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Application of Scania-HBV Model for California Hydropower

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NOTICE

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Abstract

The Scania-HBV model has been used for modeling hydropower generation of California, USA. California is a state with considerable meteorological and hydrological diversity, meanwhile with a total capacity of 14116 MW of 386 hydroelectricity generation units with capacity larger than 0.1 MW, California is the USA's second largest state on hydropower. For such a giant hydropower state, prediction of hydropower generation could yield big profit in the energy market, and the well developed Scania-HBV makes this prediction possible. However, as a conceptual model, Scania-HBV has to be adapted for individual situation, and thus model calibration and validation are compulsory for a reliable prediction. Meteorological and hydrological data together with generation data from 1981 to 2006 were collected, and used for calibration and validation of the model. The state was divided into three sub-regions that were modeled individually. Satisfactory calibration and validation results were achieved in northern (($r2_{calibration}=0.72$, $r2_{validation}=0.60$) and middle (($r2_{calibration}=0.70$, $r2_{validation}=0.61$) region; results for the southern region were slightly disappointing ($r2_{calibration}=0.60$, $r2_{validation}=0.50$) due to highly regulated hydropower system. Evaluation for the whole state also showed acceptable result ($r2_{calibration}=0.77$, $r2_{validation}=0.72$).

Keywords: California, hydropower, Scania-HBV, calibration

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Abbreviations

AF: Acre-feet
CFS: Cubic feet per second
MW: Megawatt
MWh: Megawatt hours
GWh: Gigawatt hours
TWh: Terawatt hours

Acronyms

CDEC: California Data Exchange Center
CDFG: California Department of Fish and Game
CEC: California Energy Commission
CGS: California Geological Survey
CWSC: California Water Science Center
DBW: California Department of Boating and Waterways
DWR: California Department of Water Resources
EIA: U.S. Energy Information Administration
FERC: Federal Energy Regulatory Commission
GHCN-Daily: Global Historical Climatology Network Daily
GOSIC: Global Observing System Information Center
GSOD: Global Summary of the Day
IID: Imperial Irrigation District
IOU: Investor-owned utilities
LADWP: Los Angeles Department of Water & Power
NCDC: National Climate Data Center
NOAA: National Oceanic and Atmospheric Administration
PG&E: Pacific Gas and Electric Company
SCE: South California Edison Company
SMHI: Swedish Meteorological and Hydrological Institute
USBR: U.S. Bureau of Reclamation
USCB: U.S. Census Bureau
USGS: U.S. Geological Survey
WRCC: West Regional Climate Center

1 Introduction

1.1 Background

Electricity is indispensable to life nowadays, and electricity can be generated by gas, nuclear, coal, wind and running water. Hydroelectricity, especially, is an essential part for California's power system. Its capacity on peaking reserve, load following and extremely low production cost have made hydropower an unneglectable component of the state's power market (McKinney, 2003). The potential generation capacity of hydropower system is partly natural-dominated as the availability of water is affected by precipitation and temperature significantly, and this effect makes it possible to forecast hydropower generation through the rainfall-runoff model. Moreover, the well forecasted generation can be of extremely valuable information to the energy market.

This project calibrates the conceptual rainfall-runoff model – Scania-HBV model for California. The main tasks are to test the adaptability of Scania-HBV in California through model calibration and validation, and for the forecasting of the state's hydropower generation.

1.2 Method

The basic information including location, capacity and operator of individual hydropower facilities were exploited on internet, and every hydropower plant was marked on Google Earth according to its latitude and longitude.

Daily meteorological data (precipitation and temperature) of 1981-2006 is required for simulation of the inflow. Almost 400 meteorological stations of California were exploited from sites on internet. These stations were plotted on Google Earth according to their latitude and longitude. The program EPoint2GE provided by Zonum Solutions (http://www.zonums.com/) was used to convert hundreds of coordinates into a point layer in Google Earth. Eleven stations with appropriate location and completed recording were finally used in Scania-HBV, and their recording of daily temperature and precipitation from 1981 to 2006 were collected through internet.

Scania-HBV simulates runoff in the energy unit (Gigawatt hours), thus the target data which is going to be calibrated against should have this energy unit as well. As there is little flow data provided in energy unit in California, certain conversion for the power system are required. According to this, the California hydropower facilities were divided into two categories - storage and run-of-river. Storage facilities are those that run by stored water in reservoirs of varying size, and the run-of-river plants refer to those that do not have significant storage and are run by river flow directly. For storage hydropower plants, daily storage in AF (Acre-feet), daily discharge in CFS (Cubic feet per second) and monthly generation in MWh (Megawatt hours) of 1981-2006 were collected through internet and converted to inflow in MWh. For run-of-river hydropower facilities, daily discharge in CFS and monthly generation in MWh of the same period were collected, the generation data was distributed according to daily discharge and then taken as daily inflow data in the calibration process.

Finally, based on geological and meteorological conditions, California was divided into three sub-regions. Each sub-region was calibrated and validated individually. Simulated results of each sub-region were also added together and evaluated by several objective functions.

1.3 Objectives

This project aims to calibrate Scania-HBV for California which will be used for forecasting of hydropower generation. Therefore, based on the understanding of California hydropower system and sets of well arranged data, reasonable results of model calibration and validation are expected.

2 Background of California

According to the 2008 Statistical Abstract of U.S. Census Bureau (USCB), the total area of California amounts to 403 933 km^2. The state's mean elevation is approximately 885 meters, with the highest point on Mount Whitney of 4 419 meters and lowest point in Death Valley of -86 meters. Located on the west coast of USA, the state extends from 32.5° to 42° N, and 114° to 124.5° W. According to California Geological Survey (CGS), the state is divided into eleven geomorphic provinces as shown in Figure 2.1.

The first topographical division of California is the Coast Ranges. The Coast Ranges is a comparatively gentle range in California. With a series of northwest-trending mountains and valleys, the average elevation ranges from 610 to 1 220 m above sea level. The Coast Ranges rose up along the seashore of Pacific Ocean and act as a natural barrier of Pacific and the inland California.

Another great range in California is Sierra Nevada. Sierra Nevada is a tilted block mountain range with high rugged cliff on east face and gentle slope on west; meanwhile there are a lot of deep canyons cut through the west slope. Sierra Nevada is the state's largest and highest mountain range. The range stretches 650 km and gradually increases from north to south. The extraordinary height makes this part the main field for permanent snow on top of mountains.

Between Coast Ranges and Sierra Nevada lies the Great Valley. The Great Valley is an alluvial plain and is much lower than the ranges around it. This low-relief landscape trough mainly consists of Sacramento Valley at north and San-Joaquin Valley at south.

Besides these identifiable Californian geomorphic provinces, there are several other landscape areas which complete the state's topography. In the north, Klamath Mountains, Cascade Range, Modoc Plateau and Basin & Range make up a mountain-valley-mountain pattern. The ranges peak up to 1 220 to 2 440 m above sea level at some place, while are transected by deep canyons at other places. Two of the state's major volcanic peaks, Mount Lassen and Mount Shasta are in this region.

In the south, Transverse Ranges and Peninsular Ranges consist of series of east-west trending steep mountains and northwest trending valleys. The Transverse Ranges, especially, is one of the most rapidly rising regions on earth. Further inland, the Mojave Desert is composed of low-lying mountains and fairly flat desert plains. Abounded by these provinces is the Colorado Desert which is about 74.7 m below sea level in some part and is one of the lowest regions of California.

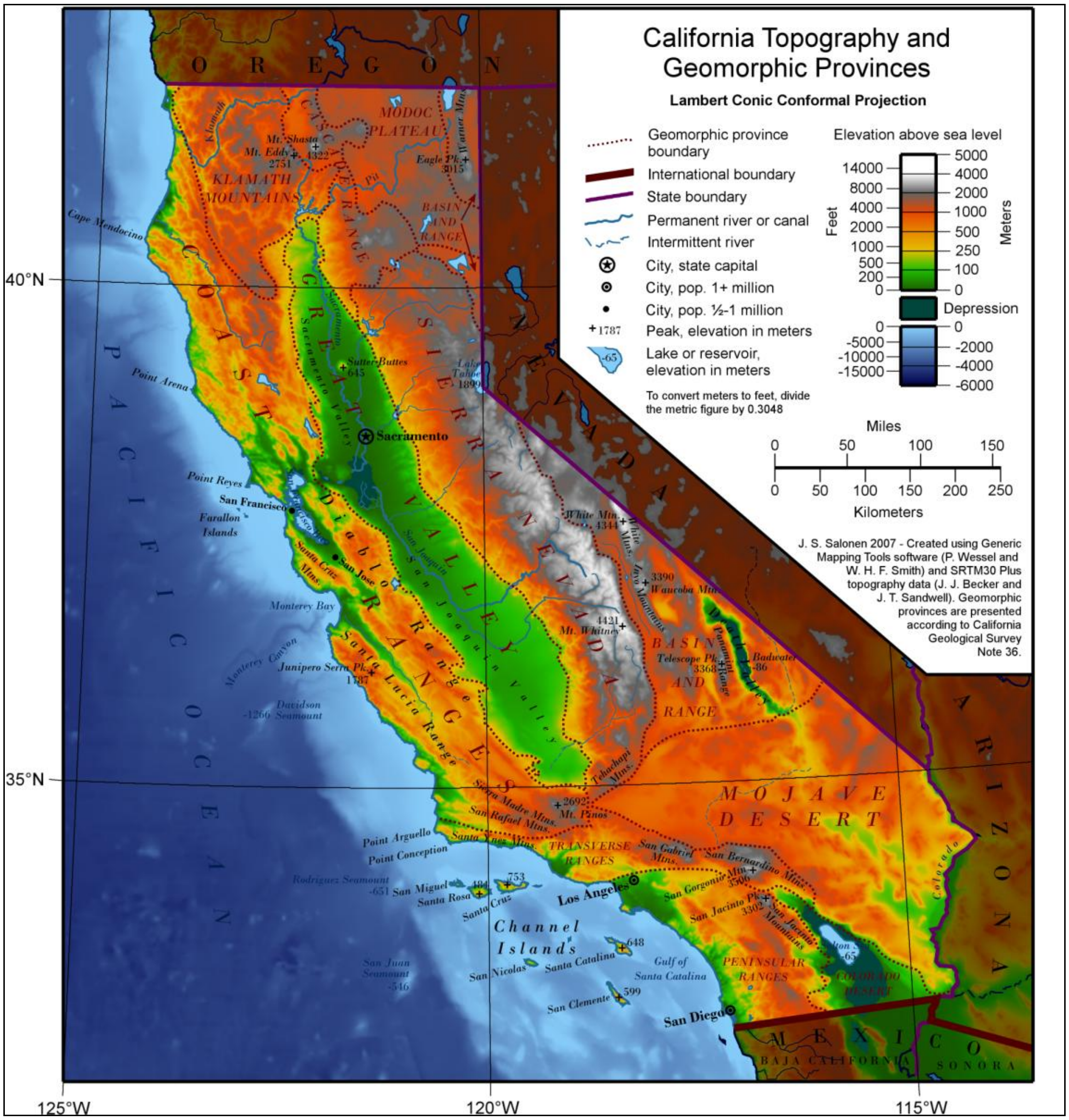


Figure 2.1: California topography and geomorphic provinces (Salonen, 2007). The eleven geomorphic provinces are: Coast Ranges, Klamath Mountains, Cascade Range, Modoc Plateau, Great Valley, Sierra Nevada, Basin & Range, Peninsular Ranges, Transverse Ranges, Colorado Desert and Mojave Desert.

2.1 Meteorological Condition of California

The meteorological condition of California is as varied as its physical condition and is too much diverse to be considered as a whole. Based on the Köppen Classification System, there are five major climate types in California (Kauffman, 2003). California climate map according to this classification is shown in Figure 2.2.

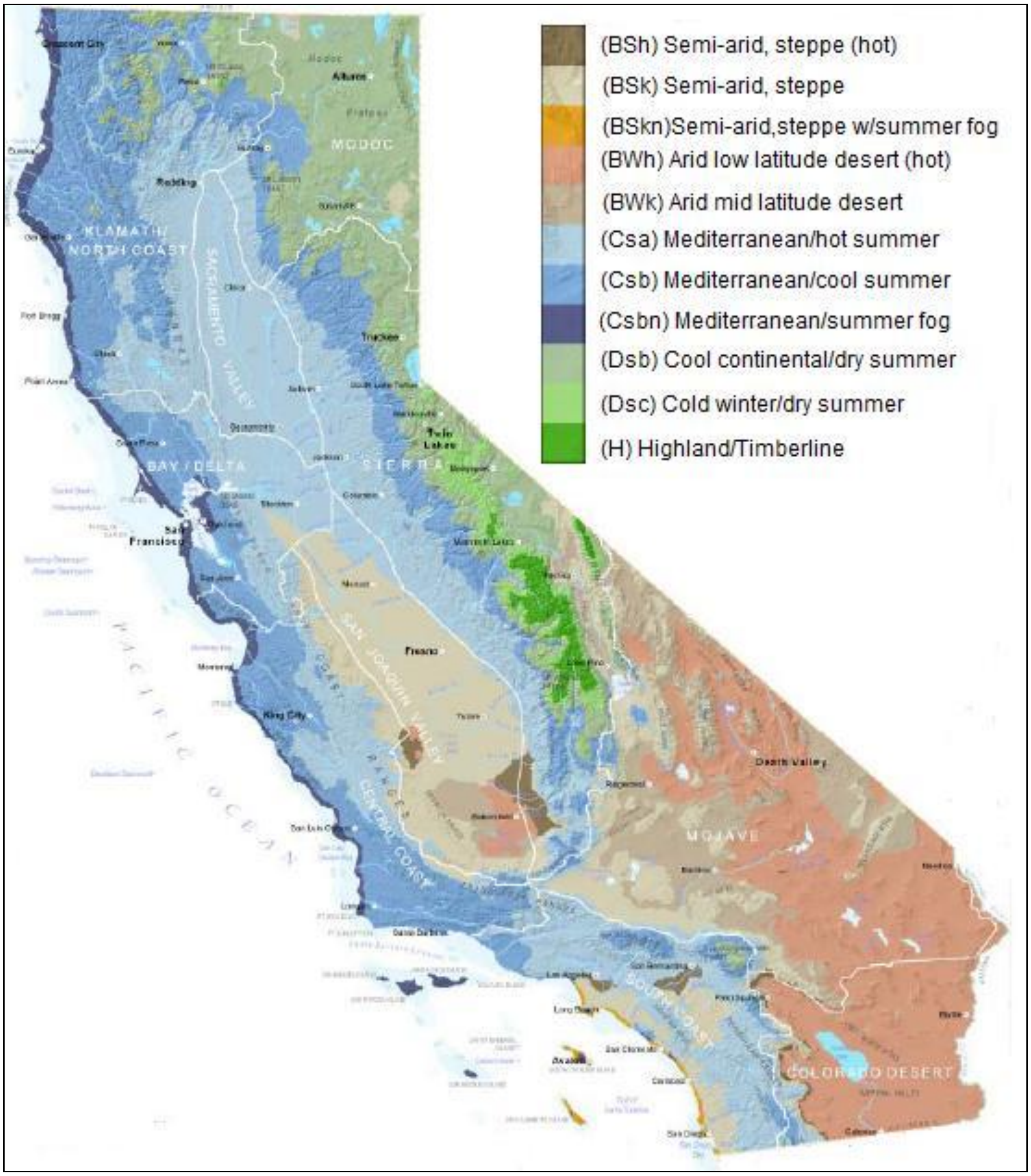


Figure 2.2: California climate map based on the Köppen Classification System (Source: CDFG)

The Cascade Ranges, Klamath Mountains, Coast Ranges, northern Great Valley, western Sierra Nevada, part of Transverse Ranges and Peninsular Ranges are distinguished with the Mediterranean Climate. Accordingly, these regions have modest temperature and variable wet weather, and most of the rain precipitates in winter rather in summer (McKnight & Hess, 2000). More specifically, Cascade Ranges, Klamath Mountains, western Coast Ranges and western Sierra Nevada have a kind of Mediterranean Climate with both cool summer and cool winter. However, northern Great Valley and the southern ranges have a kind of interior Mediterranean Climate with hotter summer and cooler winter.

The other side of Great Valley, which is dominated by the San Joaquin river basin, possesses semi-arid climate. The precipitation of this region is less than potential evaportranspiration and is characterized by middle latitude climate (Mcknight & Hess, 2000).

The east and north-east of California are featured by continental climate, especially the high latitude continental climate. Normally, these interior climate have an average temperature higher than 10°C in the warmest month, and lower than -3°C in their coldest month. It is usually dry in summer and wet in winter (Mcknight & Hess, 2000).

As expected, the Mojave Desert and Colorado Desert hold arid low latitude desert climate. Not only the potential evaportranspiration exceeds average precipitation, but also the average annual temperature is higher than 18°C (Mcknight & Hess, 2000).

When it comes to the state precipitation trend, the greatest influencing factor is the frequent movement of moisture air from northeast Pacific towards southeast. While a stable high-pressure center off the west coast of Mexico always blocks the southward movement of moisture-laden air, and forces the precipitation-producing system moving eastward onto shore. This blocking system usually moves to north during summer and to south during winter (Birdsall & Florin, 1998). As a result, average precipitation tends to decrease from northwest to southeast. As shown in Figure 2.3, The Sierra Nevada and northern part of Coast Ranges have plentiful year-round precipitation. On the other hand, the southeast California is a broad region of desert environment which receives pitiable precipitation annually. Besides, the central valley and northeast California are also regions with moderate precipitation.

Precipitation also shares a significant seasonal variation in most of California. Summer is a dry period over most of the state, and California seldom receives precipitation from Pacific storms during this time of year. As shown in Figure 2.4, precipitation decreased dramatically in June, July, August and September, while on average 95% of the annual rainfall precipitated between October and May. The only exception to the summer drought is in the southeastern deserts. In this area the moist air drifts northward from the Gulf of Mexico or Gulf of California, and cause locally moderate or heavy showers in June and August (Michaelsen, 2008).

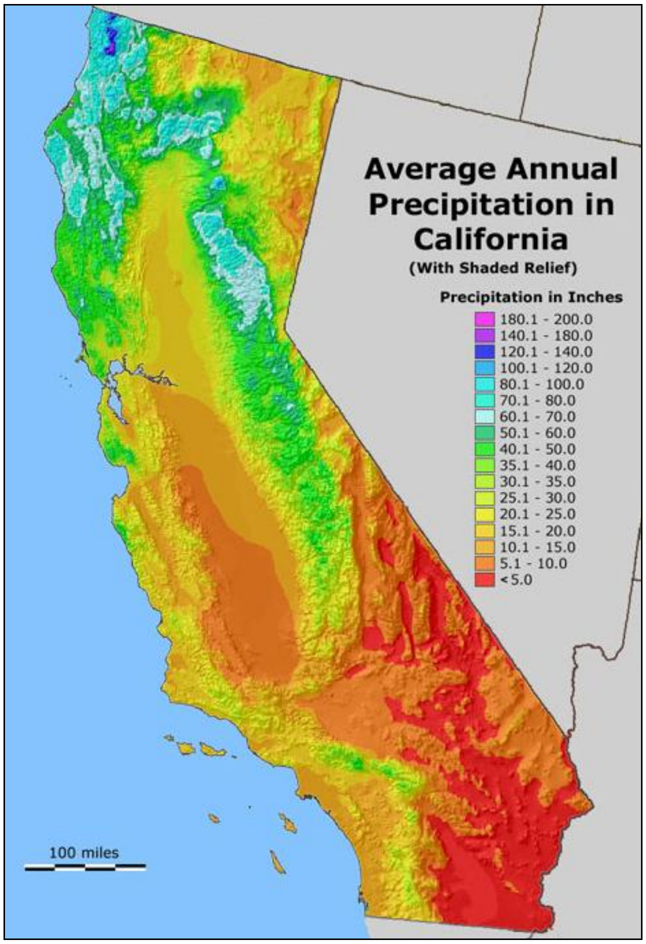


Figure 2.3: Average annual precipitation map of California (Source: USGS)

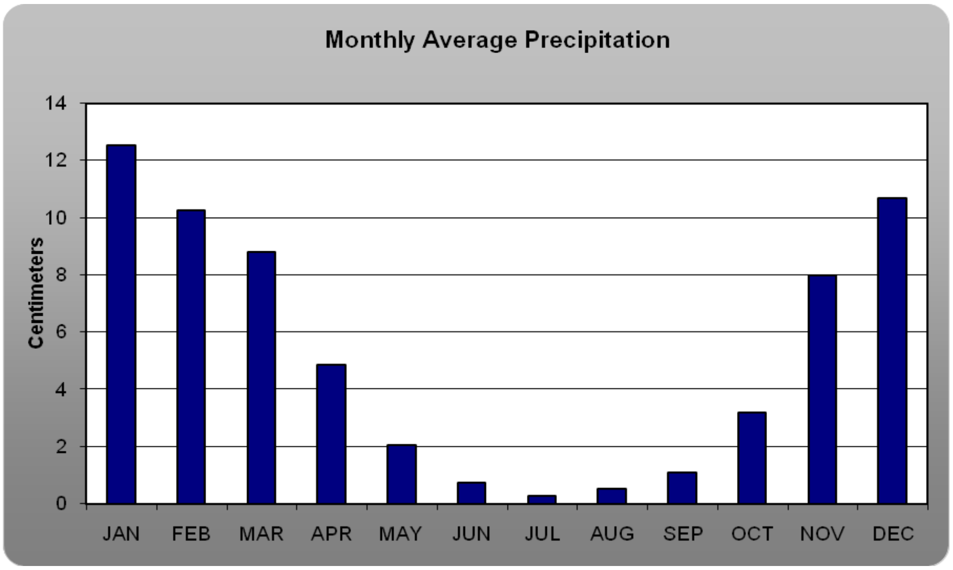


Figure 2.4: Monthly average precipitation of California (Source: WRCC). The data is an average of 827 stations across California with monthly precipitation recording of 1913-2007.

Temperature also shows a great variability across the state. In general, temperature decreases from south to north with increasing latitude, and also decreases fairly rapidly with increasing elevation (Michaelsen, 2008). However, the state's temperature is mostly influenced by maritime effect. With this effect, the coastal location shows a moderate temperature variation daily and annually, while at the rest area temperature reaches extreme values of either hot or cold. As shown in Figure 2.5, temperature varies from mild in coast and south to cold inland in January. And it is in the Sierra Nevada, high elevation area of the Coast Range and the Cascades that snow accumulated and remains on the ground each winter. In summer, coast and mountain region share moderate temperatures while the southeastern desert areas are very hot. Because the oceanic influence which is especially strong in summer, the differences between coastal and inland points at similar latitude are fairly dramatic in summer (NOAA, 1985).

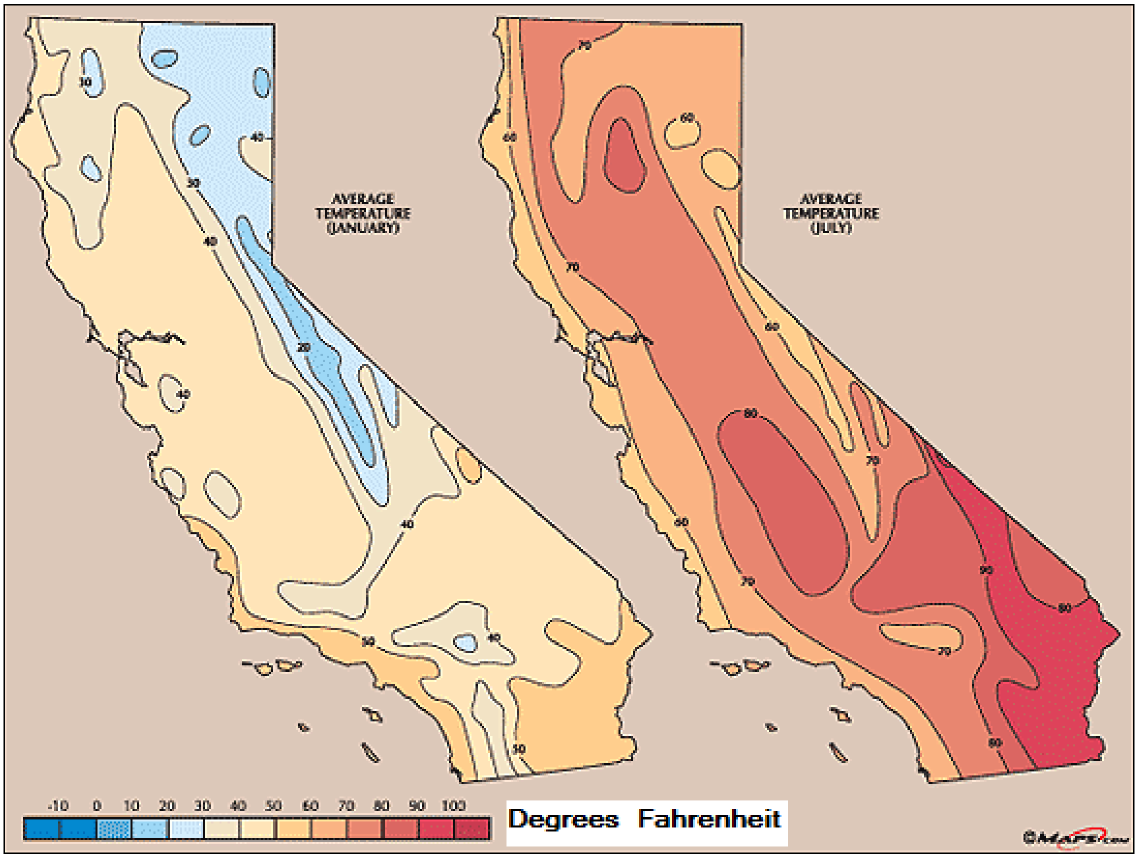


Figure 2.5: California average temperature map for January/July (Source: http://www.maps.com). The left one shows average temperature in January while the right one denotes temperature of July.

2.2 Hydrological Condition of California

California is a state blessed with abundant water resource, and the water system is fairly complex in its details. Figure 2.6 shows the major streams and lakes of California.

Figure 2.6: Map of California's major rivers and lakes (Source: www.geology.com)

The river system concentrates in northern and middle California, and the major streams like Sacramento, San Joaquin, Salinas, Russian, Eel, Klamath and Trinity River drain into Pacific Ocean. In north, the Sacramento River which starting in the Cascade Range flow through the Great Valley and drains to Pacific Ocean at San Francisco Bay. Sacramento is the longest river of California, and is mainly attributed by Pit, Feather, McCloud and American rivers. The Pit River which cut through the deep canyon of Cascade Range is the longest tributary, while Feather and American rivers carry larger amount of water (DBW, 2007). In southern Great Valley, the San Joaquin River which originates on the western slopes of the Sierra Nevada flows northwest to the Sacramento-San Joaquin Delta Valley and enters Pacific at San Francisco Bay at last. San Joaquin River is the state's second-longest river and is mainly attributed by Merced, Tuolumne, Stanislaus, Calaveras, Mokelumne and Consumnes River (Snow et al, 2005). Besides the rivers of San Joaquin River Basin, there are Kings, Kaweah, Tule and Kern River in middle California. In south California, there are only several small rivers flow through the coastal mountain region, and only one big river-Colorado River flows through the desert border region. Figure 2.7 highlights the major stream systems of California.

Map courtesy of California Department of Water Resources.

Figure 2.7: Map of major rivers of California (Source: DWR)

The prime source of water in California is precipitation originated from the North Pacific Ocean associated with snow melt (Farrara & Jin, 2001). More than 70% of the state's annual runoff originates from northern Sacramento. And on average, about 75% of the state's average rainfall precipitates between November and March, of which half falls between December and February (Stroshane, 1999). These facts have obvious influence on the northwestern streams. Such streams like the Eel and Klamath River are large streams which drain through broad basins, and it takes a long time for the flood building up in these basins. While the rivers of Sierra Nevada and Cascades, which originate from high mountain region, always affected by the heavy rainfall or snowmelt, or by a combination of them. And normally the snowmelt takes place from April to June, and it is at this time that the flood occurs. In the extreme southern part, most floods are the result of heavy shower originates from Gulf of Mexico or Gulf of California during June and August (NOAA, 1985).

Besides these natural water bodies, California is also rich of artificial water substances. And most of the man-made reservoirs and aqueduct work together as a whole system, which benefit the agriculture, hydropower and urban water supply by factitious regulation. These substances, like the Whiskeytown Lake, Trinity Lake, Stempede Lake, Central Valley Project, California Water Project, Los Angeles Aqueduct and Colorado River Aqueduct, are considerably huge water resource projects, and have significant influence on the state's hydrological condition. The major water projects of California are shown in Figure 2.8.

Figure 2.8: Major water Projects of California

2.3 Hydropower System of California

With plentiful resources of water, California's hydropower system became the second largest one among all the USA states, just behind the state of Washington. According to the California Energy Commission (CEC), there are 386 hydroelectricity generation units ranging from 0.1 MW to 1000 MW in capacity, Figure 2.9 illustrates the distribution of hydropower plants with capacity no less than 0.1 MW in California. The hydropower is a non-negligible part of the state's power system. Over the last twenty years, the electricity provided by hydropower fluctuated between 9% and 30% of annual state generation (McKinney et al., 2003). Figure 2.10 gives the annual generation of hydropower in contrast with the state's total electricity generation across 1983-2006.

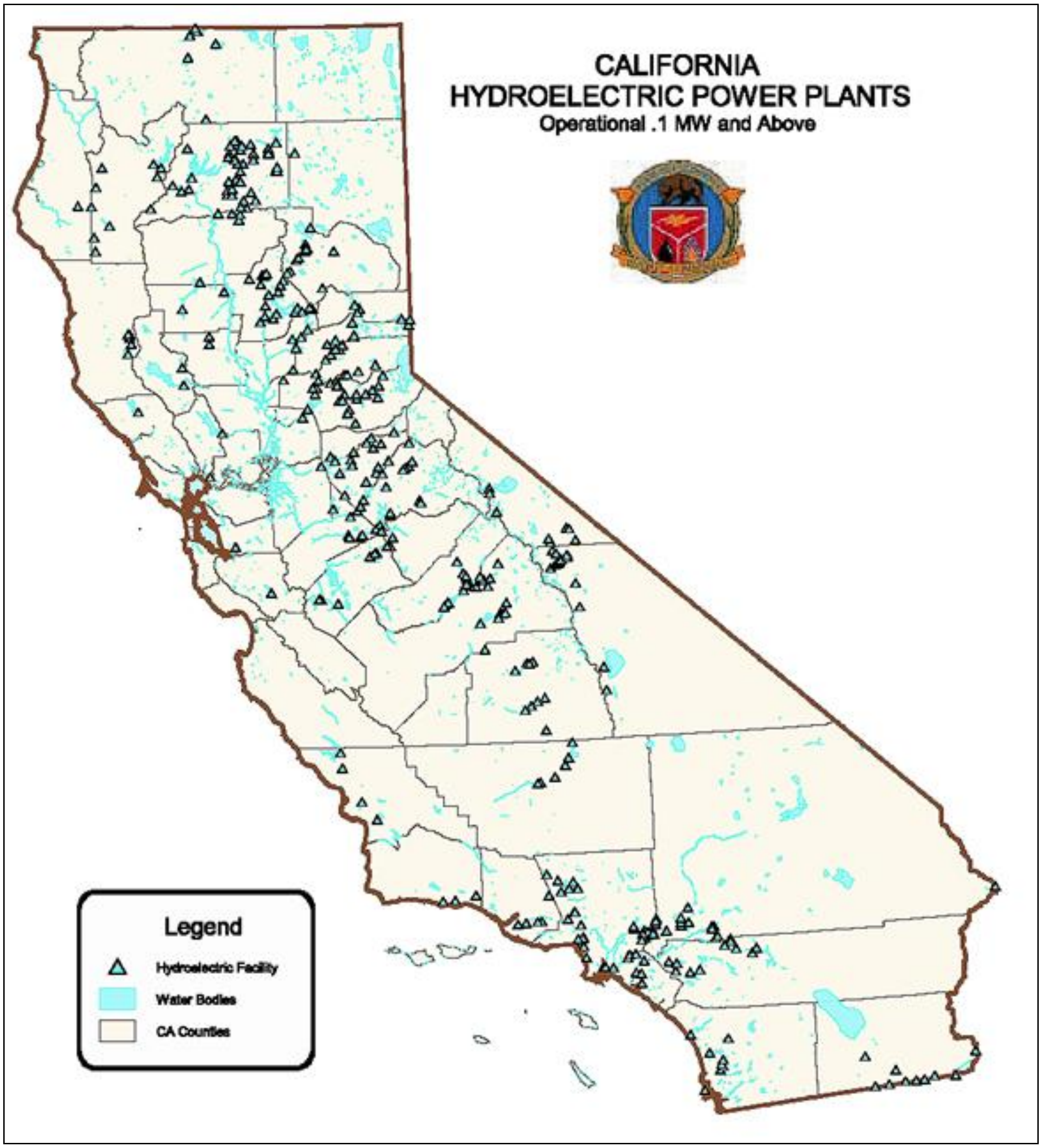


Figure 2.9: Map of California hydroelectric power plants (operational capacity 0.1 MW and above) (Source: CEC)

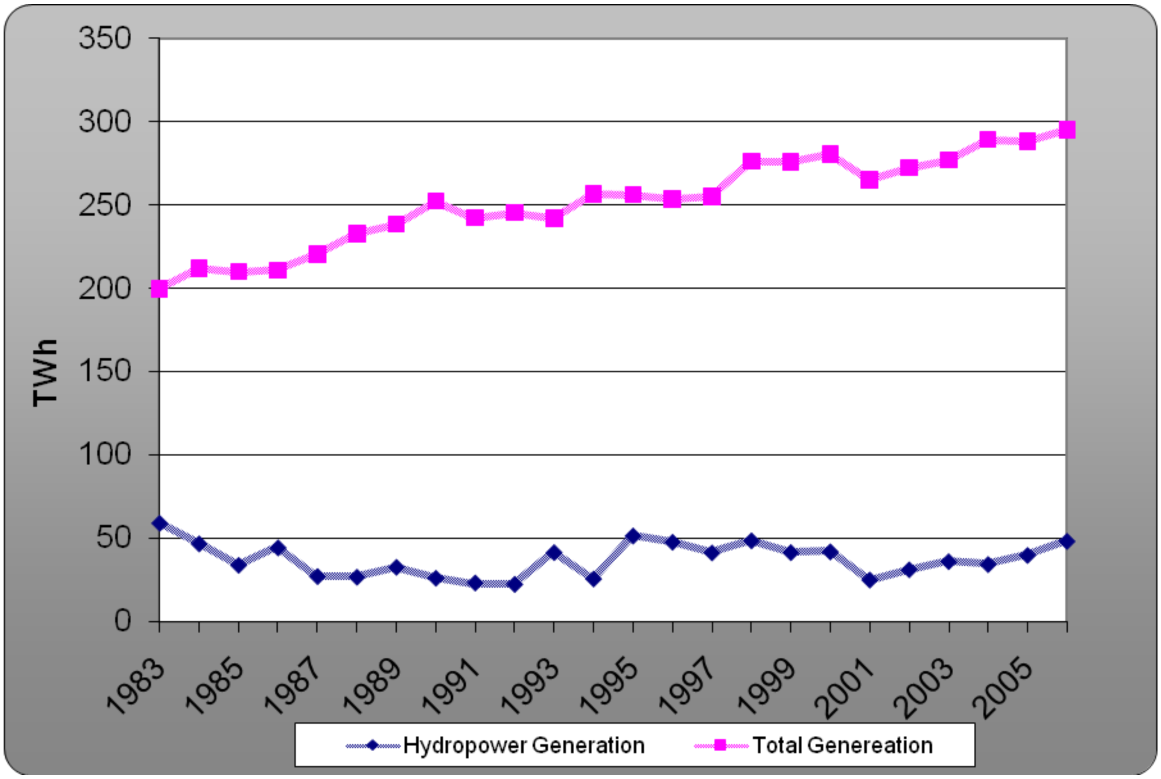


Figure 2.10: California annual total electricity generation and hydropower generation of 1983-2006 (Source: CEC)

The state's hydropower plants are operated by different utilities under the regulation of Federal Energy Regulatory Commission (FERC). In total, California has 14 116 MW of hydropower capacity out of 55 800 MW of electricity production capacity. The Investor-Owned Utilities (IOU) operates about 5 059 MW of this capacity. Municipal utilities and irrigation districts operate 4 972 MW, while the state and federal water projects hold about 3900 MW. The remains of the capacity consist of small projects with various private and public owners (McKinney et al., 2003). Table 2.1 shows ownership of California hydropower and the share capacity of main holders. However, this data is not totally dependable. As the CEC provides another file of plant list in California, of which the sum up of hydropower plants is 343 plants with total capacity of 13057 MW. And the U.S Energy Information Administration published a data of 10 083 MW hydro conventional power capacities in 2006. The data from McKinney's report gave a general profile of California hydropower of 2003.

The space distribution of California hydropower capacity varies significantly. In the region of Cascades Range and Sierra Nevada, especially on rivers like the Feather, Pit, American, Mokelumne, Stanislaus and San Joaquin, multiple hydropower plants are linked together and operated as unified systems with total capacity up to 700 MW or higher. The rest of California is distributed with small and mid-sized hydropower projects (McKinney et al., 2003).

The generation of hydropower plants also varies due to purposes of the projects. Some hydropower facilities are the primary consideration of the project, although the project may be responsible for water supply, flood control and recreation at the same time, it is still scheduled to meet load and has a comparably stable generation over the year. Most of IOU hydropower plants are of this kind. While for the State Water Project and the Federal Central Valley Project, power generation is taken as an ancillary purpose, and has to occasionally give way to water supply or flood control. This kind of facilities maybe giant in capacity but the generation is not steady (McKinney et al., 2003).

Table 2.1: Hydropower ownership in California (McKinney et al., 2003)

Owner Type	Owner	Capacity(MW)		Percentage
Investor Owned Utilities (IOU)			5059	35.84%
	Pacific Gas and Electric Company	3896		27.60%
	Southern California Edison	1163		8.24%
State/Federal Utilities			3875	27.45%
	U.S Bureau of Reclamation (Central Valley Project)	2355		16.68%
	California Department of Water Resources (State Water Project)	1520		10.77%
Municipal Utilities			4972	35.22%
	Los Angeles Department of Water Resources	1761		12.48%
	Sacramento Municipal Utility Dist	688		4.87%
	San Francisco City & County of	385		2.73%
	Other Municipal Utilities	513		3.63%
Water Districts			921	6.52%
Irrigation Districts			704	4.99%
Others			210	1.49%
Total			14116	100.00%

The state hydropower facilities can be divided into two categories: storage and run-of-river. The storage plants are of more valuable to the market as they help to meet the peak load in dry seasons. With water stored in reservoirs and operated factitiously, the effect of extreme showers and snowfall is slacked down to some extent. The run-of-river plants are facilities with low cost and high yearly variation. With the absence of direct human regulation, the production of these plants varies directly proportional to annual hydrology. The highest generation of these plants normally occurs during the spring snowmelt (McKinney et al., 2003).

3 HBV model

The HBV model was originally developed at the Swedish Meteorological and Hydrological Institute (SMHI) in Norrköping, Sweden in 1970s. After thirty years the HBV has become a commonly used rainfall-runoff model in Nordic countries, and has been applied in many other countries (Bergström, 1992). The application of HBV ranges over hydrological forecasting, water balance mapping, floods design, land use analysis, climate change studies, water quality studies and hydropower generation. Over the latest thirty years, the model has been modified by different agencies and institutes in purpose of individual application, and the model used in this project, the "Scania-HBV" has been developed by Point Carbon AS for sake of the hydropower market. This version of HBV model is featured on calculation of all results from and within the model in GWh from daily rainfall (mm) and air temperature (^{0}C).

The rainfall-runoff model is developed on the basis of general water balance which can be described as (SMHI, 2007):

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

P = Precipitation
E = Evaportranspiration
Q = Runoff
SP = Snow pack
SM = Soil moisture
UZ = Upper groundwater zone
LZ =Lower groundwater zone
lakes = Lake volume

Generally, there are three subroutines in HBV (Bergström, 1992), they are described below and illustrated in Figure 3.1. Compared to the HBV introduced by Bergström, there are several specific changes in Scania-HBV. The area-elevation distribution has been simplified, and there is no land use classification in Scania-HBV. However, the general routines and the conceptual numerical description of hydrological processes in Scania-HBV are similar with the one cited by Bergström.

a) Snow routine: Snow routine accounts for snow accumulation and melt. Below a threshold temperature (Te), the precipitation accumulates as snow. Above the threshold value, snow melts according to a melt rate coefficient (C).

$$SnowMelt = C * \left(T - Te\right)$$

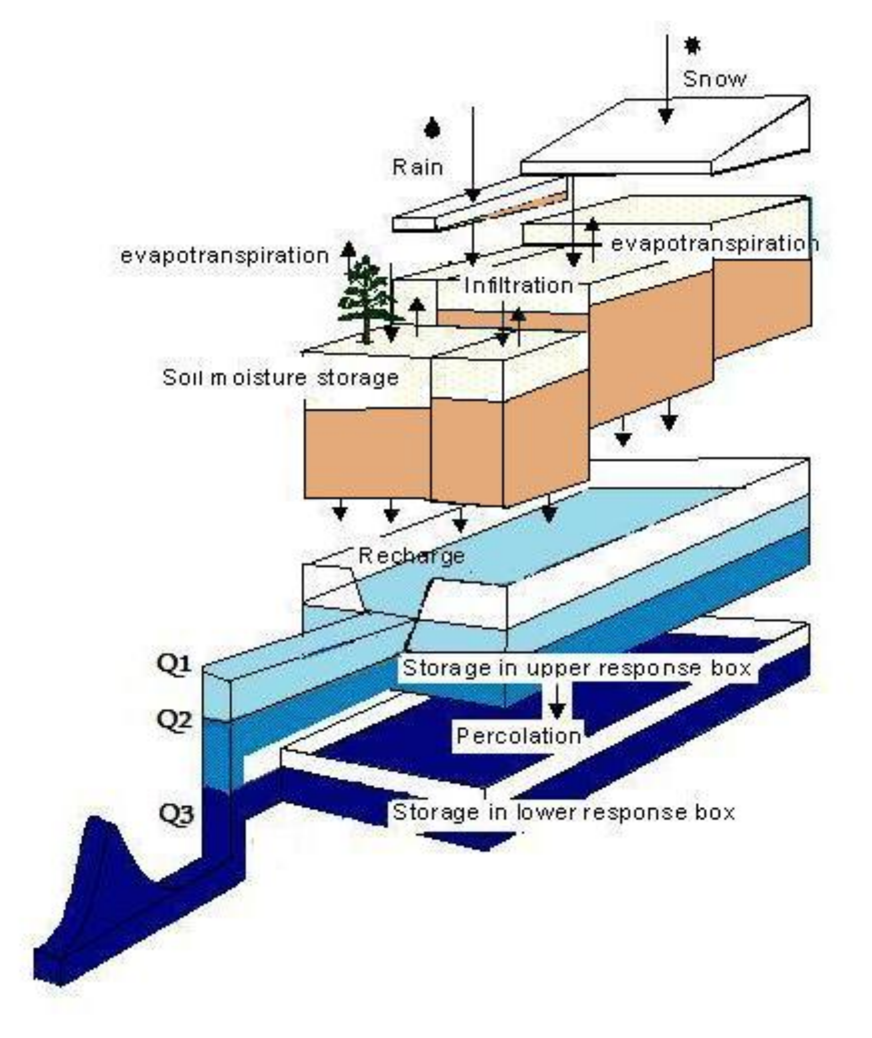


Figure 3.1: Schematic structure of HBV model (Lindström et al, 1997)

b) Soil moisture routine: The moisture of a basin is determined by precipitation, melt snow, evapotranspiration (*E*) and field capacity (*fc*). fc is the maximum soil moisture content, and water will begin to recharge into the ground water zone only when the field capacity is satisfied. The actual evapotranspiration (*E*) is controlled by the actual soil moisture (*hm*). And this is calculated as:

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

Ep: Potential evapotranspiration
hp: Boundary factor for evapotranspiration

c) Runoff routine: Runoff routine transforms excess water from the soil moisture storage into discharge. There are two reservoirs which account for the quick and slow runoff responses of hydro process. The two storage sections are simply illustrated in Figure 3.1, which makes up of one upper reservoir with non-linear routine and one lower reservoir with linear routine. The out flows from these storages are controlled by the water level and threshold level.

$$Q_1 = \frac{hu - hugvPot}{T_1}$$

$$Q_2 = \frac{hu}{T_2}$$

$$Q_3 = \frac{hl}{T_3}$$

hu: Water level of the upper response box
hugvPot: Threshold level of upper response box
hl: Water level of the lower response box
T_1: Recession factor for upper outlet of upper response box
T_2: Recession factor for lower outlet of upper response box
T_3: Recession factor for outlet of lower response box

Based on these routines, the model has a number of free parameters that can be adjusted in calibration. The main parameters used in Scania-HBV are listed in Table 3.1. Model calibration is normally done by manually changing these parameters in a trial and error technique. The model performance is judged by several objective functions. The numerical calibration criteria used in Scania-HBV are listed in Table 3.2.

Table 3.1: Main parameters in Scania-HBV

Name	Explanation
Tcorr	correction factor for temperature
Sfcf	correction factor for snow
Rfcf	correction factor for rain
Te	Threshold temperature for snow melting and refrozen of rain
c	Snow melt rate coefficient
Thorn	Coefficient of evaportranspiration
hp	Boundary factor for evaportranspiration
fc	Field capacity
b	Factor for infiltration
perc	Factor for percolation
hugvPot	Threshold level of upper 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

Table 3.2: Objective functions in Scania-HBV

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

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

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

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

4 Data Collection & Computation

Data is an essential part for calibration and validation, and the quality of data will decide the quality of model result to some extent. As data required is on daily basis from 1981 to 2006, data collection and computation is the most time consuming and complex work in this project.

4.1 Hydropower Plants

According to California Energy Commission (CEC), there are 386 hydroelectricity generation units with capacity bigger than 0.1 MW, of which about 240 plants have capacity no less than 1 MW. These 240 hydropower plants were the main target, and the basic information including plant name, utility name, capacity, location and the relationship with other unit was collected through internet.

However, information gathering is by no means an easy task. As shown in Table 2.1, PG&E and SCE are the giant utilities of the state’s hydropower, but limited information of their plants is freely provided. The municipal utilities, water districts and irrigation districts provide, as well, little information about their plants. Only the California Department of Water Resources (DWR) and U.S. Bureau of Reclamation (USBR) provide details of their plants, however, their facilities just account for approximate 27% of the state’s hydropower capacities. Information about other hydropower units is mainly provided by the California Water Science Center (CWSC) of U.S. Geological Survey (USGS). The annual report of CWSC provides schematics of each river basins of California, including the power station’s location and relationship with other units. Besides, as an agency in charge of hydroelectric licensing, the Federal Energy Regulatory Commission (FERC) also provides some information of individual hydropower plants for replenishment.

As all of these sources seldom publish information on small plants, data collection mainly concentrated on the 240 plants with capacity larger than 1 MW. Every exploited plant was plotted on Google Earth according to its latitude and longitude. Finally, data of 200 hydropower facilities were collected, and they are shown in Figure 4.1. And the generation of these plants accounts for about 80% of the state’s annual hydropower generation.

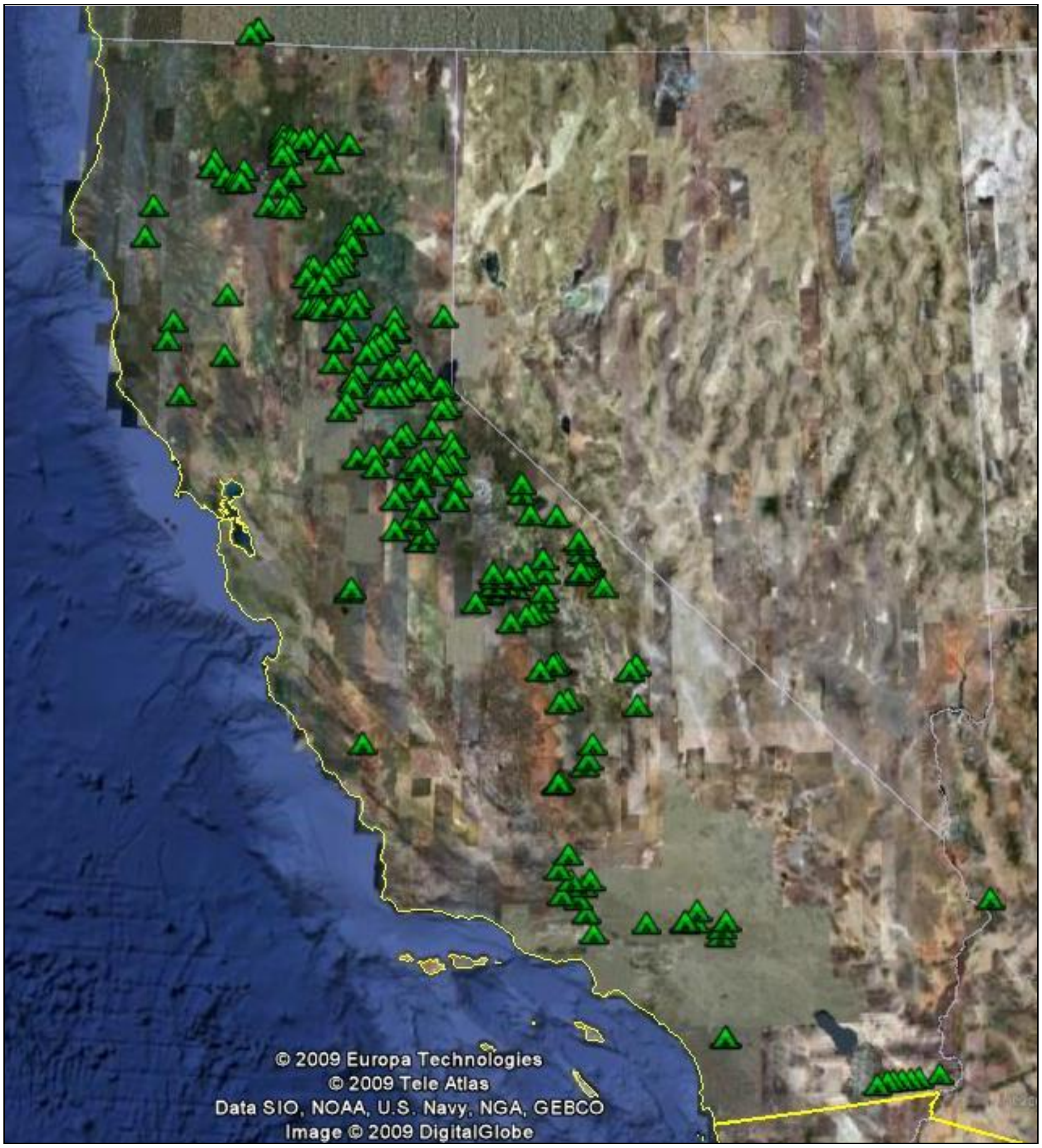


Figure 4.1: Map of California with 200 hydropower facilities extracted from Google Earth. The green points denote hydropower units.

4.2 Division of California

HBV can be used as a semi-distributed model by dividing the catchment into sub-basins, and the basin is divided according to geological, meteorological or hydrological features. And as a big state with considerable variance in geological, meteorological and hydrological conditions, it should be more reasonable to divide California into several sub-regions and calibrate each of them individually. Besides, as a conceptual model for which the simulation respects physical condition of catchment to some extent, a better calibration result would be expected if the zones with similar geological and meteorological conditions were put together. Based on the discussions of Chapter 2 and the distribution of hydropower plants shown in Figure 4.1, the state was finally separated into three sub-regions as shown in Figure 4.2.

The northern region includes northern Great Valley, Cascades Ranges, northern Sierra Nevada and northern Coastal Ranges, and Sacramento River Basin is the domain catchment here. The hydropower facilities mainly gather along Cascades Ranges and Sierra Nevada, through which Pit, Sacramento and Feather River flow. There are also some plants along Eel and Russian River of northern Coastal Ranges. In total, there are 101 hydropower plants with total capacity around 5 350 MW in northern region, which makes it the largest basin of California in terms of generation capacity. And there are 9 meteorological stations with complete recording from 1981-2006 ready for use in this basin.

The middle region is made up of southern Great Valley, southern Sierra Nevada and southern Coastal Ranges, and San Joaquin is the main river basin in this region. Generally, the middle region is similar with northern region in terms of natural conditions. There are 65 hydropower plants with total capacity of 4 943 MW concentrate in Sierra Nevada, mainly along the east-west rivers like Mokelumne, Stanislaus, Merced, Kings and Kern River. As to hydropower capacity, middle region is the second largest. And 7 meteorological stations with complete recording of 1981-2006 were prepared for use in this region.

The southern region consists of Transverse Ranges, Peninsular Ranges, Mojave and Colorado Desert. Most of the hydropower facilities are distributed in the ranges through which several short streams flow, another seven plants spread along All-American Canal in the state's border. The southern region is the smallest regions both in terms of area and hydropower capacity, there are only 34 units with total capacity of 674 MW locate in south. Besides, 11 meteorological stations with recording from 1981 to 2006 were chosen in this region.

Table 4.1: Number and capacity of hydropower plants of the three regions of California

Plant Type	**Northern Region**		**Middle Region**		**Southern Region**	
	Capacity (MW)	No. of plants	Capacity (MW)	No. of plants	Capacity (MW)	No. of plants
Storage	5024	71	4613	52	273	11
Run of River	326	30	331	13	401	24
Total	5350	101	4943	65	674	34

Figure 4.2: Divisions of California with the hydropower units extracted from Google Earth. The orange lines are the dividing lines which divide California into three sub-basins. The blue points denote hydropower facilities of northern sub-basin, the red points denote hydropower units in middle basin, and the green points denote hydropower plants of southern region.

4.3 Meteorological Data

As a rainfall-runoff model, HBV simulates runoff from precipitation and temperature of the watershed. Commonly the model estimates catchment precipitation and temperature by a weighted mean of the meteorological data from stations within and in the vicinity of the catchment (SMHI, 2007), and the weights of stations are determined manually by try-and-error in Scania-HBV.

One useful source of meteorological data is the Global Summary of the Day (GSOD) from National Climate Data Center (NCDC). Up to 350 meteorological stations in California were collected from this source. The recording dates back to 1941, but most stations have record from 1980s to 2006. Temperature data of GSOD is in degrees Fahrenheit which has to be converted to Degrees Celsius for HBV, while precipitation data is in inch and has to be converted to millimeter. These 350 stations, with their coordinates were converted to a Google Earth file by the program Epoint2GE.

Another source for meteorological data is Global Historical Climatology Network Daily (GHCN-D) from Global Observing System Information Center (GOSIC). In total, 54 GHCN-D meteorological stations in California are provided in GOSIC, and most stations also have the recording from 1980s to 2006. The temperature of the record is in degrees Celsius and precipitation is in millimeter which can be used directly in HBV. The GHCN stations were also converted to a Google Earth file for a direct viewing, and for the selecting of candidacy stations.

Besides NCDC and GOSIC, the Western Regional Climate Center (WRCC) also offers some stations with historical recording. Although most WRCC stations only provide recordings since 1990s, some stations occupy quite ideal locations in the river basin. The WRCC was thus used as a supplementary resource.

The HBV model used in this project accepts a maximum of ten meteorological stations. Thus the stations located within or in the vicinity of the area where hydropower plants are densely concentrated were chosen as candidacy stations, another requirement for the candidacy stations is the quantity of records. Priority was given to stations with complete recording of 1981-2006. In calibration, candidate stations were tested with different weight manually until the simulated inflow matches the observed one perfectly. Finally, 27 stations were selected as candidate stations, and their recordings of temperature and precipitation of 1981-2006 were collected. The candidate stations are shown in Figure 4.3.

Figure 4.3: Map of California with candidate meteorological stations extracted from Google Earth

4.3 Target Data

Besides the meteorological data, the HBV model needs observed inflow data for calibration. As mentioned before, Scania-HBV model simulates runoff in the energy unit (MWh), which means the observed data that is going to be calibrated against should also be in MWh. Unfortunately, runoff data of California is seldom published in energy unit, but mostly the flow rate unit (CFS). To solve this problem, all the hydropower plants were divided into two categories- the storage plants and run-of-river plants, and different computation methods were applied to each of them in order to convert the observed data into MWh.

For storage plants, water resource is conserved in lake or reservoir, and the inflow to power unit is usually affected by reservoir regulation. Consequently, with daily storage change of the reservoir and daily discharge from the generators, the daily flow into the system can be calculated. Daily storage data in AF was taken from California Water Science Center (CWSC) of USGS and California Data Exchange Center (CDEC). Daily discharge in CFS was collected from USGS.

The daily inflow to the system is:

$$Inflow_{.day}(CFS)=\frac{(Storage_{day1}-Storage_{day0})(AF)\times 43600}{24\times 3600}+Discharge_{day1}(CFS)$$

To get the inflow in MWh, the generation of the system should be taken into account. Generation data in MWh of each plant was collected from EIA-906 and EIA-920 database from EIA, and all of them are in monthly basis. The relationship between generation and discharge reveals the characteristic on energy producing of the hydropower system, thus it should be reasonable to covert inflow into MWh according to this relationship. As the generation data is on monthly basis, a monthly conversion factor was used for this conversion. The conversion factor is calculated as:

$$ConversionFactor_{.month}=\frac{Generation_{month}(MWh)}{\sum_{i=1}^{31}Discharge_{.day}(CFS)},\quad \text{(i=1, 2, 3……31, day of the month)}$$

For each month, the daily inflow in CFS is multiplied by the conversion factor of this month, which will result in the daily inflow in MWh:

$$Inflow_{.day}(MWh)=Inflow_{.day}(CFS)\times ConversionFactor_{.month}$$

For run-of-river unit, the power system is sustained by running water, and there is no significant storage. Thus the inflow to the system equals to the discharge directly:

$$Inflow_{.day}(CFS)=Discharge_{.day}(CFS)$$

Same with the storage ones, generation data is only available on monthly basis through EIA, so a conversion factor on monthly basic is required. Again, the generation data in MWh was collected from EIA-906 and EIA-920 database, and daily discharge data in CFS was collected from CWSC. The conversion factor is calculated as:

$$ConversionFactor_{.month} = \frac{Generation_{month}(MWh)}{\sum_{i=1}^{31} Discharge_{.day}(CFS)}, \quad \text{(i=1, 2, 3……31, day of the month)}$$

Then the daily energy inflow is:

$$Inflow_{.day}(MWh) = Inflow_{.day}(CFS) \times ConversionFactor_{.month}$$

After the inflow of each plant was converted to MWh, all the inflow of plants in the same region was added together. And it is this sum up of inflow that was taken as target inflow in Scania-HBV.

5 Result & Discussion

With California being divided into three sub-basins, the Scania-HBV model was applied to each of these basins. And the period for calibration is taken as 1999-2006 while period for validation is 1981-1998. The reason behind this division is that, firstly, there are about 26 nonutility hydropower plants for which the generation data is confidential at the plant level prior to 1999 in EIA. Before 1999, generation of these plants were estimated according the average proportion of their generation to the region's total generation, which makes the accuracy of target data much higher after 1999, thus year 1999 was taken as the break point for calibration and validation period. Secondly, the meteorological and hydrological conditions were changing fast over the past decades, while the model is going to be used for forecasting of generation in the future, so it will be more accurate to calibrate in the period for which the meteorological and hydrological conditions are closer to current conditions.

The agreement between observed and computed runoff can be evaluated by several criteria of fit. As shown in Table 3.2 of Chapter 3, the objective functions include coefficients of determination on daily, weekly and monthly basis, together with accumulated difference, relative error, and all these functions help to evaluate the agreement numerically. In addition, the hydrograph gives source for visual inspection of general fitting of observed and simulated runoff.

5.1 Northern Region

Northern region is the largest sub-region in terms of hydropower capacity and quality of hydropower plants. This part is also abundant of water resources, and is the region where several huge streams flow through. Calibration was made by optimizing the parameters with trial and error technique until an acceptable agreement with observed runoff is achieved, and finally 4 meteorological stations (station ID: 1001, 1002, 1003, 1004) were used for simulation of the inflow. Table 5.1 illustrates the location of these meteorological stations together with the final values of objective functions of both calibration and validation, and the details of meteorological stations are listed in Table 5.2. The graphs of calibration and validation are shown in Figure 5.1 and Figure 5.2 respectively.

Table 5.1: Results of calibration and validation of northern region. The mini map shows the distribution of hydropower facilities and the four meteorological stations.

Objective Function	Unit	Calibration	Validation	Power Units & Meteorological stations
r2		0.72	0.60	
r2_W		0.81	0.71	
r2_M		0.89	0.81	
Std-AccD	GWh	1514	5530	
Accdiff	GWh	-1851	-16129	
QrecSum	TWh	163	337	
QcalcSum	TWh	161	320	
RelErr		0.19	0.24	

Table 5.2: Recording period, position and source of meteorological stations used in northern region

Station ID	Name	Recording Period	Latitude (^{o}N)	Longitude(^{o}W)	Source
1001	MOUNT SHASTA	198 1-2006	41.33	122.33	GSOD
1002	REDDING MUNICIPAL ARPT	1981-2006	40.52	122.31	GSOD
1003	QUINCY	1981-2006	39.93	120.93	GHCN-D
1004	BLUE CANYON AP	1981-2006	39.29	120.71	GSOD

Table 5.1 shows that in calibration, the coefficient of determination reached 0.72 on a daily basis, while the weekly and monthly value reached 0.81 and 0.89 respectively. In calibration, the sum of simulated inflow and observed inflow are 161 TWh and 163 TWh severally, and the relative error is 0.19. All these values indicate that the simulated inflow agrees with the observed one highly. In validation, the coefficient of determination is 0.60 of daily inflow, 0.71 of weekly inflow and 0.81 of monthly inflow. The discrepancy of total volume between observed and simulated series increased a bit, the relative error also inclined and reached 0.24. After all, as the generation data is monthly data, it will be more reasonable to evaluation on monthly resolution, which is represented by r2_M. r2_M reached 0.89 in calibration and 0.81 in validation, which indicates a satisfactory modeled inflow in northern region. In addition, Figure 5.1 and 5.2 are both about monthly observed and simulated inflow, the graphs also show that the observed and simulated flow agrees with each other well both in calibration and validation.

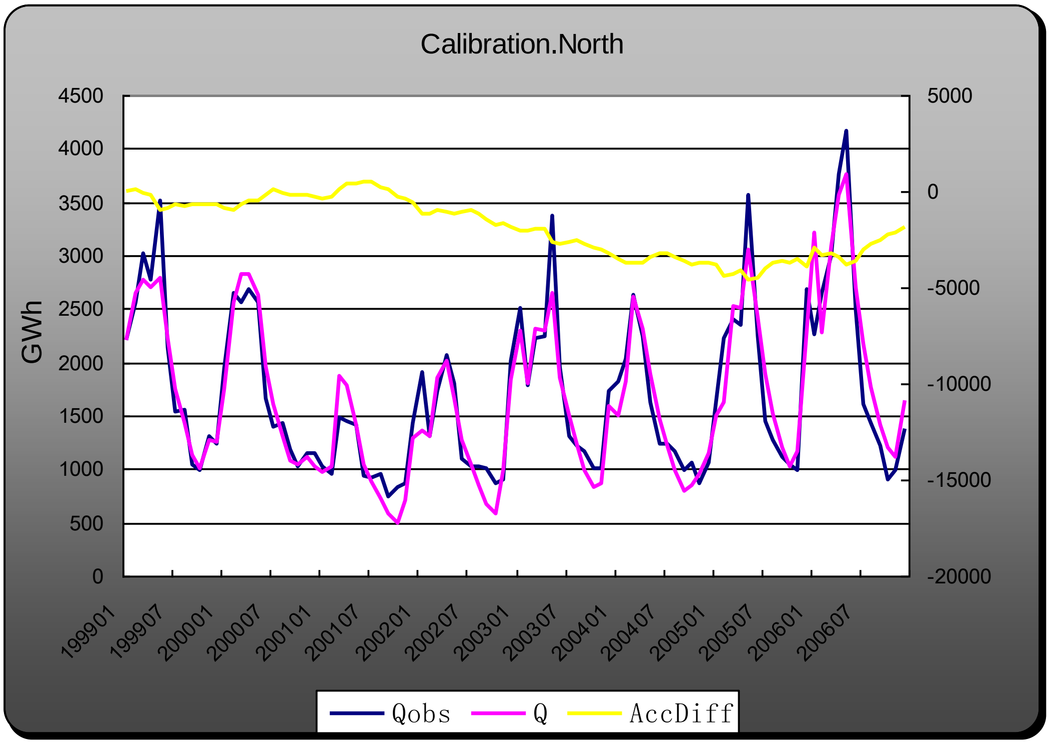


Figure 5.1: Graph of simulated and observed monthly inflow together with the accumulated difference from calibration of the northern region. The pink line denotes observed inflow, while the blue line indicates simulated inflow and the yellow line denotes the accumulated difference between them.

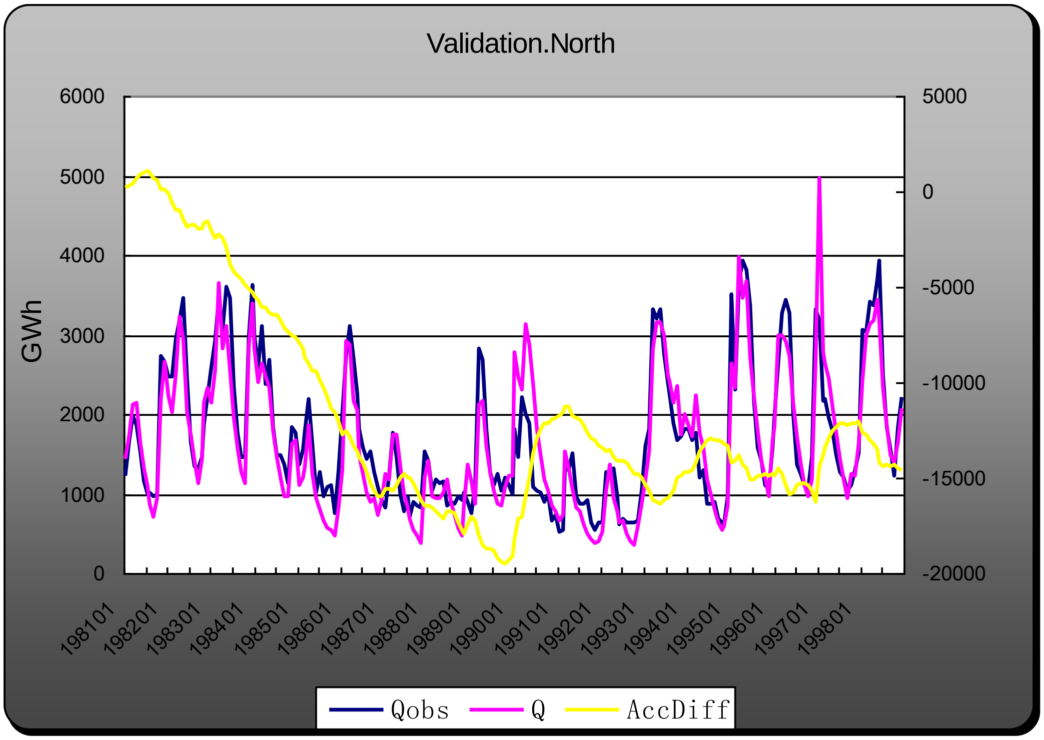


Figure 5.2: Hydrograph of simulated and observed monthly inflow together with the accumulated difference from validation of the northern region. The pink line denotes observed inflow, while the blue line indicates simulated inflow and the yellow line denotes the accumulated difference between them.

5.2 Middle Region

Middle region has similar geological, meteorological and hydrological situations to the northern region, with the main river basin lying in the center and surrounded by several high ranges. With 4943 MW of hydropower capacity, it is the state's second largest hydropower region. However, as most of the streams originate on the high elevation of Sierra Nevada, the hydropower facilities also concentrate along Sierra Nevada. Four meteorological stations were finally used to simulate the flow of middle basin, the meteorological station locations (station ID: 1006, 1007, 1010, 1011) together with the results of calibration and validation are shown in Table 5.3, and the details of meteorological stations are listed in Table 5.4. The graphs of calibration and validation are shown in Figure 5.3 and Figure 5.4 respectively.

Table 5.3: Results of calibration and validation of middle region. The mini map shows the distribution of hydropower facilities and the four meteorological stations.

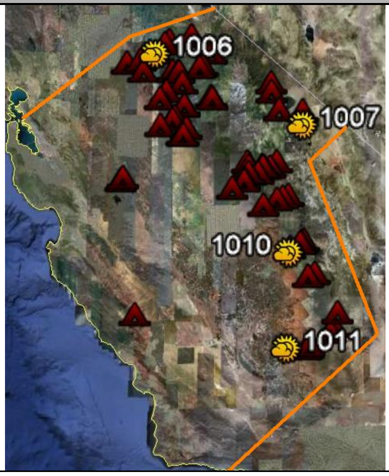
Objective Function	Unit	Calibration	Validation	Power Units & Meteorological stations
r2		0.70	0.61	
r2_W		0.74	0.72	
r2_M		0.81	0.78	
Std-AccD	GWh	1155	2356	
Accdiff	GWh	-2667	-1833	
QrecSum	TWh	89	201	
QcalcSum	TWh	87	199	
RelErr		0.35	0.33	

Table 5.4: Recording period, position and source of meteorological stations used in middle region

Station ID	Name	Recording Period	Latitude(^{o}N)	Longitude(^{o}W)	Source
1006	ELECTRA P H	1981-2006	38.32	120.67	GHCN-D
1007	YOSEMITE PARK HDQTRS	1981-2006	37.75	118.58	GHCN-D
1010	LEMON COVE	1981-2006	36.37	119.02	GHCN-D
1011	BAKERSFIELD MEADOWS FIELD	1981-2006	35.43	119.06	GSOD

The result of middle region is quite similar to that of northern region, with a well simulated runoff following the manner of observed inflow both in calibration and validation. The satisfactory result is also proven by the values of the objective functions listed in Table 5.3. The coefficient of determination of daily inflow is 0.70, of weekly inflow is 0.74, and of monthly inflow is 0.81 in calibration. The total observed inflow is 89 TWh and the total simulated one is 87 TWh, while the accumulated difference between them is -2 667 GWh. The relative error in calibration reached 0.35. Again, the validation shows a slightly worse result, with r2 of 0.61 of daily inflow, 0.72 of weekly inflow and 0.78 of monthly inflow. However, there are still only 2 TWh differences between the total simulated and observed inflow and the accumulated difference decreased to -1833 GWh, the relative error declines to 0.33. In general, although the result of middle region is slightly worse than that of northern region, the runoff is still well simulated in middle basin.

It is interesting to notice that middle region and northern region share a resembling graph, and the model results are quite satisfactory in northern and southern region. It may be because of the similarity of hydrological and meteorological conditions in these two regions, and the high representativeness of meteorological stations. The main deficiency is the poor simulation of the value and timing of peak flow where the observed inflow leaped highly. However, these leaps are mostly caused by the factitious regulation of reservoirs, although some damping functions have been applied to HBV in an effort to diminish this discrepancy, it is still difficult to simulate some extreme irregular leap (Bergström, 1980). And when the model is used for forecasting for short term generation, a well understanding of the reservoir regulation routine is suggested.

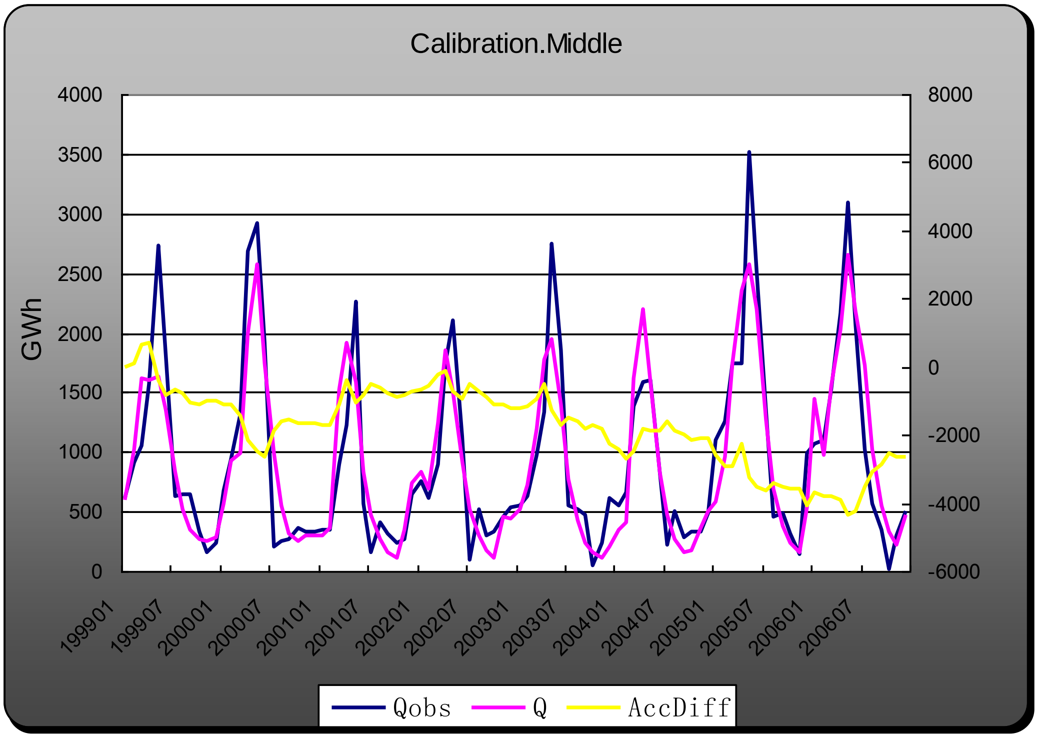


Figure 5.3: Hydrograph of simulated and observed monthly inflow together with the accumulated difference of calibration of the middle region. The pink line denotes observed inflow, while the blue line indicates simulated inflow and the yellow line denotes the accumulated difference between them.

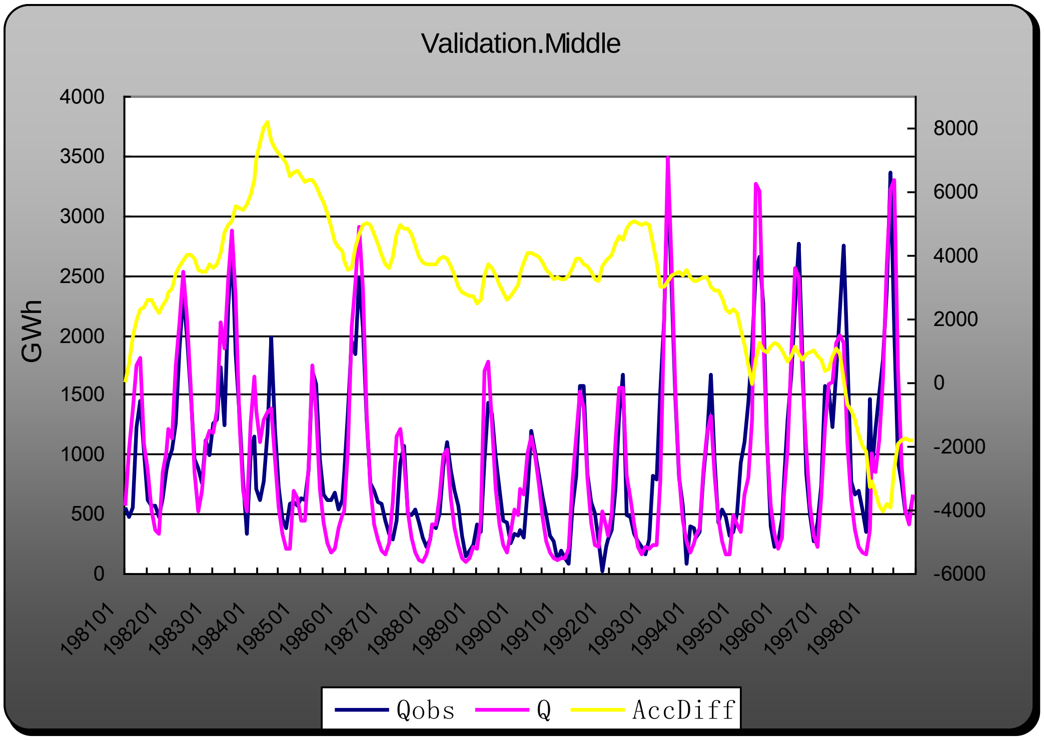


Figure 5.4: Hydrograph of simulated and observed monthly inflow together with the accumulated difference of validation of the middle region. The pink line denotes observed inflow, while the blue line indicates simulated inflow and the yellow line denotes the accumulated difference between them.

5.3 Southern Region

Southern region is the warmest and driest region, and it also possesses the least number of hydropower facilities and the lowest total hydropower capacity. Although there are 11 meteorological stations distributed in this region, only three of them cooperated to give acceptable result at last. The three meteorological stations (station ID: 1008, 1009, 1012) together with the results of calibration and validation are shown in Table 5.5, and the details of meteorological stations are listed in Table 5.6. The graphs of calibration and validation are shown in Figure 5.5 and Figure 5.6 respectively.

Table 5.5: Results of calibration and validation of southern region. The mini map shows the distribution of hydropower facilities and the three meteorological stations.

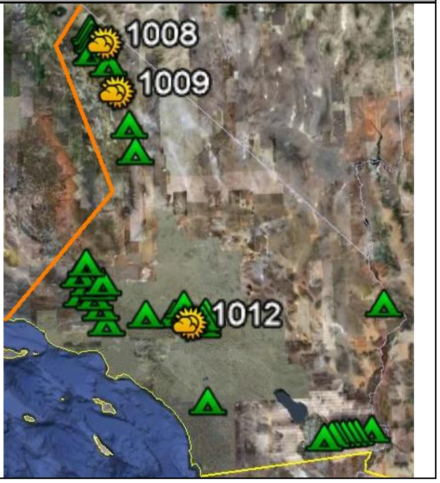
Objective Function	Unit	Calibration	Validation	Power Units & Meteorological stations
r2		0.60	0.50	
r2_W		0.65	0.52	
r2_M		0.69	0.55	
Std-AccD	GWh	264	424	
Accdiff	GWh	-648	-1112	
QrecSum	TWh	20	43	
QcalcSum	TWh	19	42	
RelErr		0.13	0.17	

Table 5.6: Recording period, position and source of meteorological stations used in southern region

Station ID	Name	Recording Period	Latitude(^{o}N)	Longitude(^{o}W)	Source
1008	BISHOP AIRPORT	1981-2006	37.37	118.36	GSOD
1009	INDEPENDENCE	1981-2006	36.80	118.20	GHCN-D
1012	SAN BERN	1981-2002	34.05	117.14	GSOD

For southern region, the simulated inflow agrees poorly with the observed one in calibration and validation. In calibration, the coefficient of determination reached 0.60 and 0.65 of daily and weekly respectively, even the monthly data only reached 0.69. The total observed inflow is 20 TWh while the simulated one is 19 TWh, accordingly the accumulated difference is -648 GWh, and the relative error is 0.13. Without surprise, the coefficient of determination decreased in validation. The coefficient of daily inflow is 0.5, of weekly inflow is 0.52 and of monthly is 0.55. There are still only 1 TWh differences between the total simulated and observed inflow and the accumulated difference increased to -1 112 GWh, the relative error reached 0.17.

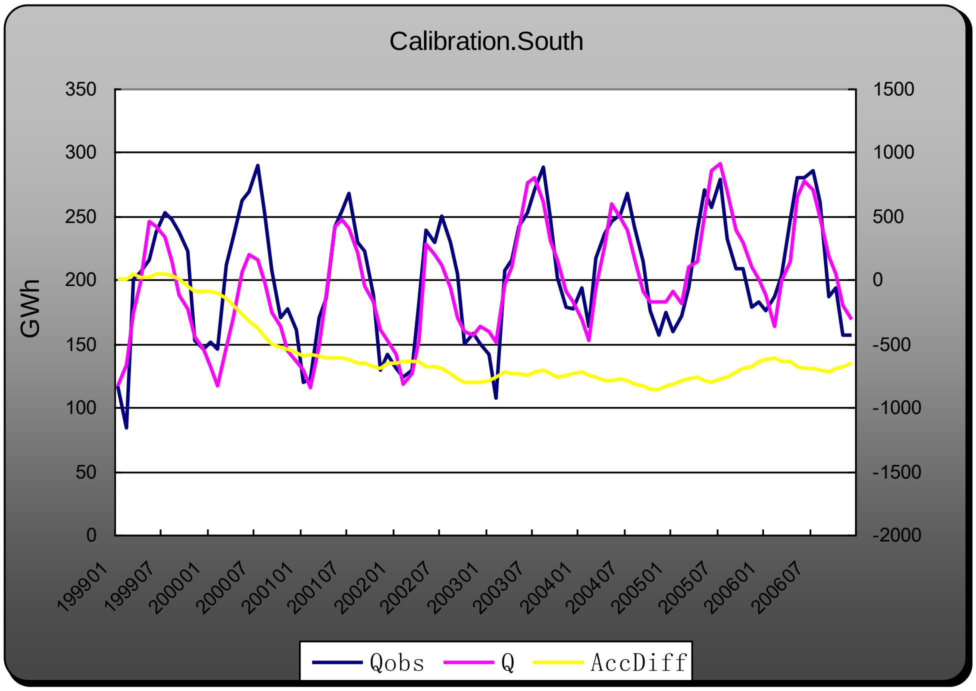


Figure 5.5: Hydrograph of simulated and observed monthly inflow together with the accumulated difference of calibration of the southern region. The pink line denotes observed inflow, while the blue line indicates simulated inflow and the yellow line denotes the accumulated difference between them.

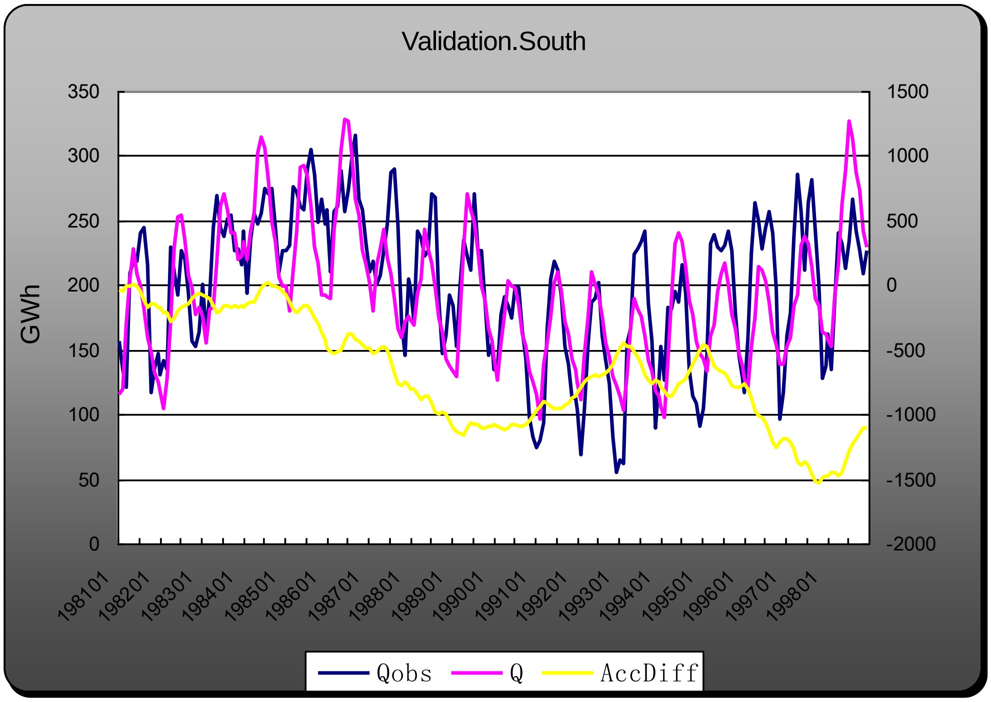


Figure 5.6: Hydrograph of simulated and observed monthly inflow together with the accumulated difference of validation of the southern region. The pink line denotes observed inflow, while the blue line indicates simulated inflow and the yellow line denotes the accumulated difference between them.

Figure 5.7: California Aqueduct, Los Angeles Aqueduct and All-American Canal together with the hydropower plants connected to them.

Obviously, the general style of southern region (Figure 5.5 and Figure 5.6) is quite different from that of the northern and middle regions (Figure 5.1 to Figure 5.4). The reason behind this is that, of all the 34 hydropower facilities in this part, there are 12 plants with total capacity of 213 MW connected to the Los Angeles Aqueducts, 4 facilities with total capacity of 214 MW connected to the California Aqueduct, and 7 plants with total capacity of 82 MW connected to the All-American Canal. All these plants and the aqueducts are shown in Figure 5.7. The Los Angeles Aqueduct delivers water from Owens Valley to the city of Los Angeles to meet the mega city's requirement on water. The California Aqueduct carries water from the San Joaquin-Sacramento River Delta to south region, and several pump stations and reservoirs along the aqueduct work together to deliver water southward (DWR, 2001). The All-American Canal delivers water of Colorado River to the Imperial Valley, and became the only source of water for the valley. Besides, there is also Parker powerhouse with capacity of 120 MW situated at the base of Parker

Dam. Behind Parker dam is the Lake Havasu which is the water source of Colorado River Aqueduct, and the aqueduct also aims to supply water to Los Angeles region. All together, these 24 plants hold about 93% hydropower capacities out of 674 MW of southern region. And it is these intense regulated aqueducts that make it more difficult to simulate the runoff in southern region. As a conceptual model based on the meteorological condition within the basin, it is not possible to simulate the part of water that comes from another basin during part of the year. The results of southern region indicate that for the arid region where the resources for hydropower are mostly transited from another basin, and where the system is highly affected by human regulation, the simulated inflow represents the hydro-potential poorly.

Additionally, the special meteorological circumstance of southern region contributes to the poor result as well. This desert region is affected by the humid air from Gulf of Mexico and Gulf of California which generates abrupt but short showers in summer, but for the rest of the year it rarely rains. During the dry season, water resource for hydropower is mostly transferred by the aqueducts from other basins, which are not related to the in-basin hydrological circle. As shown in Figure 5.6, there is a distinct yearly fluctuation of runoff during 1981 - 1998. And Figure 5.8, which is about flow at Drop No.1 power house of All-American Canal from 1989 to 1998 illustrates a similar trend, with the runoff decreased to the lowest at 1992, and then increased again.

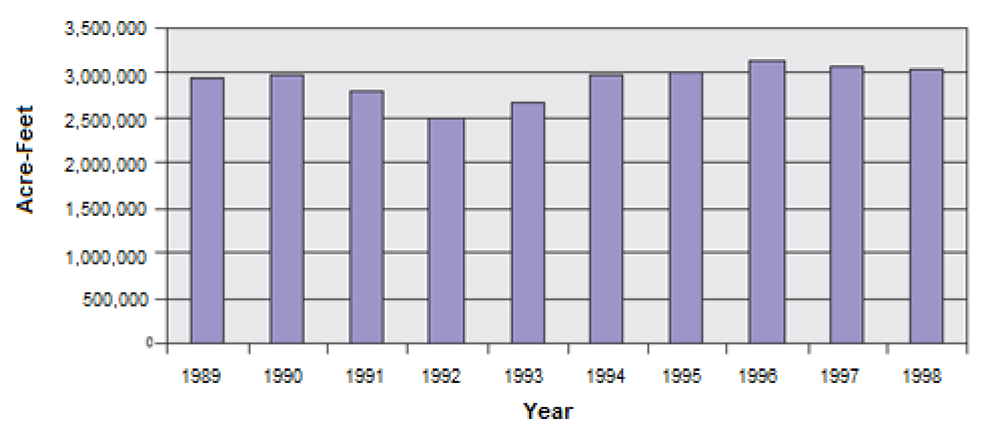


Figure 5.8: Annual flow in the All-American Canal at Drop No.1, 1989-1998 (AF) (Source: IID, 2002)

By comparing the results from the three sub-regions, it is easy to find that the result of validation is always worse than that of calibration. One reason lies on the difference of time span. The calibration period is 1999-2006 which is about 30% of the entire recording time, while period for validation is 1981-1998 which occupies 70% of the recording. With longer duration, the chance for a good fitting decrease. Another reason is the changing condition over the past decades, the model parameters are optimized in a condition which is much closer to current meteorological and hydrological conditions. Nevertheless, the first recording used in validation is of about 28 years ago, the circumstances are of course distinguished very much from that of calibration period, but the conceptual model still performed as the physical conditions unchanged, thus the simulated result would be quite different for validation and calibration. After all, the model is going to be developed for forecasting of generation after 2006, a time for which the meteorological and hydrological circumstances holds a high similarity with the calibration period, thus a better result could be expected.

5.4 California as a Whole

After applying the model to individual basins, it is still necessary to add the contributions from all sub-basins and evaluate the model for the entire state. Therefore, based on the simulated inflow from northern, middle and southern regions, the daily, weekly and monthly values were added together respectively, and objective functions were calculated accordingly. The results of objective functions are listed in Table 5.7. Meanwhile, graphs of observed inflow, simulated total inflow together with the accumulated difference between them are also made to give a visualized impression of the result. The graphs are shown in Figure 5.9 and Figure 5.10.

Table 5.7: Results of objective function of calibration and validation of the whole state

Objective Function	Unit	Calibration	Validation
r2		0.77	0.72
r2_W		0.82	0.81
r2_M		0.87	0.88
Std-AccD	GWh	2382	7101
Accdiff	GWh	-4019	-16997
QrecSum	TWh	272	580
QcalcSum	TWh	268	563
RelErr		0.19	0.20

Figure 5.9 and 5.10 reveal that the inflow of California holds the same manner with northern and middle region. Although the trend of southern runoff is quite different, it is too slim to arouse any obvious discrepancy in the hydrograph. To the whole state, r2_W reached 0.82 in calibration and 0.81 in validation, r2_M reached 0.87 in calibration and 0.88 in validation. All of these objective functions reached values higher than 0.80, which indicate the model gave reliable simulated weekly and monthly inflow. The simulated total inflow is 268 TWh while the observed one is 272 TWh in calibration, and the relative error is 0.19 accordingly. In validation, the difference of total inflow between simulated and observed increased to 17 TWh, consequently the relative error rose to 0.20. Both values of relative error are better than the ones of northern and middle region, but slightly worse than the ones in southern region. As to the daily inflow, it is also inspiring to notice that the coefficient of determination is 0.77 and 0.72 in calibration and validation respectively, which are higher than that of any of the sub-basins, and which indicates that the negative values of southern basin are too small to affect the whole state. All the values in Table 5.7 indicate that with recording of 11 meteorological stations across California, the Scania-HBV model simulated a series of inflow which has a high consentience with the observed inflow in the period 1981-2006.

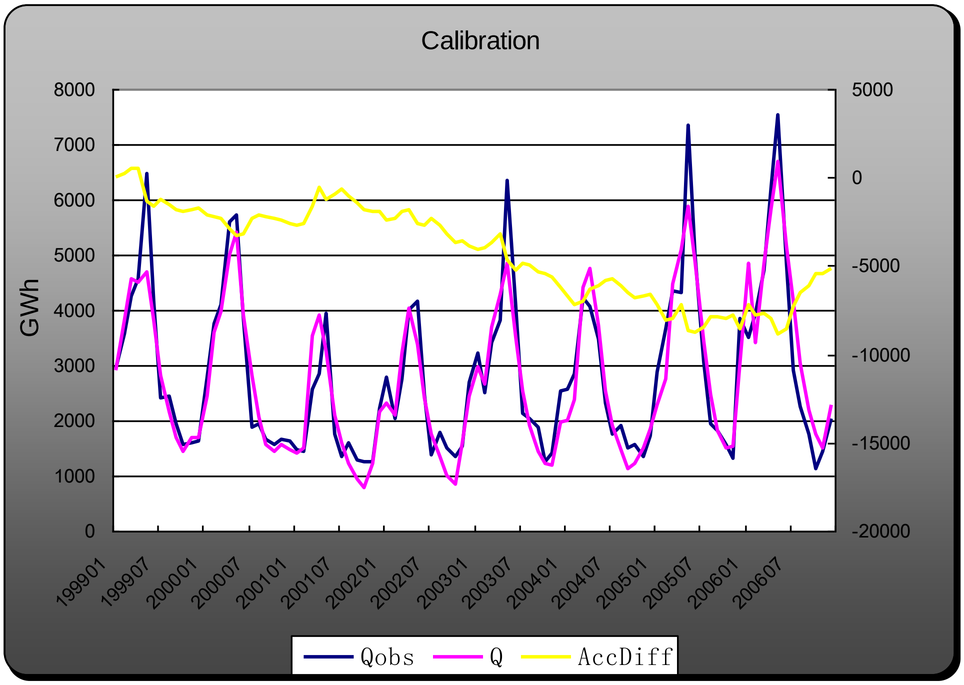


Figure 5.9: Simulated and observed monthly inflow of the entire state in calibration. The blue line indicates the simulated inflow while the pink line is the observed one. Accumulated difference between observation and simulation is expressed by yellow line.

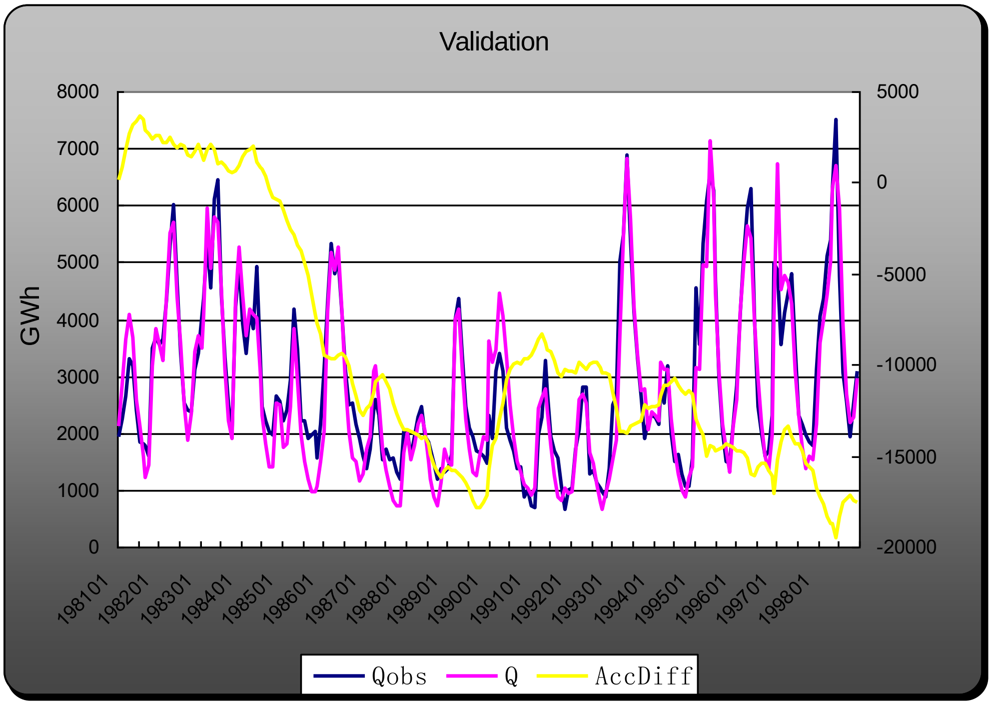


Figure 5.10: Simulated and observed monthly inflow of the entire state in validation. The blue line indicates the simulated inflow while the pink line is the observed one. Accumulated difference between observation and simulation is expressed by yellow line.

6 Conclusions

Of all the tasks in this project, data collection is the most critical segment. Fortunately, the well gauged California is generous in providing meteorological and hydrological data, which makes the application of rainfall- runoff model feasible. The generation data, because of its sensitivity in power market, is only available in monthly level. It is this low resolution data which restrained the simulated result to some extent.

As an entire state, the Scania-HBV model gives good results. For a basin of 403 933 km^2 and 10967 MW capacity of hydropower, with 11 meteorological stations, the simulated inflow reaches 0.87 of calibration and 0.88 of validation for general monthly fitting. As separated regions, the northern and middle regions are well modeled by Scania-HBV, with r2_M reaches to 0.89 and 0.81 individually in calibration, and relative error attains 0.19 and 0.35 and respectively. However, due to the intensely regulated hydropower system in California, and the limited data quality, the general fitting in daily inflow and peak value is slightly worse in northern and middle region as well as for the whole state. The southern part is much worse as the meteorological and hydrological conditions are quite special in this arid region.

And from the result of this primary dig at the field of hydropower, it shows that Scania-HBV gives very good simulation on weekly and monthly basis, which means the Scania-HBV is dependable on long-term forecasting of hydropower generation. And for the short term forecasting as daily prediction, it is not so trustable. If the model is going to be used for forecasting of power generation, tracing of the hydropower system regulation routine and updating it regularly is recommended, which will help to give a more accurate short term prediction.

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