	**MW**	**MW**	**MW**	**MW**
1997	6398.9	2179.8	4074.8	1233.6	2651.6	835.6
1998	6531.7	2235.1	4279.1	1249.1	2810.2	836.4
1999	6577.2	2310.1	4676.9	1292	2868.0	1070.3
2000	7070.5	2358.1	4947.2	1451.2	2951.5	1327.0
2001	7125.6	2409.6	4995.6	1450.7	3118.3	1268.0
2002	7213.9	2426.1	5836.3	1462.3	3238.6	1195.5
2003	11537.2	3713.7	6543.2	1462.3	3280.6	1329.8
2004	14713.6	6213.7	10943.2	2962.3	4030.6	1464.1
2005	17890.0	8713.7	15343.2	4462.3	4780.6	1598.4
2006	18320.0	11213.7	19743.2	5962.3	5530.6	1732.7
2007	24060.0	13346.0	24143.2	7251.9	6395.1	1867.0
2008	29050.0	15846.0	28543.2	8751.9	7145.1	2001.3
2009	29130.0	18346.0	32943.2	10251.9	7895.1	2135.6
2010			36480.0			835.6

Table 2-5 Ratio of installed capacity and production of the whole value in each region

	Hu Bei	Gui Zhou	Yun Nan	Shan Xi	Gan Su	Chong Qing
Installed	0.727	0.577	0.679	0.358	0.272	1
Production	0.741	0.471	0.665	0.375	0.299	1

Next problem is that not all of stations in the list belong to Yangtze River Basin. So, with their names, their locations could be found on Google earth and it is clear to see if they are inside the study area or not. After that, use the list again to find out the sum of those concerned stations' installed capacity and production in 2007.

Table 2-6 Production of the part in each province located inside the study area.

	Hu Bei	Gui Zhou	Yun Nan	Shan Xi	Gan Su	Chong Qing
	GWh	**GWh**	**GWh**	**GWh**	**GWh**	**GWh**
1997	18175.84	5219.93	11143.18	843.02	2463.47	31.38
1998	19431.98	5646.13	11299.39	1170.55	2764.83	40.14
1999	16675.15	6288.97	12291.86	738.34	3508.53	32.29
2000	20854.12	8638.97	13064.30	1305.61	3062.61	38.22
2001	20388.72	10453.04	14390.47	5595.36	3523.47	40.70
2002	20200.49	10432.79	13909.20	972.45	3158.19	37.48
2003	28208.65	9807.38	18672.78	1753.94	3227.78	46.19
2004	51671.39	10645.66	19931.15	1594.12	3566.78	93.50
2005	60298.36	10047.56	23212.35	1896.13	4945.16	67.32
2006	56030.45	10641.42	23646.43	1496.20	5090.91	56.43
2007	69491.51	16041.24	28647.33	2080.35	5647.34	83.75
2008	94300.80	18557.02	43027.84	2409.75	5636.59	171.61
2009	89368.88	18879.14	41400.53	2798.43	7473.14	165.74

Table 2-7 Installed capacity of the part in each province located inside the study area.

	Hu Bei	Gui Zhou	Yun Nan	Shan Xi	Gan Su	Chong Qing
	MW	**MW**	**MW**	**MW**	**MW**	**MW**
1997	4650.36	1257.97	2766.73	441.24	720.42	835.60
1998	4746.87	1289.88	2905.45	446.79	763.51	836.40
1999	4779.94	1333.16	3175.55	462.13	779.21	1070.30
2000	5138.44	1360.86	3359.08	519.07	801.90	1327.00
2001	5178.49	1390.58	3391.94	518.89	847.22	1268.00
2002	5242.66	1400.11	3962.76	523.04	879.90	1195.50
2003	8384.59	2143.18	4442.74	523.04	891.31	1329.80
2004	10693.02	3585.94	7430.27	1059.57	1095.08	1464.10
2005	13001.45	5028.69	10417.81	1596.10	1298.85	1598.40
2006	13313.95	6471.45	13405.34	2132.63	1502.62	1732.70
2007	17485.46	7702.00	16392.87	2593.90	1737.50	1867.00
2008	21111.91	9144.75	19380.41	3130.43	1941.27	2001.30
2009	21170.05	10587.51	22367.94	3666.96	2145.04	2135.60
2010			24769.38			835.60

Then, it is assumed that the proportion of these stations 'installed capacity and production out of each province stays the same in every year. With these numbers shown in table 2-5 and the original data of each region shown in table 2-3 and 2-4, production and installed capacity of the Lower area can be obtained which are shown in table 2-6 and 2-7.

Table 2-8. Growth Number in each province of Lower area.

	Hu Bei	Gui Zhou	Yun Nan	Shan Xi	Gan Su	Chong Qing
1997	4.5523	8.4164	8.0846	8.3106	2.9775	2.5558
1998	4.4598	8.2081	7.6986	8.2074	2.8094	2.5533
1999	4.4289	7.9416	7.0438	7.9349	2.7528	1.9953
2000	4.1199	7.7800	6.6590	7.0644	2.6749	1.6093
2001	4.0881	7.6137	6.5944	7.0669	2.5319	1.6842
2002	4.0380	7.5619	5.6445	7.0108	2.4378	1.7864
2003	2.5249	4.9401	5.0347	7.0108	2.4066	1.6060
2004	1.9798	2.9525	3.0104	3.4608	1.9588	1.4586
2005	1.6283	2.1054	2.1471	2.2974	1.6515	1.3361
2006	1.5901	1.6360	1.6686	1.7194	1.4275	1.2325
2007	1.2107	1.3746	1.3645	1.4137	1.2346	1.1439
2008	1.0028	1.1578	1.1542	1.1714	1.1050	1.0671
2009	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Following the steps done in Middle subarea, growth number of Lower subarea is shown in table 2-8 and corrected production of each day can be obtained and shown in table 2-9.

Table 2-9 Production of entire Lower area after correction and the daily production from 1997—2009

	Hu Bei (GWh)	Gui Zhou (GWh)	Yun Nan (GWh)	Shan Xi (GWh)	Gan Su (GWh)	Chong Qing(GWh)	**Sum up** (GWh)	**Daily production**(GWh)
1997	82742.71	43932.83	90088.34	7005.95	7334.95	80.20	231184.96	633
1998	86662.53	46344.19	86989.83	9607.17	7767.64	102.49	237473.86	651
1999	73853.16	49944.75	86581.56	5858.69	9658.38	64.43	225960.98	619
2000	85917.63	67211.11	86994.64	9223.38	8192.32	61.51	257600.60	704
2001	83350.66	79586.43	94897.16	39541.65	8920.93	68.55	306365.38	839
2002	81570.33	78892.03	78510.95	6817.68	7699.07	66.95	253557.01	695
2003	71223.34	48449.30	94012.30	12296.55	7767.98	74.18	233823.64	641
2004	102299.07	31431.38	60000.36	5516.91	6986.56	136.38	206370.67	564
2005	98182.84	21154.33	49838.96	4356.27	8166.87	89.95	181789.22	498
2006	89092.08	17409.72	39456.07	2572.64	7267.43	69.55	155867.51	427
2007	84134.98	22051.00	39089.05	2940.95	6971.95	95.80	155283.74	425
2008	94560.50	21484.73	49660.68	2822.76	6228.25	183.13	174940.04	478
2009	89368.88	18879.14	41400.53	2798.43	7473.14	165.74	160085.87	439

By using the daily data from table 2-9, the target value curve of Lower subarea is shown in figure 2.13

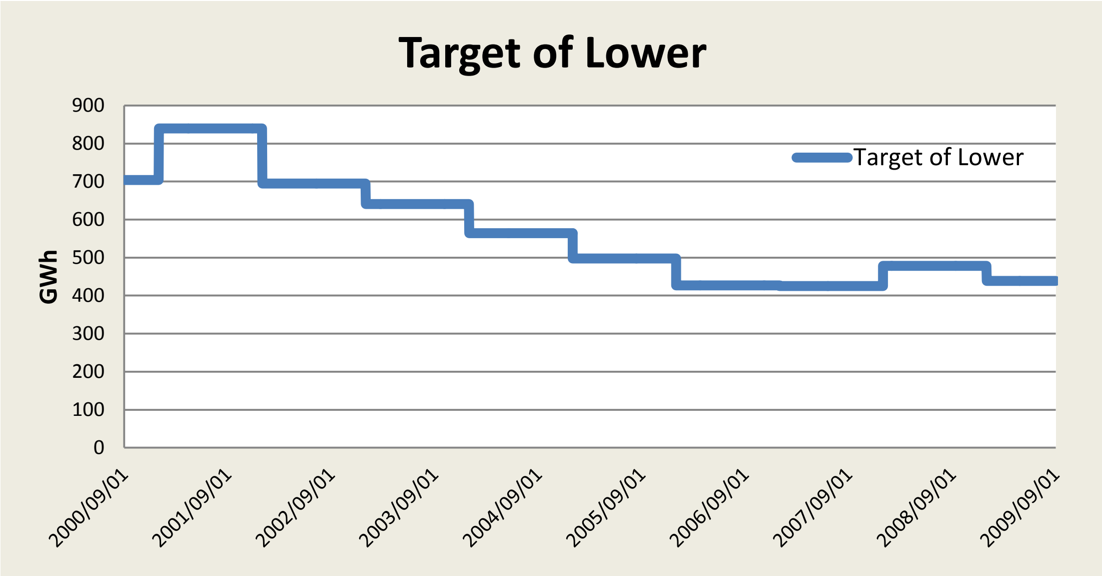


Figure 2.13 Target Value Curve of Lower Area.

2.2.5 Upper (Qing Hai)

In Upper subarea, the situation there is quite similar to Middle subarea. Only one administrative region is involved—Qing Hai. However the difference is that this region involved is not the entire administrative province like in Lower subarea. Same method as Lower area has to be done as well.

It is assumed that the proportion of installed capacity and production belonging to study area stays the same from 1997 to 2009. And data of installed capacity of this province is available from internet for year 1997—2003 and 2007. So for other years, same assumption and estimation method done in Middle subarea is used to find out installed capacity in other years ending by 2009. After this, growth rate, corrected production and the daily production can be obtained shown in table 2-10.

Table 2-10 Target Data used in Upper area

	Production (GWh)	Installed (MW)	Growth number	Corrected Production	**Daily Production (GWh)**
1997	551.83	165.28	7.7997	4304.09	12
1998	731.56	196.35	6.5654	4802.98	13
1999	961.63	227.13	5.6758	5458.01	15
2000	1183.79	229.99	5.6053	6635.44	18
2001	1039.79	230.98	5.5810	5803.11	16
2002	978.01	236.81	5.4437	5324.00	15
2003	732.10	246.77	5.2241	3824.58	10
2004	1223.47	420.33	3.0670	3752.30	10
2005	1765.19	593.90	2.1706	3831.55	11
2006	2303.82	767.47	1.6797	3869.79	11
2007	2283.82	942.00	1.3685	3125.41	9
2008	2276.56	1115.57	1.1556	2630.76	7
2009	3037.47	1289.13	1.0000	3037.47	8

And the target value curve is also flat without dynamic change in each year which can be seen in figure 2.14.

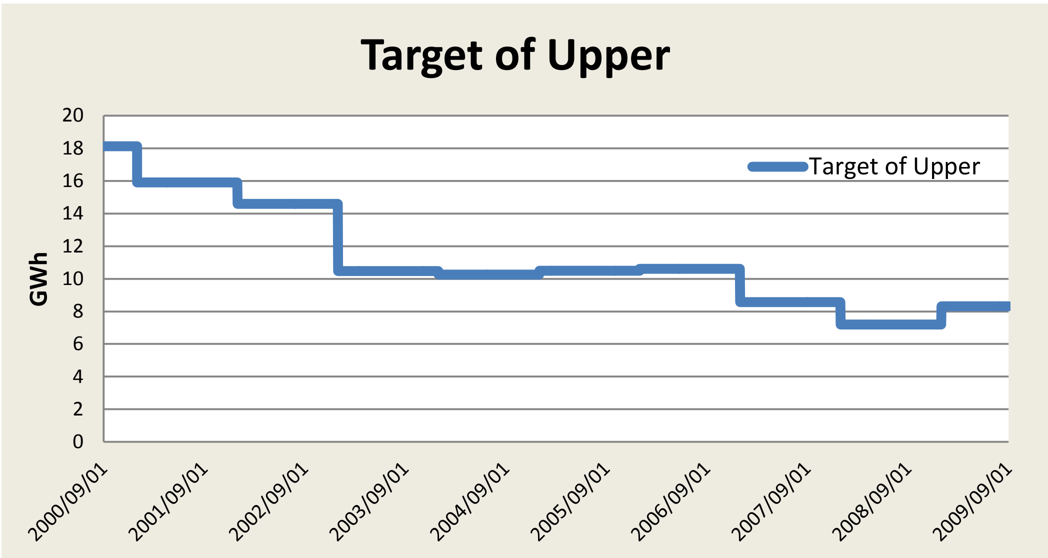


Figure 2.14 Target Value Curve of Upper Area.

3. HBV model

3.1 HBV model

HBV model is a hydrological forecasting model for calculation and modeling of flows developed by Swedish Meteorological and Hydrological Institute (SMHI). The calculations are carried out on a calibrated river with observations for water level and volume of discharge and with observations and forecasts for precipitation and temperature. Different versions of HBV model have been applied in more than 40 countries all over the world in many areas (SMHI, 2009):

- Tool for hydrological work within the hydroelectric power industry, authorities and research
- Calculate and forecast flows in rivers
- Calculations for the transport of substances in watercourses.
- Runoff modeling of areas where there are no observed flows
- Hydrological forecast and warning services at SMHI
- Statistical analyses

The energy model used in this project has already been developed by Thomson Reuters for hydropower market (He, 2009). But the basic conception and routines behind are similar. Thus, the model used in this project is called HBV-TR.

The general water balance in the model can be described as (SMHI, 2006):

$$P - E - Q = \frac{d}{dt}[SP + SM + UZ + LZ + lakes]$$

Where:

P = precipitation
E = evapotranspiration
Q = runoff
SP = snow pack
SM = soil moisture
UZ = upper groundwater zone
LZ =lower groundwater zone
lakes = lake volume

The model is consisted of several hydrological routines including snow routine, soil moisture routine that accounts for soil field capacity and changes in soil moisture storage due to rainfall, snow melt and evapotranspiration and runoff generation routine which transfers water from soil moisture zone to runoff as can be seen in figure 3.1. (Primožič, Kobold and Brilly, 2008)

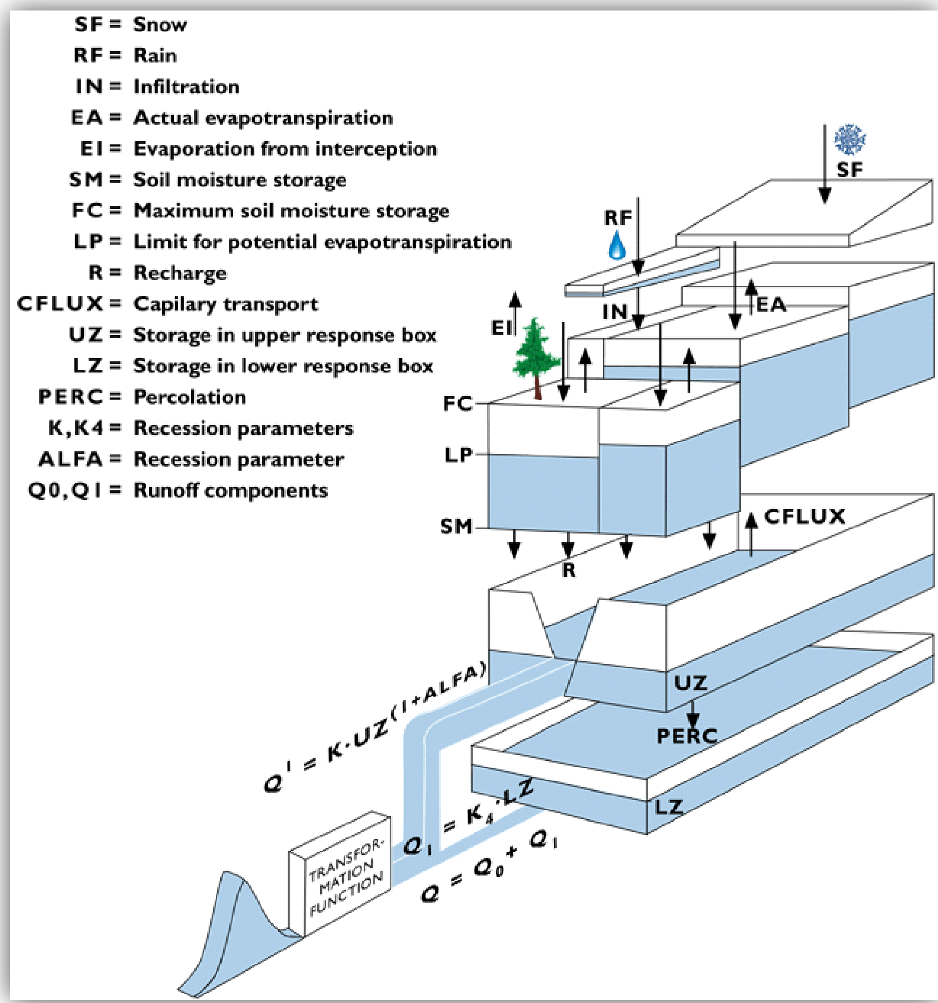


Figure 3.1 Structure of the HBV-96 model. (Source: Lindström et al, 1997)

Use a schematic configuration to show the model used in the project, it will be like the following figure3.2:

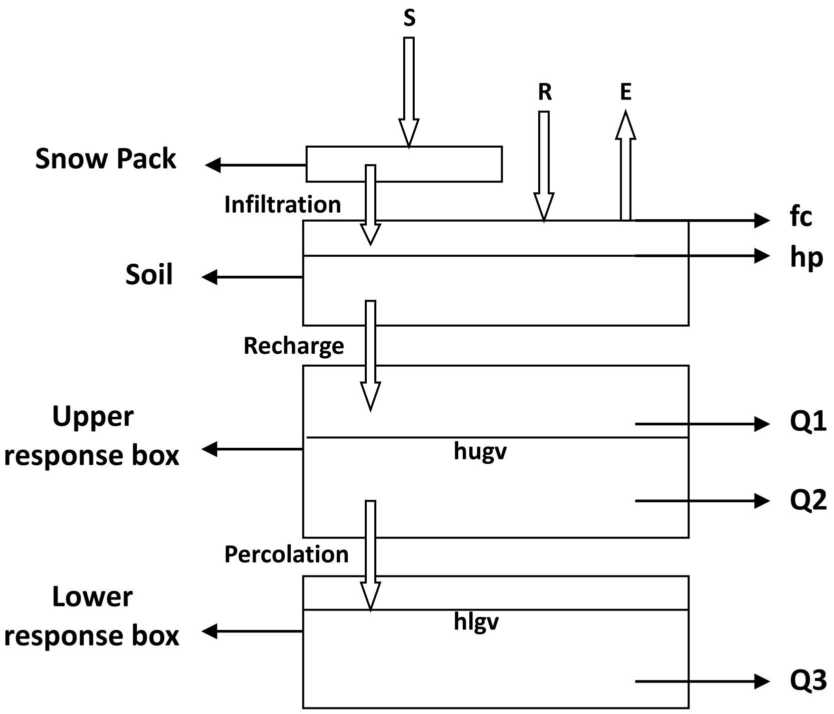


Figure 3.2 Schematic structure of the HBV-TR model used in the

First—Snow routine:

$$SnowMelt = C * (T - Te)$$

Snow routine will take charge of snow accumulation and melting. Precipitation will be in snow (*S*) when the air temperature (*T*) is lower than the value in a threshold temperature (*Te*) which is around 0℃. If higher, snow will start to melt and the precipitation will be in rain (*R*). And the melting rate will determined also by the coefficient (*C*). (Primožič, Kobold and Brilly, 2008)

Second—Soil moisture routine:

This routine is the main process controlling the runoff formation. There are three main parameters in this routine, *fc, hp* and *hm*. *fc* is the maximum soil moisture storage in the basin. *hp* is kind of a fraction of *fc* above which the evapotranspiration will reach the maximum value as potential evapotranspiration (*Ep*) and vice versa. And *hm* is the actual soil moisture which will determine the actual evapotranspiration (*E*) as shown in the equation below (Primožič, Kobold and Brilly, 2008):

$$E = \begin{cases} Ep & hm \geq fc * hp \\ Ep * \dfrac{hm}{fc * hp} & hm < fc * hp \end{cases}$$

Third—Runoff routine:

This routine is in charge of transforming excess water from the soil moisture zone to runoff. It is consisted of two reservoirs—upper, non-linear and lower, linear. The upper reservoir accounts for the quick flow *Q1* and *Q2* when the lower one accounts for the slow runoff *Q3.* Normally, in quick flow *Q1* and *Q2, Q2* will take most of the runoff when there is no heavy precipitation happens. But *Q1* will appear when the water level in the upper response box is higher than the threshold level of upper response box, for example heavy rainfall. These three outflows are determined by water level and threshold level (Primožič, Kobold and Brilly, 2008):

$$Q1 = \frac{hu - hugvPot}{T1}$$

$$Q2 = \frac{hu}{T2}$$

$$Q3 = \frac{hl}{T3}$$

hu: Water level of the upper response box

hugvPot: Threshold level of upper response box

hl: Water level of the lower response box

T1: Recession factor for upper outlet of upper response box

T2: Recession factor for lower outlet of upper response box

T3: Recession factor for outlet of lower response box

The model used in this project is build up based on these essential routines and it has more free parameters can be adjusted in calibration which are shown in table 3-1.

Table 3-1 Parameters in HBV-TR-model used in project

Calibration Parameters	Explanation
Tcorr	correction factor for temperature
Sfcf	correction factor for snow
Rfcf	correction factor for rain
AltDeltaT	Height distribution for Temperature
Te	Threshold temperature for snow melting and refrozen of rain
c	Snow melt rate coefficient
Thorn	Coefficient of evapotranspiration
hp	Boundary factor for evapotranspiration
fc	Field capacity
b	Factor for infiltration
perc	Factor for percolation
hugv	Threshold level of upper response box
hlgv	Threshold level of lower response box
T1	Recession factor for upper outlet of upper response box
T2	Recession factor for lower outlet of upper response box
T3	Recession factor for outlet of lower response box
GWh	GWh factor

The calibration part normally is finished manually by trier and error technique. And the parameters in table 3-1 can influence the model performance in different ways.

Among them, the parameter GWh deserves more attention. As has been discussed before, the target value in the model is the hydropower production after correction with GWh as its unit. However, the input data for the model are precipitation in millimeter and temperature in centigrade. And in the HBV-TR model, the final output would be the runoff from different layers in different time as said before. So here the parameter GWh is kind of a transform number which can transfer precipitation into energy.

One of the classic energy equations is:

$$Energy = mgh$$

The precipitation in the model can be seen as the *m* in the equation. And gravitation coefficient *g* can be seen as constant. But water flow in different areas would have different energy according to its water head, fall distance and etc. So the parameter GWh here can be regarded as the *h* in the equation which can give the water potential energy.

But another thing need to be clear in mind is that the value of GWh parameter result after calibration does not stand for the real potential energy under natural condition. Because in the model, the target value is hydropower production and it is determined by water amount and the current installed capacity in hydropower stations. With the development of hydropower stations, the more turbines there will be in hydropower stations, the bigger this GWh number will be. Natural water flow energy is kind of constant which determined only by natural water amount and other natural conditions.

4. Calibration result and analysis

After preparing the target value data and input data Tobs and Pobs, the calibration can be done for each subarea.

As has been discussed in data analysis part, there are 56 qualified meteorological stations spread over the whole study area. And for each subarea there will be a couple of stations having candidacy. These candidate stations should have good location either in the subarea or in the vicinity, and they must be able to be the representatives of meteorological condition of the subarea. They are supposed to spread evenly from high to low in data value and evenly in geographical location.

In HBV-TR model, there are maximum 10 stations can be selected for input data, and each of them will have a certain weight in the input and the sum up of these weights should be 1. Weight here means how much share each station has in the input data.

Excel evaluation program from Thomson Reuters is used to show the data from meteorological stations. In 1999 all stations have no precipitation data. So, under this circumstance, the time period 2000 to 2009 is selected as the model calibration time interval.

And there are some objective functions in the model shown in table 4-1 are used as the numerical criteria to value the calibration results.

Table 4-1 Objective functions in calibration

Objective function	Explanation	Formula
r2	Coefficient of determination of daily inflow	$1-\frac{\sum(Q_{obs}-Q_{cal})^2}{\sum(Q_{obs}-\bar{Q}_{cal})^2}$
r2_W	Coefficient of determination of weekly inflow	$1-\frac{\sum(Q_{obs.w}-Q_{cal.w})^2}{\sum(Q_{obs.w}-\bar{Q}_{cal.w})^2}$
r2_M	Coefficient of determination of monthly inflow	$1-\frac{\sum(Q_{obs.m}-Q_{cal.m})^2}{\sum(Q_{obs.m}-\bar{Q}_{cal.m})^2}$
Std-AccD	Standard deviation of accumulated difference	$\sigma(Accdiff)$
Accdiff	Accumulated difference between the observed and simulated daily inflow	$\sum(Q_{cal}-Q_{obs})$
QrecSum	Sum of observed inflow	$\sum Q_{obs}$
QcalcSum	Sum of simulated inflow	$\sum Q_{cal}$
RelErr	Relative volume error of daily inflow	$\frac{\sum\lvert Q_{obs}-Q_{cal}\rvert}{\sum Q_{obs}}$

$\boldsymbol{Q_{obs}}, \boldsymbol{Q_{obs.w}}, \boldsymbol{Q_{obs.m}}$: Observed inflow (daily, weekly, monthly)

$\boldsymbol{Q_{cal}}, \boldsymbol{Q_{cal.w}}, \boldsymbol{Q_{cal.m}}$: Simulated inflow (daily, weekly, monthly)

$\boldsymbol{\bar{Q}_{cal}}, \boldsymbol{\bar{Q}_{cal.w}}, \boldsymbol{\bar{Q}_{cal.m}}$: Average of the observed inflow (daily, weekly, monthly)

In this project, as has been discussed before, the target value curves for each subarea are flat without dynamic change. So it is not a good idea to look forward to find the objective functions like r2, r2_W and r2_M ended up with reasonable value, for example above 0.8.

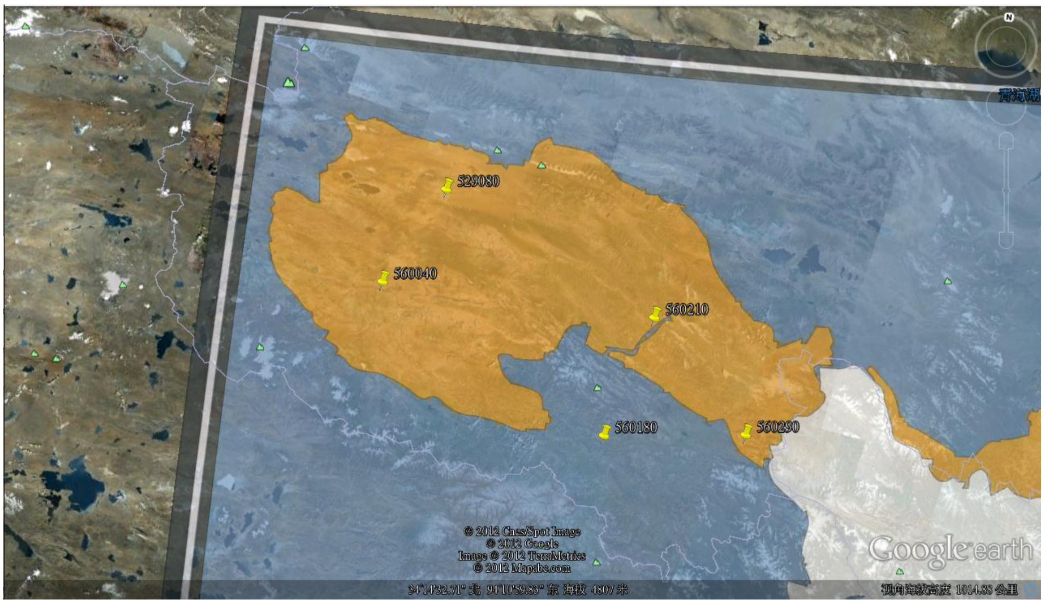
Fortunately, besides the numerical criteria, some hydrographs in the model can also offer visual inspections which can offer great help to make the calibration results plausible. Different flows from different layers should have reasonable relationship between each other according to the properties of different layers. And according to climate study, each subarea should have reasonable amount of snow.

4.1 Upper

Upper subarea is the original part of Yangtze River Basin. In this area, there are indeed some hydropower stations have been built. But unfortunately, maybe because they are quite new or small, they are not found by Google Earth. According to the station list from SPIN, there are 7 hydropower stations located within study area by the end of 2007. The total area of Upper is about 180 300km^2 and the total installed capacity as showed in data analysis chapter is 12 754.2 MW, production is 46 395 GWh.

Five meteorological stations are selected for calibration shown in table 4-2.

Table 4-2 Basic information about meteorological stations in Upper area



Station number	529080	560040	560210	560180	560290
Latitude	35.217	34.217	34.133	32.9	33.017
Longitude	93.083	92.433	95.783	95.3	97.017
Elevation	4613	4535	4176	4068	3682
Begin year	1957	1957	1957	1957	1956
End year	2011	2011	2011	2011	2011
Temp. Weight	0.1	0.1	0.2	0.3	0.3
Prec. Weight	0.325	0.325	0.25	0.05	0.05

It happens to coincide that temperature and precipitation stations are the same in this subarea because there are not too many options for this subarea. Their weights as temperature stations and precipitation stations in the model are also given out in table 4-2. After calibration, the result is shown in figure 4.1.

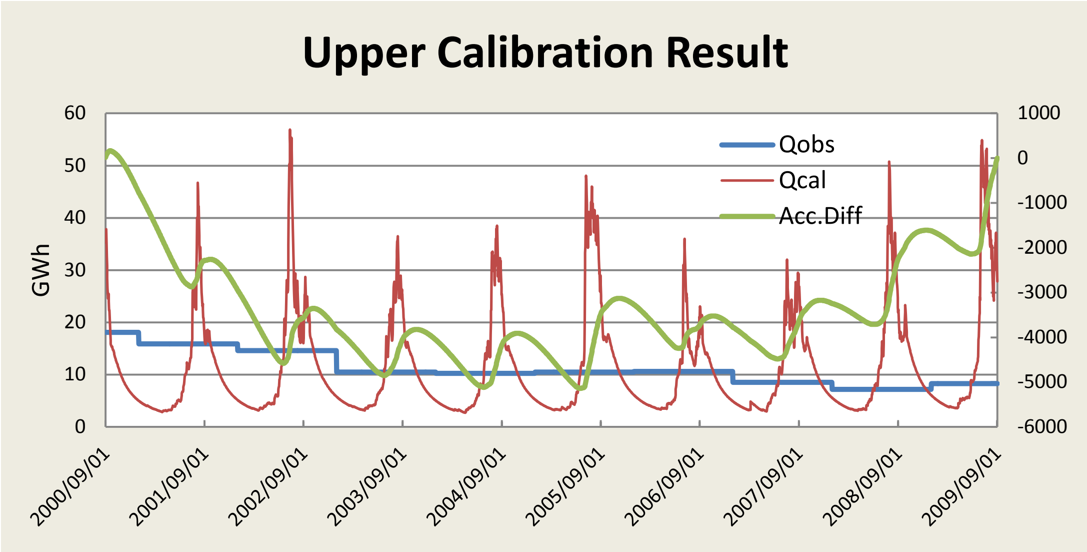


Figure 4.1 Calibration result of Upper Area.

From figure 4.1, it can be seen that not too much agreement of the Qobs and Qcal can be found because Qcal is quite dynamic while Qobs is just flat. So it is hard to do trial and error with parameters according to this graph neither the objective functions. Basically, the patterns of Qobs and Qcal are similar, Qcal falls when Qobs decrease and vice versa. Maybe the only function has some meaning is the Acc.Diff. It tells the total difference between the target value Qobs and calculated value Qcal in energy inflow with GWh as its unit. In this Upper subarea, it is good enough at just -1.2716.

Another conclusion from this graph is that, the peak flow of this area appears in summer time mainly from May to September. However, it is quite different compared with the curve in Sweden. In Sweden, the peak value always appears around April mostly due to the snowmelt runoff (Ågren, et al., 2008). From climate study, it is easily known that this area has dry and wet seasons and most precipitation comes in May to September. (Zhang and Chen, 2004). The evaluation excel program shows the sum-up of average precipitation in each month in the time period from 1981 to 2011 which can be seen in figure 4.2. Obviously from this figure that, in winter time or maybe dry season especially from November to February, the precipitation is quite low when summer time has much more water. So this would make the result shown in figure 4.1 reasonable without obvious spring runoff.

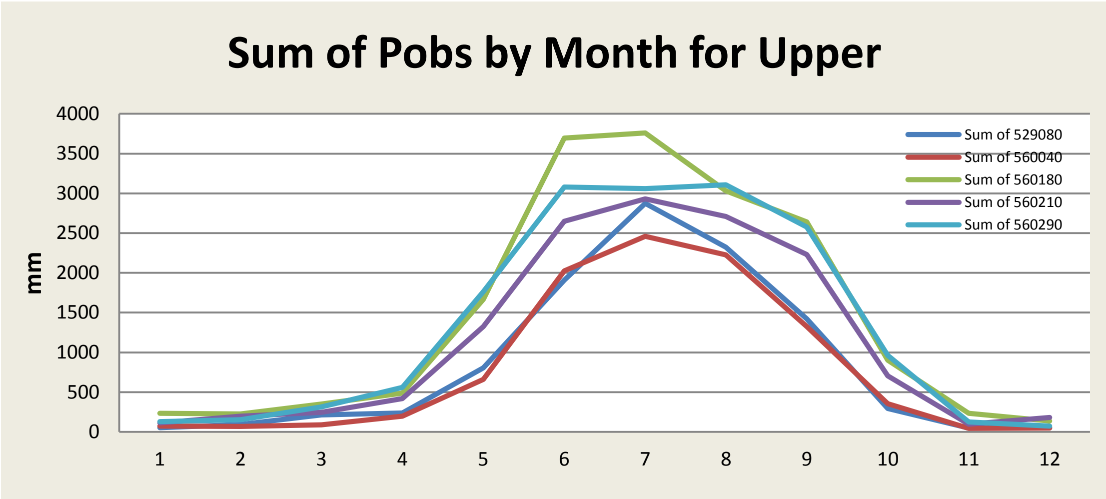


Figure 4.2 Sum-up of Precipitation of candidate stations in each month from 1981 to 2011.

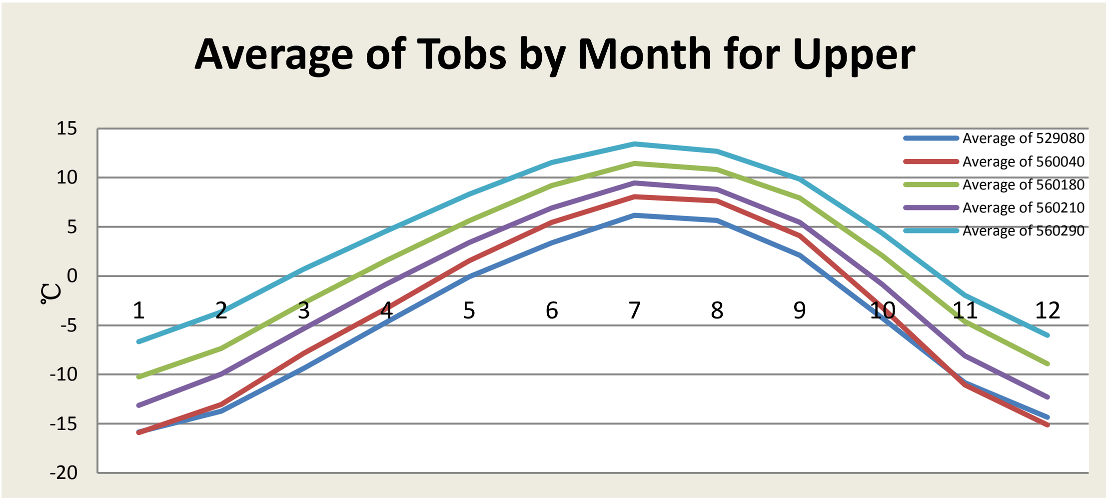


Figure 4.3 Average Temperature of Candidate Stations of Upper area in each month from 1981 to 2011

As said before, if it is not able to judge model result from the numerical perspective, other helpful graphs and information should be used. If looking back to table 4-2, it can be seen that these stations' elevation are quite high from 3600m to 4600m because this subarea is located on Tibet plateau. Also, according to the climate study in chapter 2, this subarea is much drier and colder than other parts in Yangtze River Basin. The average temperature and sum-up of precipitation in each month can be seen in figure 4.2 and 4.3. In theory, the temperature will decrease 6 °C when the elevation increase 1000 meters. So, on some mountains and high elevation zone, snow will never disappear in the whole year. Another graph shown in figure 4.4 illustrates the snow pack condition in this subarea. Clearly that during the whole year, there is snow in this area and not all of them will melt even in hot season. Only small part as shown in red color will melt due to the low elevation and higher temperature.

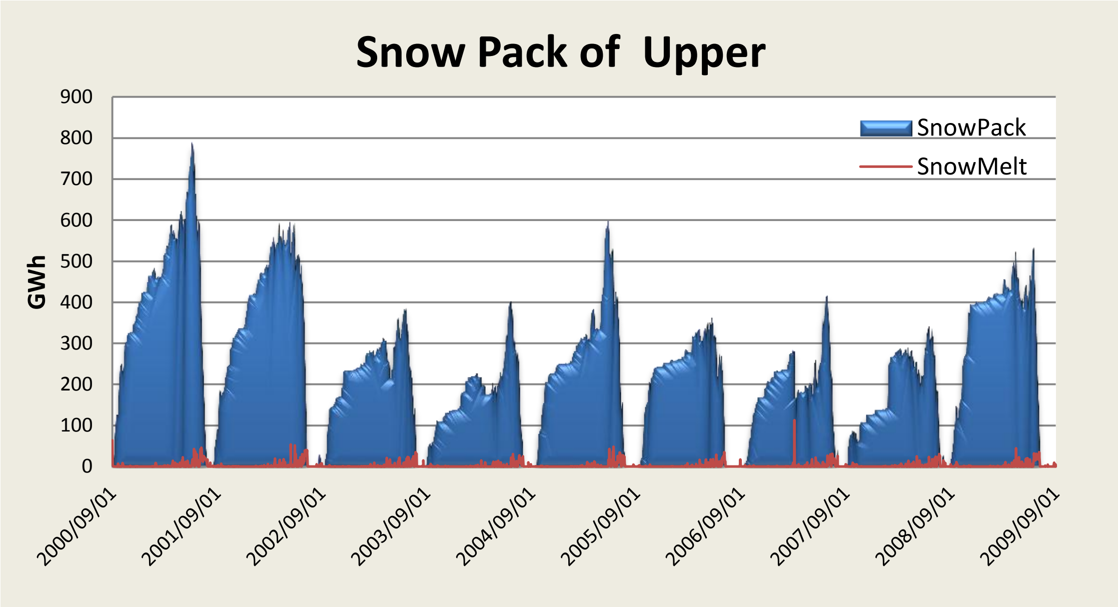


Figure 4.4 Snow Pack of Upper Area.

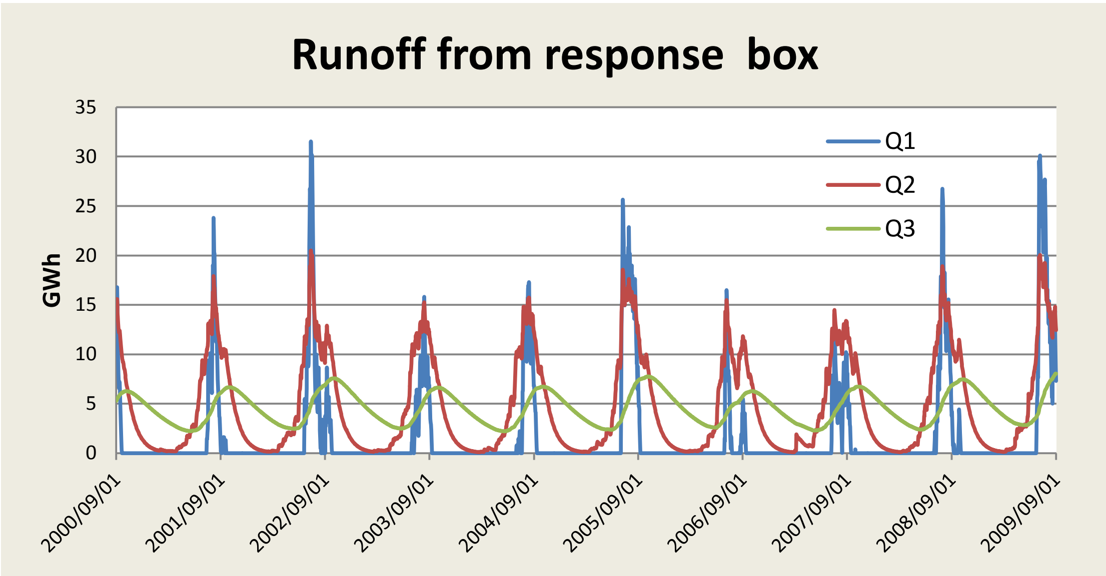


Figure 4.5 Runoff from both Upper and Lower response boxes of Upper Area

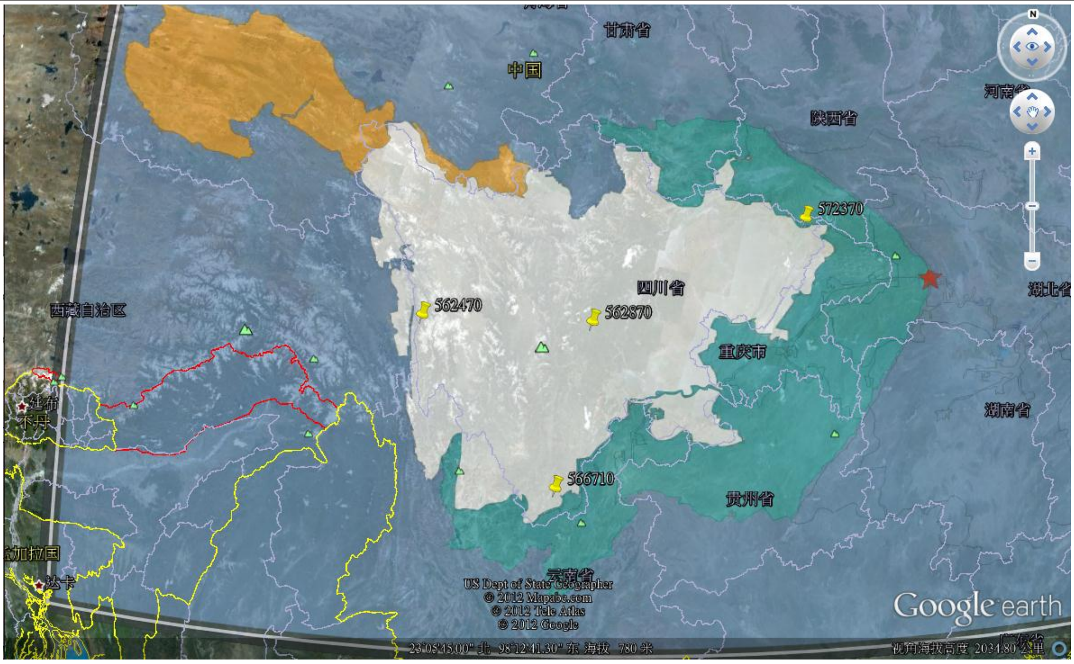
Another criterion is the runoffs Q1, Q2 and Q3 from the response boxes. Q1 and Q2 are from the upper response box while Q3 is from the lower as shown in figure 3.2. Normally, it can be seen that Q2 will always quickly response to the change of precipitation while Q1 will just appear in the wet seasons when the heavy precipitation happens and fully saturates the upper box exceeding its field capacity. Q3, compared with Q1 and Q2, always get attenuated mainly due to the reason that the water for Q3 comes from the percolation from the upper response box and this process will take some time to make the lower response box fully saturated. But as long as there is percolation from upper box to lower box, there will be Q3. And the water pressure in the lower box will determine how big Q3 is. Figure 4.5 give out the calibration result which conforms to reality.

4.2 Middle

Middle subarea is in the upstream area of Yangtze River basin. In this area, it is supposed to have some hydropower stations. But unfortunately, stations' data are not available. The total area of middle area is about 545400 km^2. And as discussed in the study area background chapter, this area has great both potential hydro energy and exploitable energy shown in figure 2.3.

There are four meteorological stations are selected for Pobs in calibration shown in table 4-3. And their sum-up of average value in each month from 1981 to 2011 is shown in figure 4.6.

Table 4-3 Basic information about Precipitation stations in Middle subarea



Station number	562870	572370	566710	562470
Latitude	29.983	32.067	26.65	30
Longitude	103	108.033	102.25	99.1
Elevation	629	674	1788	2589
Begin year	1956	1956	1956	1956
End year	2011	2011	2011	2011
Prec. Weight	0.4	0.4	0.1	0.1

It can be seen that, these four precipitation stations are evenly spread both in geological locations and amount of water. Through changing the weight of each station, it is possible to improve the calibration result.

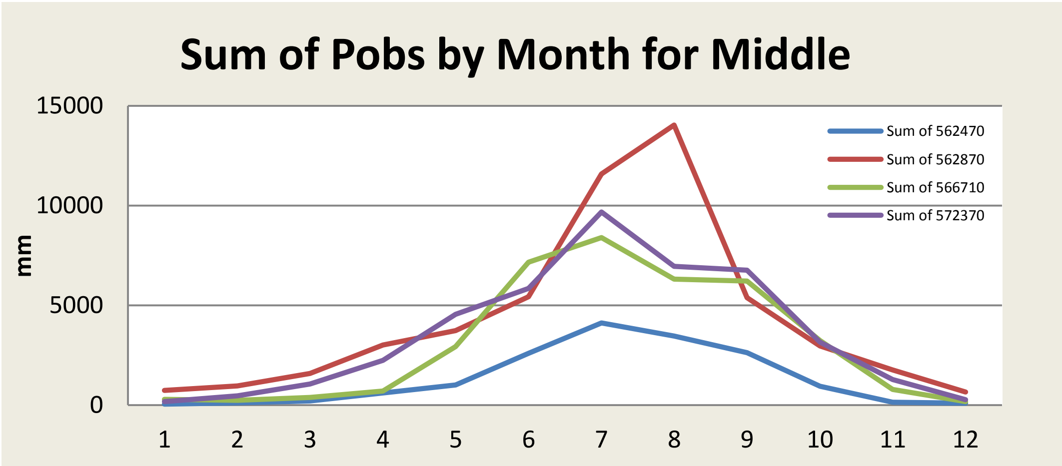
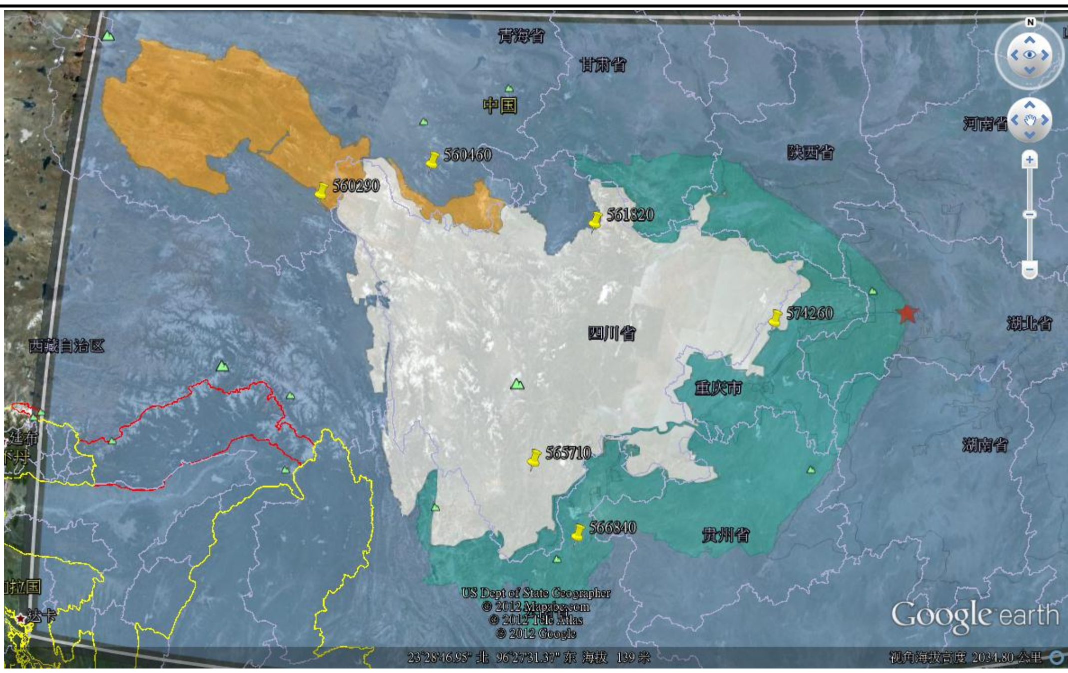


Figure 4.6 Sum-up of Precipitation of Candidate Stations in each month from 1981 to 2011.

Six stations are chosen for Tobs shown in table 4-4. Average temperature in each month is shown in figure 4.7.

Table 4-4 Basic information about Temperature stations in Middle subarea.



Station number	565710	574260	566840	561820	560290	560460
Latitude	27.9	30.683	26.417	32.65	33.017	33.75
Longitude	102.267	107.8	103.283	103.567	97.017	99.65
Elevation	1599	455	2110	2852	3682	3968
Begin year	1944	1956	1957	1956	1956	1956
End year	2011	2011	2011	2011	2011	2011
Temp. Weight	0.1	0.1	0.15	0.15	0.15	0.35

Obviously, these temperature stations are also evenly spread in each month from high to low.

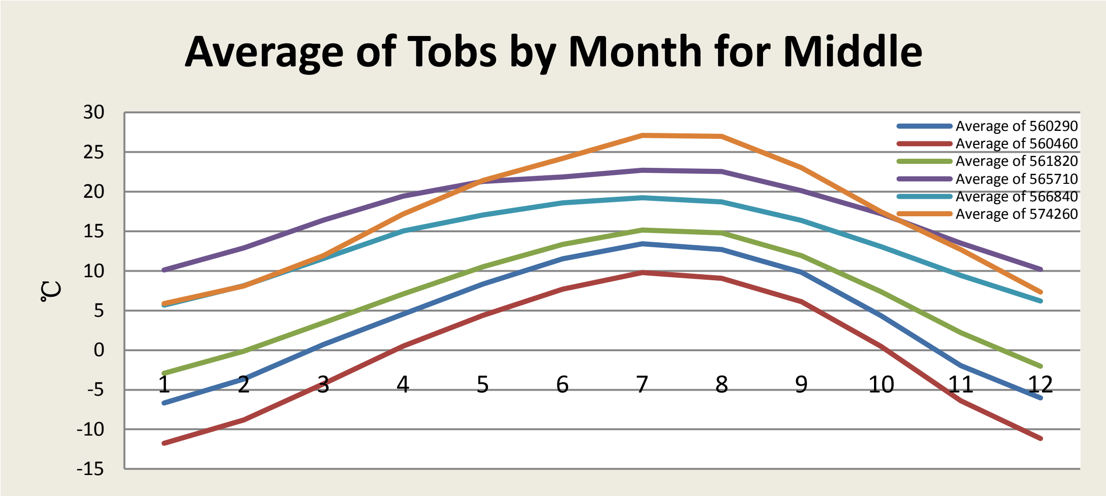


Figure 4.7 Average Temperature of Candidate stations in each month from 1981 to 2011

After picking out proper input Pobs and Qobs, the calibration result is obtained and shown in figure 4.8.

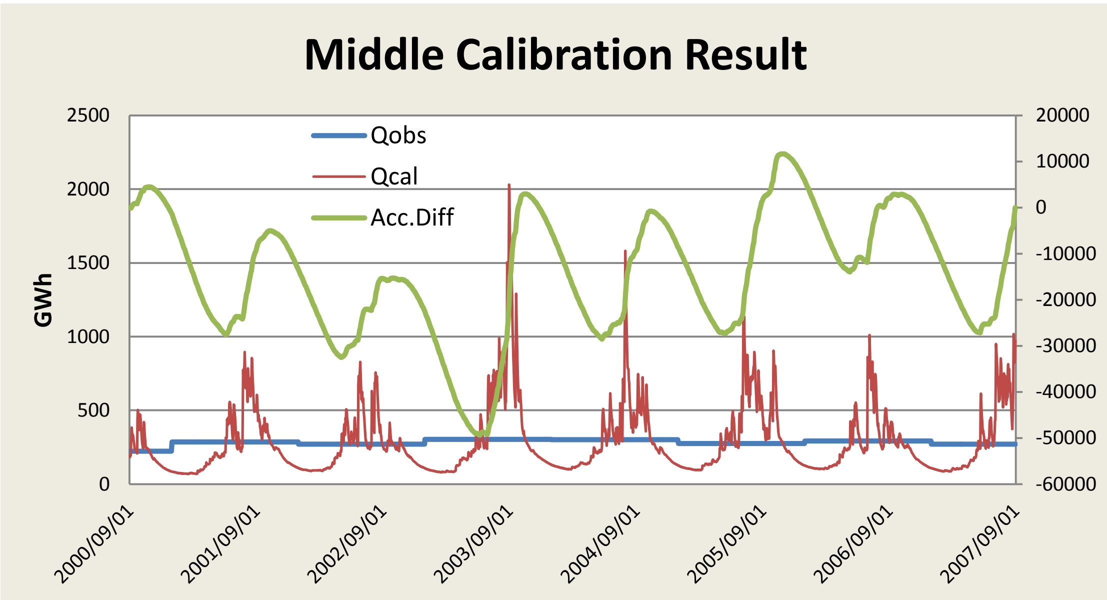


Figure 4.8 Calibration result of Middle Area.

The same as Upper area, there is almost no meaning to see the objective functions because they are far away from good except AccDiff.

If looking at the precipitation stations, from west to east, the elevation gradually decreases. On the west part, mainly plateau and mountain as discussed in topography part, the elevation there is much higher than the east part which is mainly basin area. In high elevation zone, there will be snow which would last for the whole year when temperature in basin area is much higher with almost no snow all the time. The snow pack is shown in figure 4.9.

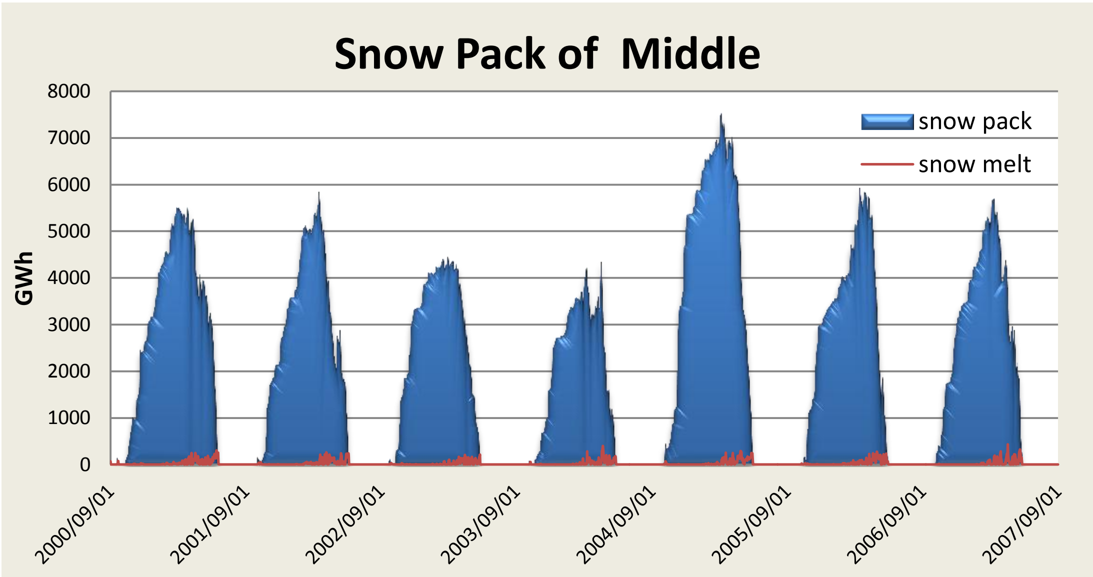


Figure 4.9 Snow Pack of Middle Area.

Compare with Upper subarea, from figure 4.9, snow pack in Middle subarea is smaller and narrower. The reason is that this area has higher average temperature than Upper Area, which can be drawn from the comparison of figure 4.3 and figure 4.7, and the fraction of snow area is smaller. After adjustment of model parameters, this snow pack graph looks reasonable.

In Middle subarea, the runoffs from different response boxes perform differently from the Upper subarea as shown in figure 4.10. First is that the runoffs, no matter Q1, Q2 or Q3, are much bigger than Upper subarea due to its much higher precipitation and bigger area. Second, Q1 appears more frequently and bigger in quantity which indicates the high frequency of heavy precipitation as well. The curve shown in this figure corresponds with the climate study result.

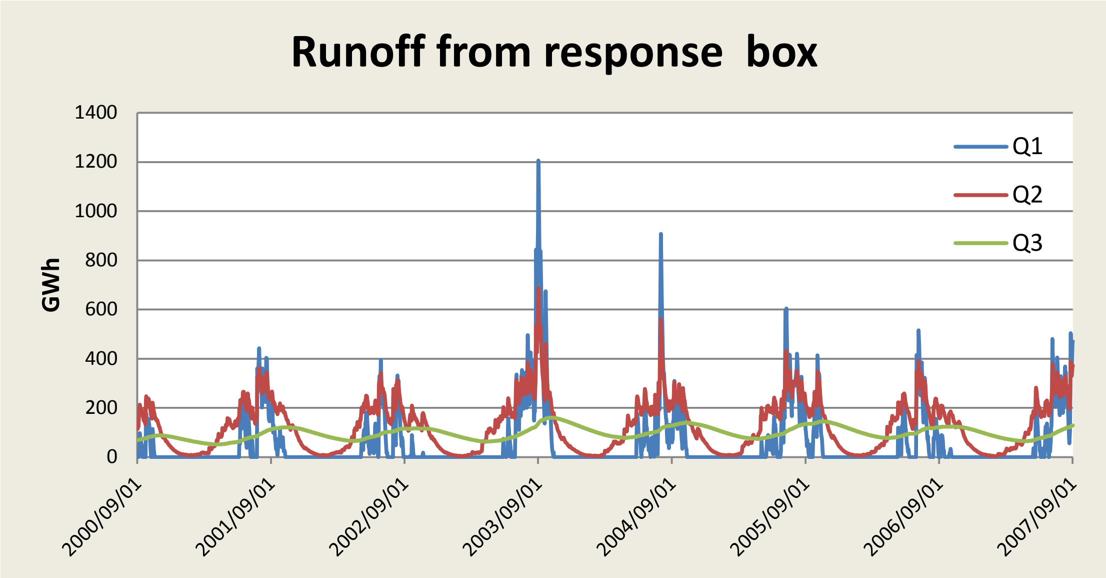


Figure 4.10 Runoff from both Upper and Lower response boxes of Middle Area

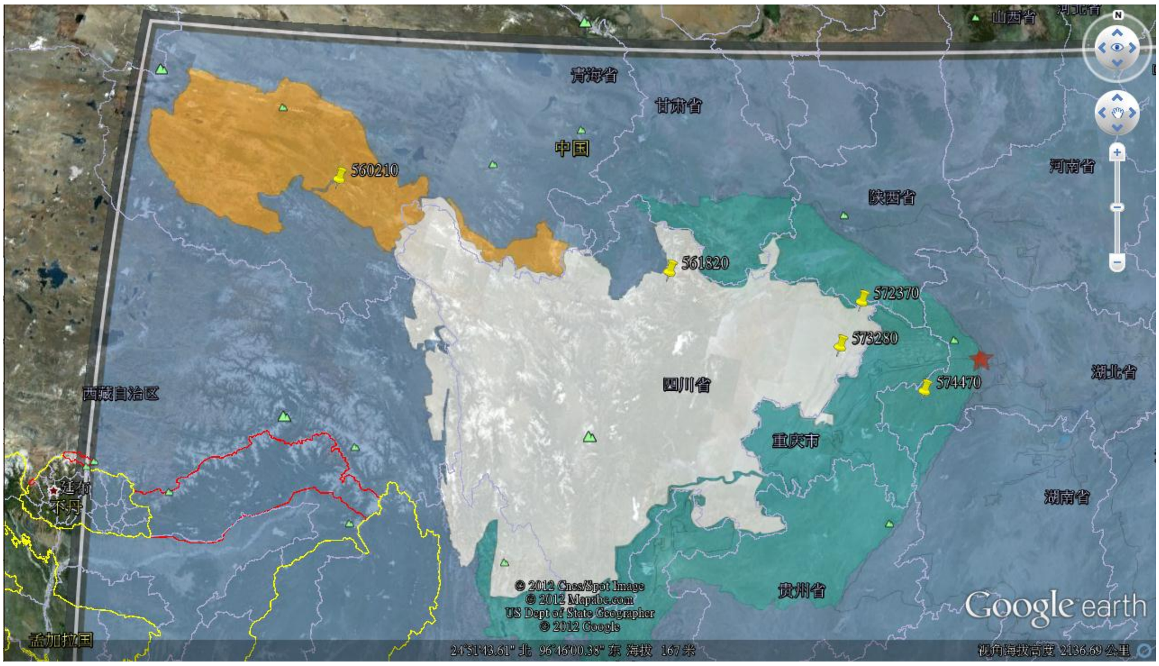
4.3 Lower

Lower subarea approximately belongs to midstream area of Yangtze River Basin. In this area, there are quite a lot of hydropower stations has been built including world famous Three Gorges. According to the station list from SPIN, by the end of 2007, there are 109 hydropower stations located in this subarea (Chong Qing Municipality is not included). The total area of Lower subarea is about 380753 km^2.

For this area, the selection of meteorological stations would be different from former two regions. Water in this area is not only from precipitation in this area, but also upstream area. So water is from the whole watershed area. Thus, meteorological stations for Lower subarea should stand for the meteorological condition of the whole study area.

There are five stations chosen for Pobs and five for Tobs. Their information is shown in table 4-5 and table 4-6 and evaluation shown in figure 4.11 and 4.13.

Table 4-5 Basic information about Precipitation Stations in Lower subarea



Station number	574470	560210	561820	573280	572370
Latitude	30.283	34.133	32.65	31.2	32.067
Longitude	109.467	95.783	103.567	107.5	108.033
Elevation	458	4176	2852	344	674
Begin year	1945	1957	1956	1956	1956
End year	2011	2011	2011	2011	2011
Prec. Weight	0.2	0.2	0.2	0.2	0.2

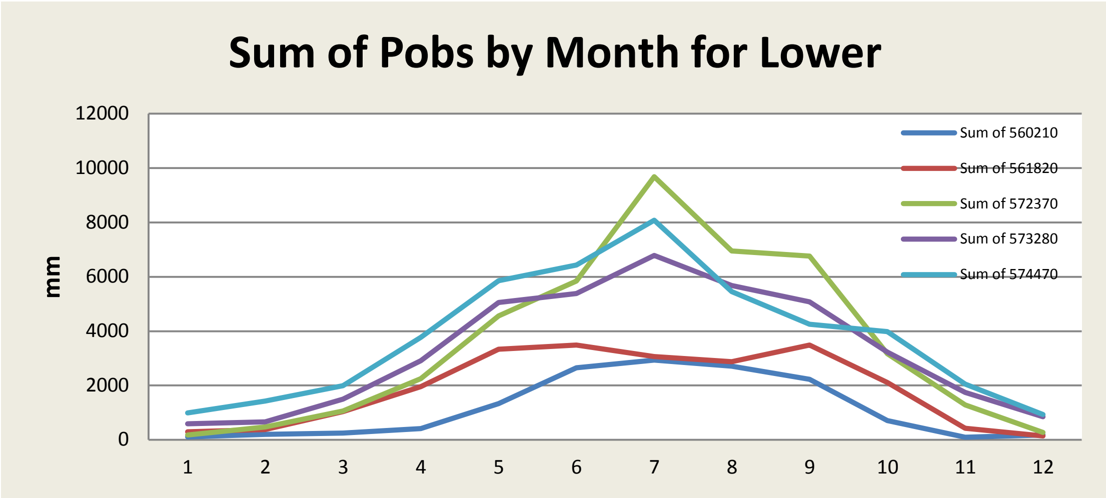
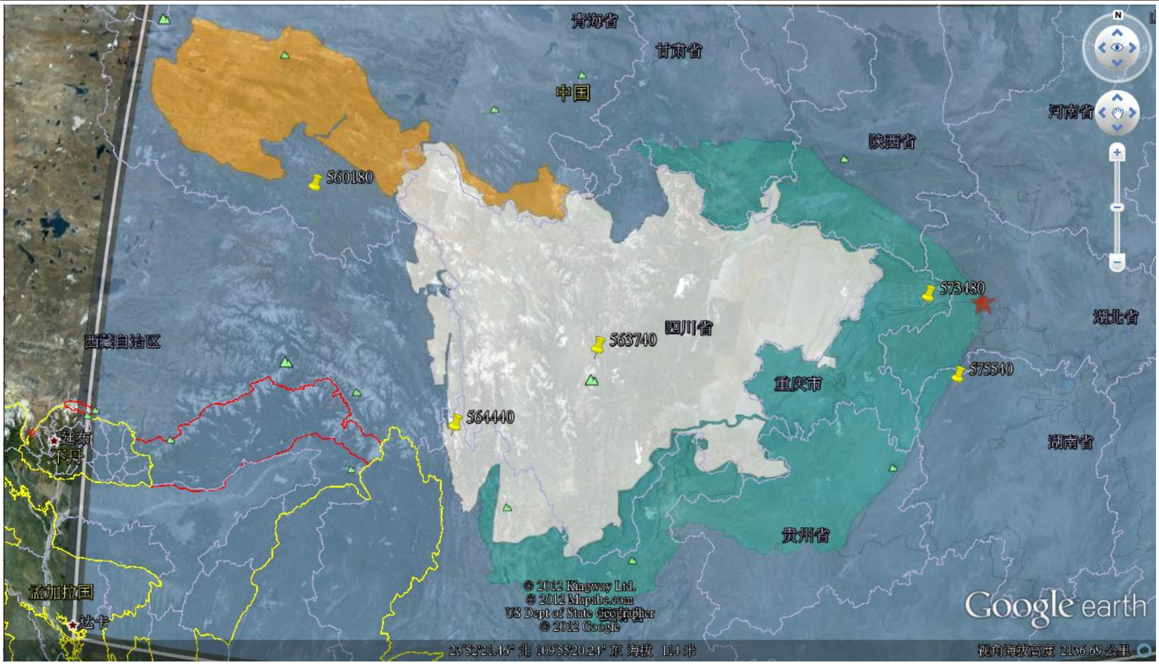


Figure 4.11 Sum-up of Precipitation of Candidate Stations in each month from 1981 to 2011

Table 4-6 Basic information about Temperature Stations in Lower subarea



Station number	573480	560180	564440	563740	575540
Latitude	31.017	32.9	28.45	30.05	29.4
Longitude	109.533	95.3	98.883	101.967	110.167
Elevation	303	4068	3320	2617	322
Begin year	1956	1957	1956	1957	1959
End year	2011	2011	2011	2011	2011
Prec. Weight	0.2	0.2	0.2	0.2	0.2

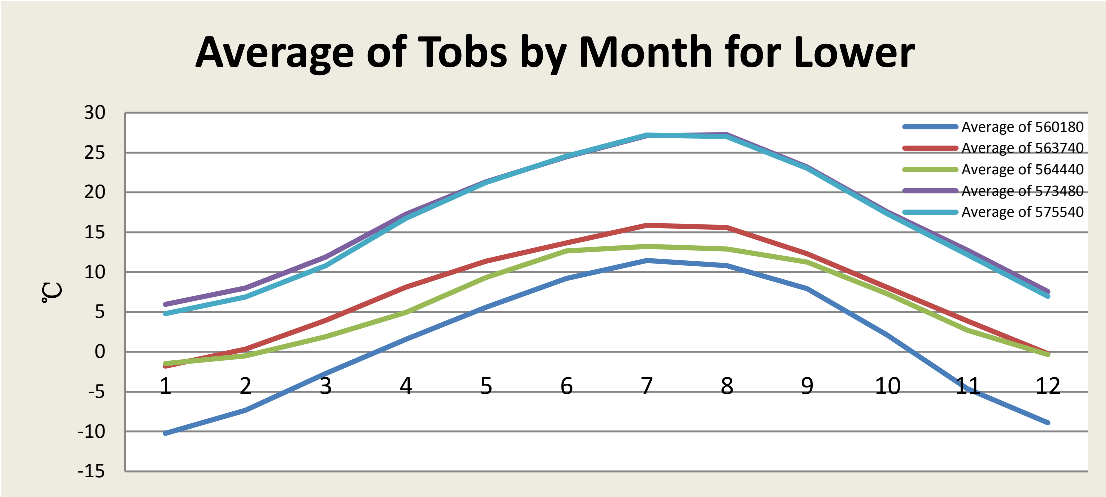


Figure 4.12 Average Temperature of Candidate stations in each month from 1981 to 2011

Some stations have been chosen in former calibration results in Upper and Middle and have different weights in Pobs and Tobs. But the results of Upper and Middle are obtained based on assumptions and climate study. So those candidate stations are not surely the representative of real condition in each subarea.

By using the excel evaluation for each subarea, the candidate stations for Lower area are those stations with average value either in precipitation or temperature of each subarea and the weight of each candidate stations is the same at 0.2. This is a new assumption that each candidate station with the mean value of each subarea can stand for the meteorological situation there.

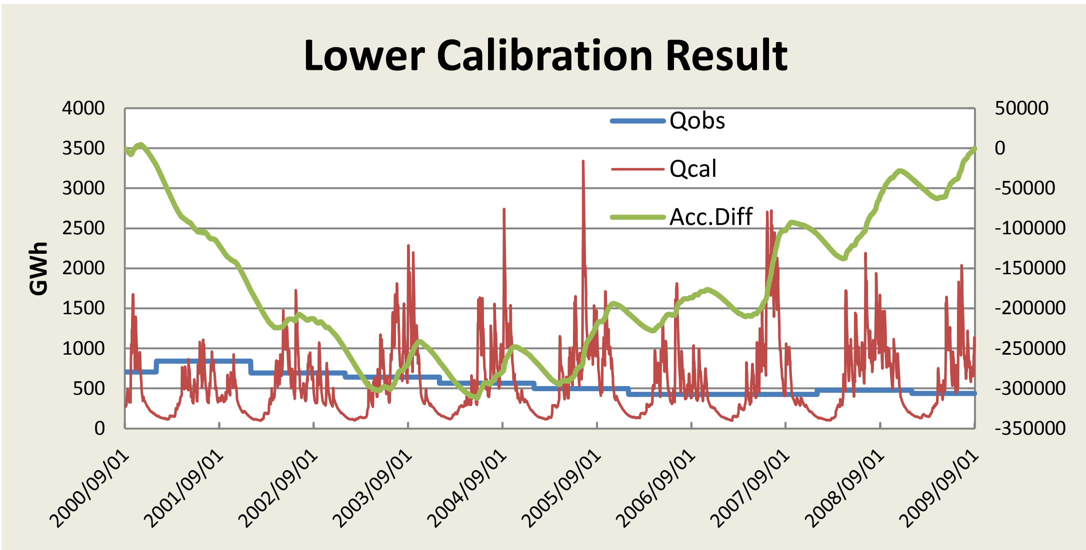


Figure 4.13 Calibration result of Lower area.

Calibration result of Lower subarea is shown in figure 4.13.

Still, there is not too much information from the graph and objective functions. But there is one problem can be seen from the graph, Qcal and Qobs did not follow the same trend. From 2001 to 2005, it is quite obvious that Qobs gradually decreases when Qcal seems to increase gradually. This kind of contradiction did not appear in Upper and Middle subarea. There are some possible reasons for this phenomenon.

First, because of lacking target value data, the data used as Qobs in Lower subarea might not be representative of the real situation.

Second, the meteorological input data Pobs and Tobs are not perfectly match with the real condition, neither their weights in the input data. One possible test for this problem is to evaluate all 56 stations in study area. With the evaluation result, it might be able to see the whole area's precipitation trend. The evaluation result is shown in figure 4.14

In the evaluation result, it can be seen that the sum up of precipitation in 56 stations show the similar trend as Qcal that it has a small increase from 2001 to 2004, then decrease in 2005 and 2006 followed by an increase again in 2007 and 2008. So, the contradiction in Lower area might come from the target data.

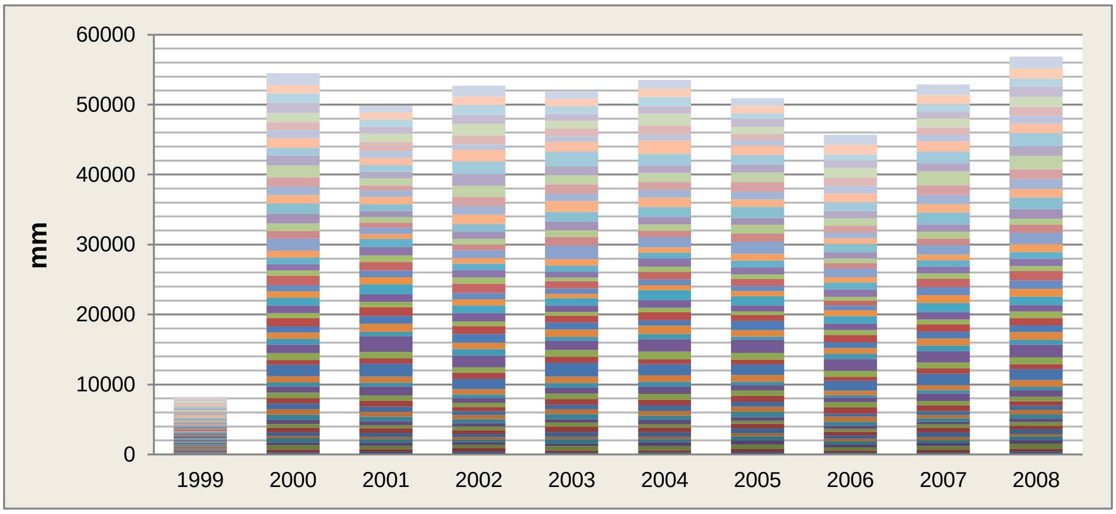


Figure 4.14 Precipitation result for 56 stations

For the snow pack condition in Lower subarea, it can be seen from figure 4.15 that snow pack in Lower subarea is much smaller than Upper and Middle. From the climate study, it can be known that most parts of the Lower Area are warm with heavy precipitation. The snow mainly appears in those areas in the upstream, like Gan Su or Yun Nan province.

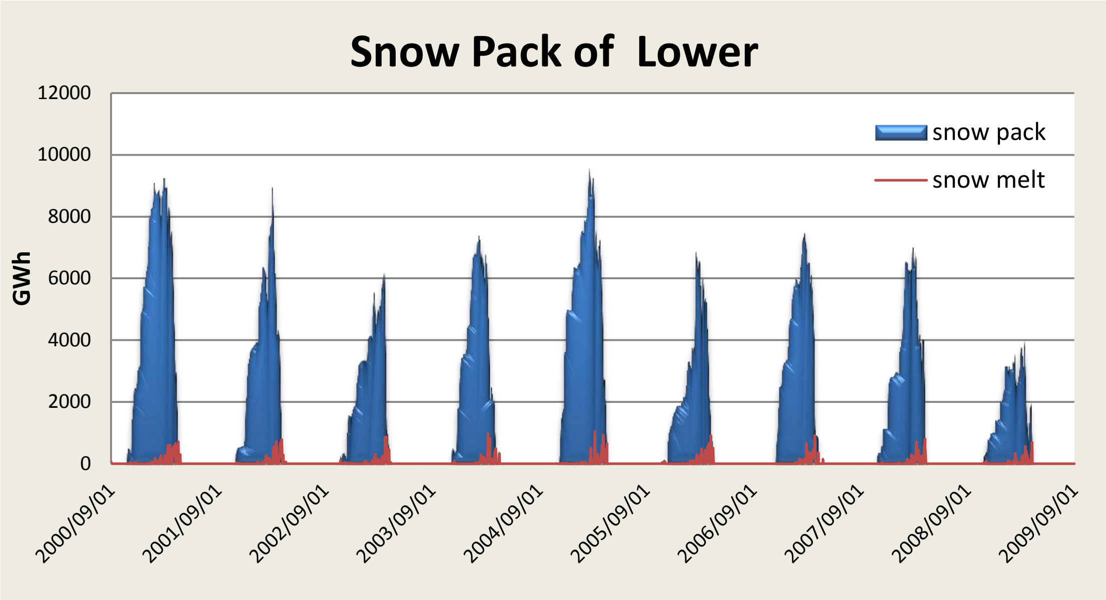


Figure 4.15 Snow Pack of Hind Area.

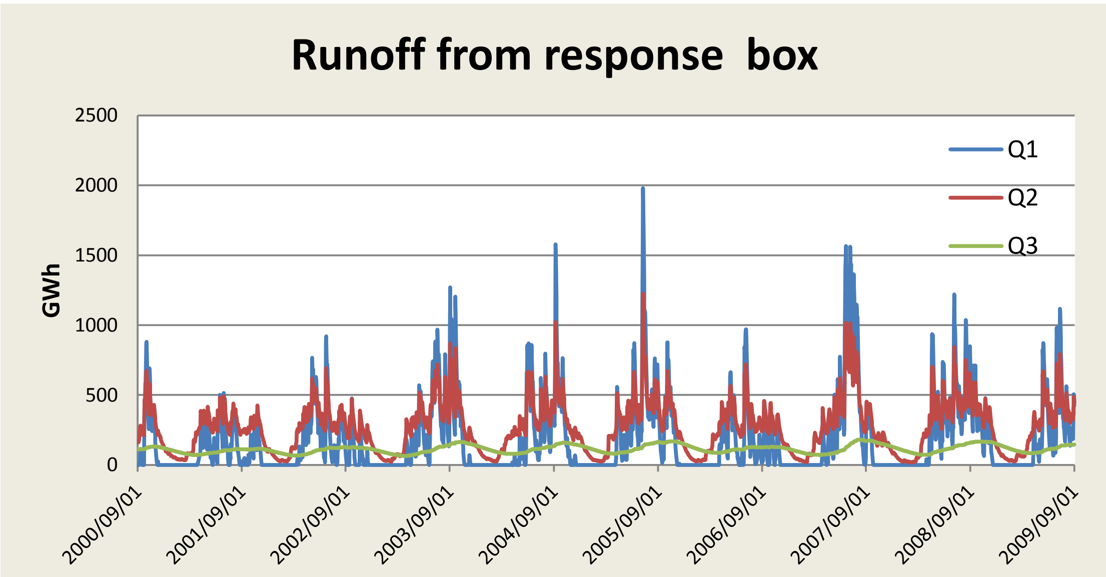


Figure 4.16 Runoff from response box of Lower Area.

The runoffs in Lower subarea are higher than those in Middle and Upper. From figure 4.16, it can be seen that the peak value of quick flow Q1 sometimes approaches

2000 GWh. Because, in Lower subarea, it is supposed that water comes from the whole watershed area. This is also the reason stations throughout the whole study area are chosen for input data. The relationship of runoffs in Lower subarea is reasonable according the calibration result shown in figure 4.16.

5. Conclusion

In this degree project, HBV-TR model is tried to be utilized in Yangtze River Basin for energy inflow prediction. Raw data collection and parsing are done before model calibration. After calibration, some useful information can be drawn from model results.

Model calibration, which is restricted by high resolution data deficiency, changes from the most time consuming part to a relatively easy task. Most time was taken by raw data collection and manipulation.

The calibration results either in graph or numbers are not good enough compared with normal cases. So, forecasting and prediction from the model will be impractical. But still some useful conclusion can be drawn from them. In Upper subarea, the GWh parameter for calibration stays at 15.02 which is a relatively low value. The daily average hydropower stays at 8—20 GWh when the peak value appears in summer time around 30—50 GWh. For the whole year in 2009, the hydropower production of Upper subarea is around 3 TWh. When comes to Middle subarea, the GWh parameter rises to 74.551 which obviously indicate that this area has much more stations and bigger installed capacity. The daily average hydropower is 200—300 GWh and the peak value also appear in summer time around 800—1000 GWh. For the whole year in 2009, the hydropower production of Middle subarea is around 106 TWh. In Lower subarea, the GWh parameter soars to 229.975 which illustrates the huge hydropower generation in this area and the daily average hydropower generation is around 400—850 GWh. Peak value still appears in summer time at 1500—2000 GWh. In 2009, the hydropower production of Middle subarea is around 160 TWh. Combining with the background study, it can be known that in Upper subarea, the installed capacity still stays at a low level because of the small amount of precipitation. In Middle and Lower subarea, rich precipitation adding hydro-profitable geological condition and of course current existing massive hydropower stations give these two areas huge hydropower production and also great potential in the future for further development.

This project gives out a rough overview of hydropower condition in upstream and midstream area of Yangtze River Basin. As a model, the accuracy is far away for commercial use. And it is also hard to say this model is adaptable or not for Yangtze River Basin from current model results. Some people use HBV-TR model in Tibet, in Dongkemadi River Basin to simulate the total runoff, the glacier runoff and glacier mass balance and get good results, calculated result fits well with the observed value. (Gao, He, Ye and Pu, 2012). However, situation in Yangtze River Basin is different with more precipitation, higher temperature and less snow and glacial. So, in order to test the adaptability of HBV-TR model in Yangtze River Basin, more and higher resolution data will be helpful.

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