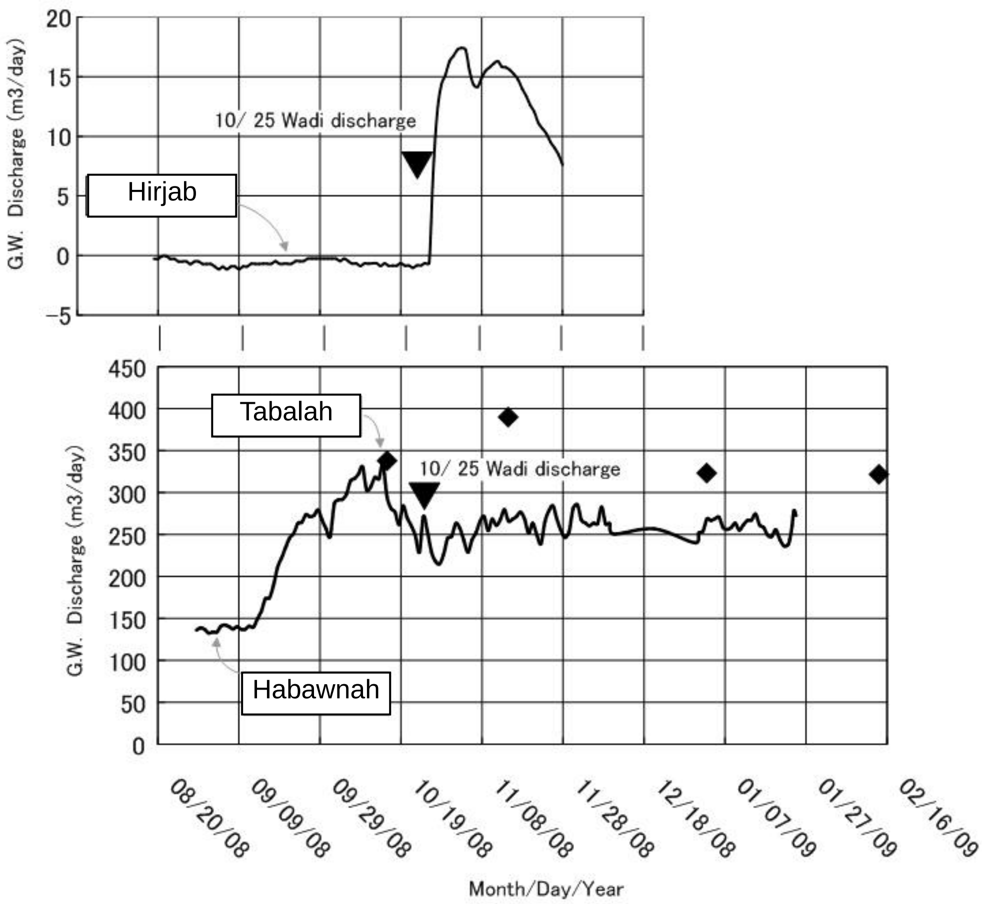


Figure 3-20 Discharge of Baseflow

4. Water Resource Potential

4.1 SWAT Model

(1) Outline

Using simulation model, water balance was analyzed for the 161,000 square kilometers covering major area except the eastern area of Najran of which is 309,000 square kilometers of Project area. The analytical tool applied was SWAT, the acronym for ‘Soil and Water Assessment Tool’, a river basin, or watershed, scale model developed for USDA Agricultural Research Service. It has been properly developed to predict impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time.

In the analysis, SWAT was used for the evaluation of water balance, in particular groundwater recharge as a preparation of groundwater simulation being planned for Jazan. As well, the general information of a replenishment water amount was preliminary estimated for major basin of the project area.

The physical processes to analyze the water balance are briefly summarized in following sub-section.

(2) Catchments Delineation

For the modeling purpose, a model area should be partitioned into 1,269 sub-basins (Called as ‘catchments’ in SWAT). The use of catchments in the simulation is particularly beneficial when different areas of the watershed are dominated by water uses enough in properties to impact hydrology.

To partition the watershed into catchments, DEM (Digital Elevation Model) was used to one another spatially use distribution and stream network for wide-scaled (watershed) analysis.

Using algorism of automatic delineation and segmentation of watersheds, model area was divided into various areas ranging from 1.6 to 1,982 km^2. Figure 4-1 shows major watershed applied for catchments division.

Figure 4-1 Major Watersheds - Applied for SWAT -

4.2 Input Information

For the preparation of SWAT run, the meteorological and hydrological information were prepared as input information. In general, input information for each sub-basin is to be grouped into the following categories:

a. Climate Data;
b. Land Use Map and Soil Taxonomy Map
c. Hydrologic Response Units (HRUs)
d. Hydrologic data

- Dams/Ponds / wetlands;
- Groundwater; and the main channel, or reach,
- Draining the catchments.

Input information (a – d), the actual data applied to the analysis is described in each sub-section.

<Process of SWAT Calculation>

No matter what type of problem studied, in particular groundwater discharge or surface discharge, with SWAT, water balance is the driving force behind everything that happens in the watershed. To accurately predict even the groundwater recharge, the hydrologic cycle as simulated by the model must conform to what is happening in the watershed.

Simulation of the hydrologic cycle of a watershed can be separated into two major divisions. The first division is the land phase of the hydrologic cycle. The land phase of the hydrologic cycle controls the amount of water to the main channel in each catchment. The second division is the water or routing phase of the hydrologic cycle which can be defined as the movement of water through the channel network of the watershed to the outlet.

(1) Climate

The climate of a watershed provides the moisture and energy inputs that control the water balance and determine the relative importance of the different components of the hydrologic cycle. The climatic variables required by SWAT consist of daily records of precipitation, maximum / minimum air temperature, solar radiation, wind speed and relative humidity.

In the analysis, the data from 85 stations, selected from MOWE’s 135 stations, and PME’s eight(8) stations (Abha, Al Baha, Bisha, Jizan, Khamis Mushayt, Makkah, Najran, Jeddah) were processed and 30 years’ records from 1975 to 2004 were applied for SWAT.

Although the continuous data were chosen for the analysis, their recording period was different and most of them contained missing data.

Conforming data reliability, comprehensive set of data from 1975 to 2004 was prepared as model input (refer to sub-section 4.5.1). In Figure 4-2, the location of all rain gage stations observed by MOWE and PME is shown.

Figure 4-2 Meteorological Stations

(2) Recent Trend of Rainfall

In accordance with the registration of MOWE's database, the annual precipitation from 1968 to 2004 was reviewed, and rainwater amount in 5 regions was calculated by Tiesen Polygon method.

The result shows in Figure 4-3. As well, the isohyets line created with the database was drawn in Figure 4-4.

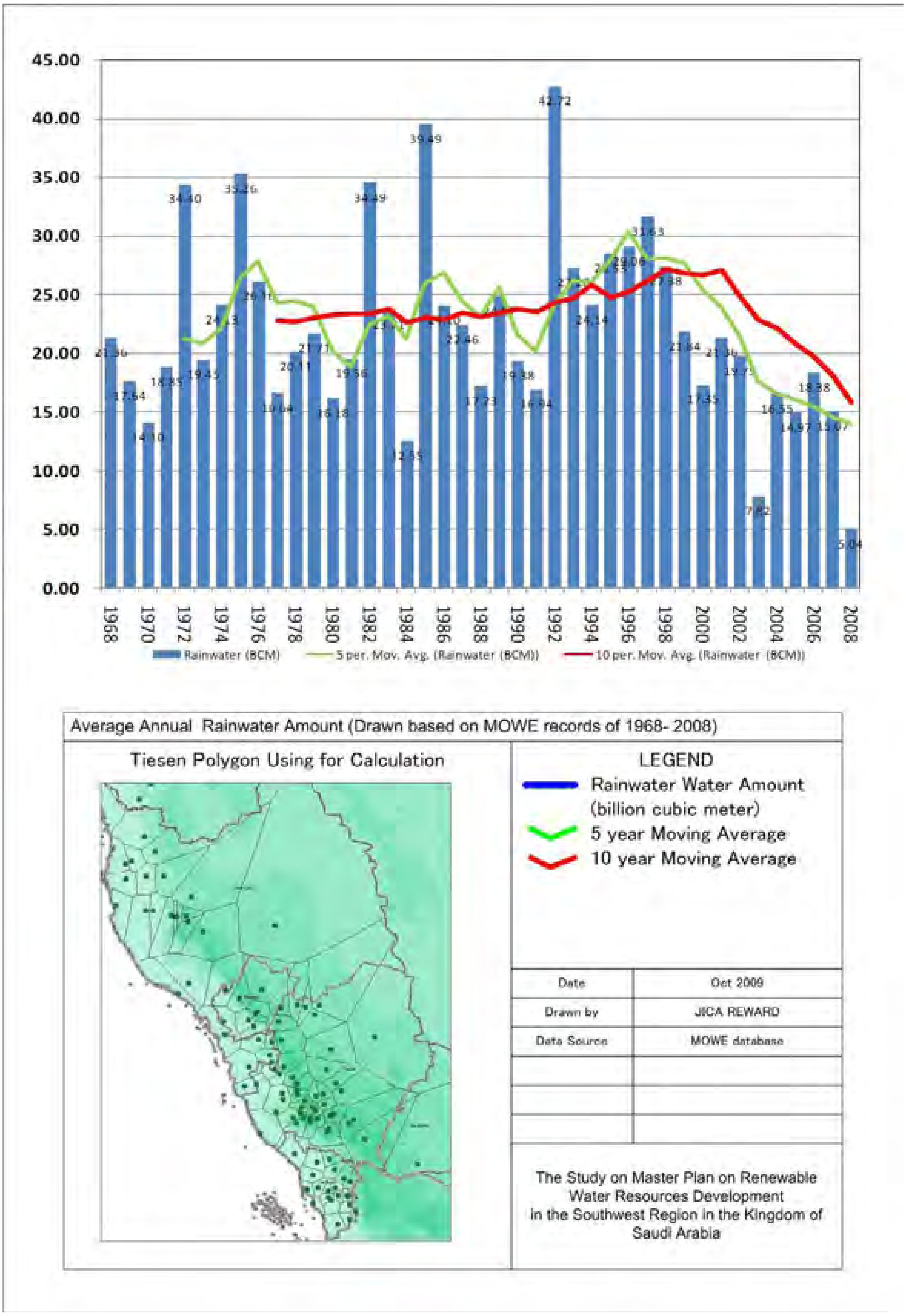


Figure 4-3 Yearly Variation of Rainwater in Project Area

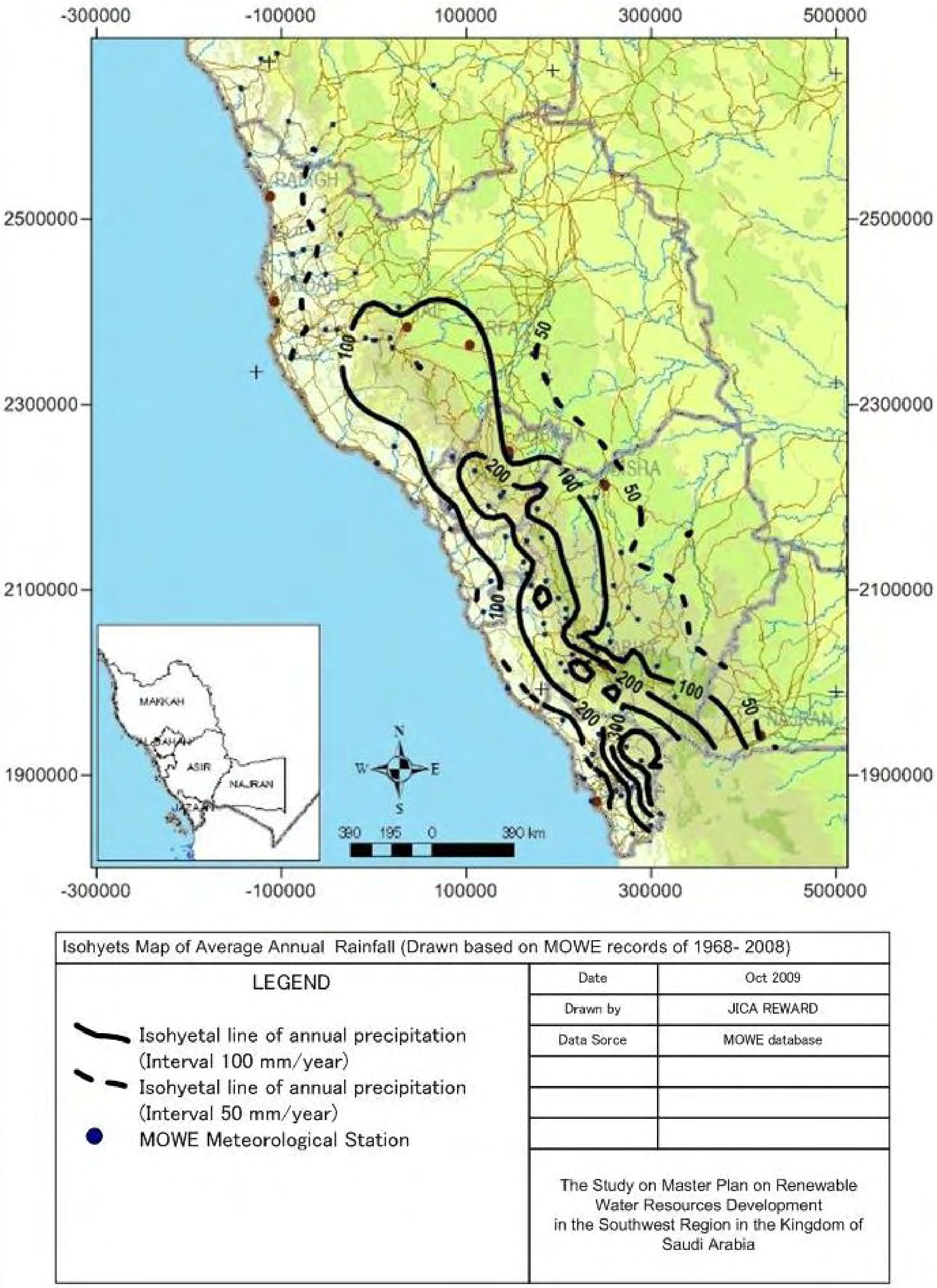


Figure 4-4 Isohyets Map of Average Annual Rainfall

(3) Land Use Map and Soil Taxonomy Map

Land use map and soil characterization map was prepared as GIS themes, as shown in Figure 4-5. They were used to load land use and soil themes into the project area and determine the land use/soil class combinations and distributions for the delineated watershed(s) and each respective catchments. Once the land use and soil themes was imported and linked to the SWAT databases, the criteria of superficial condition was specified in determining the calculation units (HRUs, refer to Sub-section 4.2.4) distribution. Then, one or more unique land use/soil combinations were created for each sub-basin.

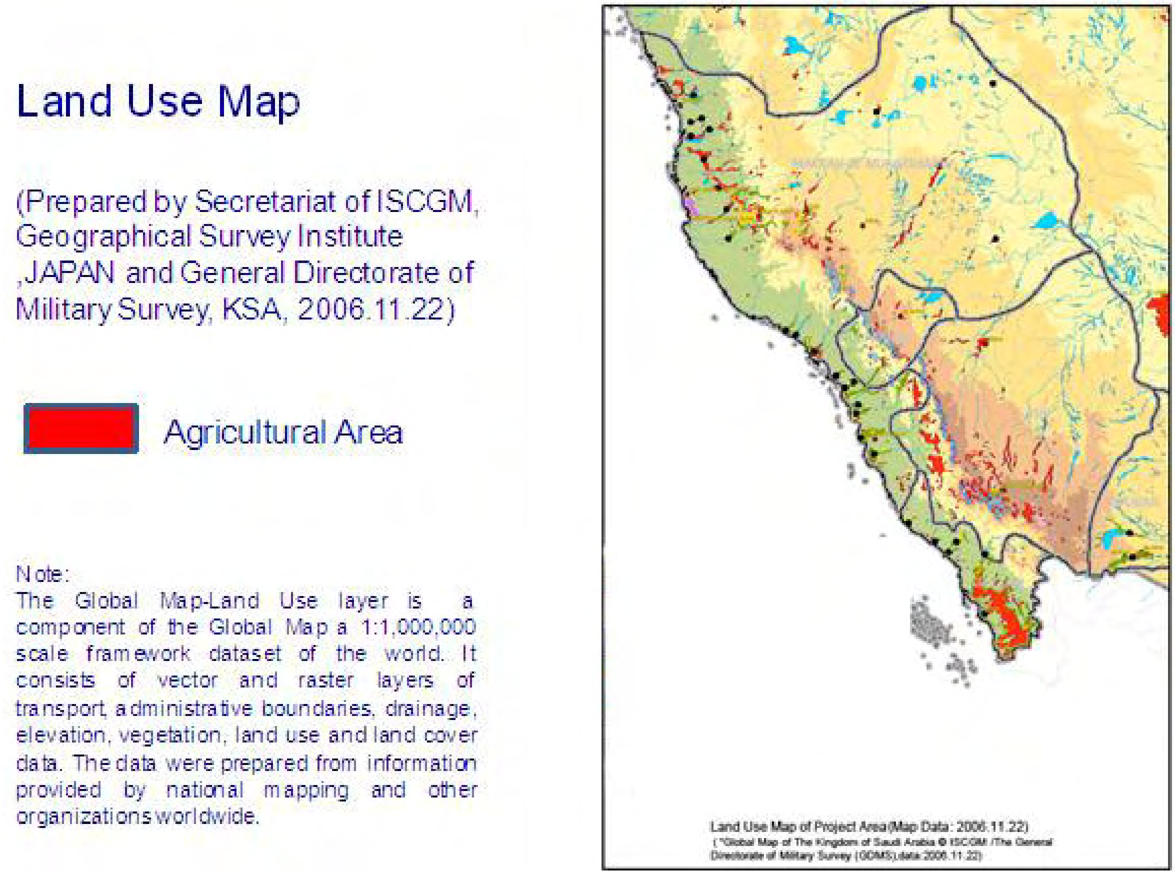


Figure 4-5 Landuse Map (ISCGM, 2006)

In actual processing, the land use and soils classification was overlain each other and determine land use/soil class combinations and distributes for the delineated watershed(s) and each catchments.

As internal database in the calculation, SWAT requires the hydrologic parameters of each land-soil category simulated within each catchment. To provide necessary hydrologic information for the calculation, personal soil database was developed with existing soil data.

Figure 4-6 shows the result of the Ministry of Agriculture (MOA)'s soil survey applied to SWAT as soil permeability (permeability in saturated condition).

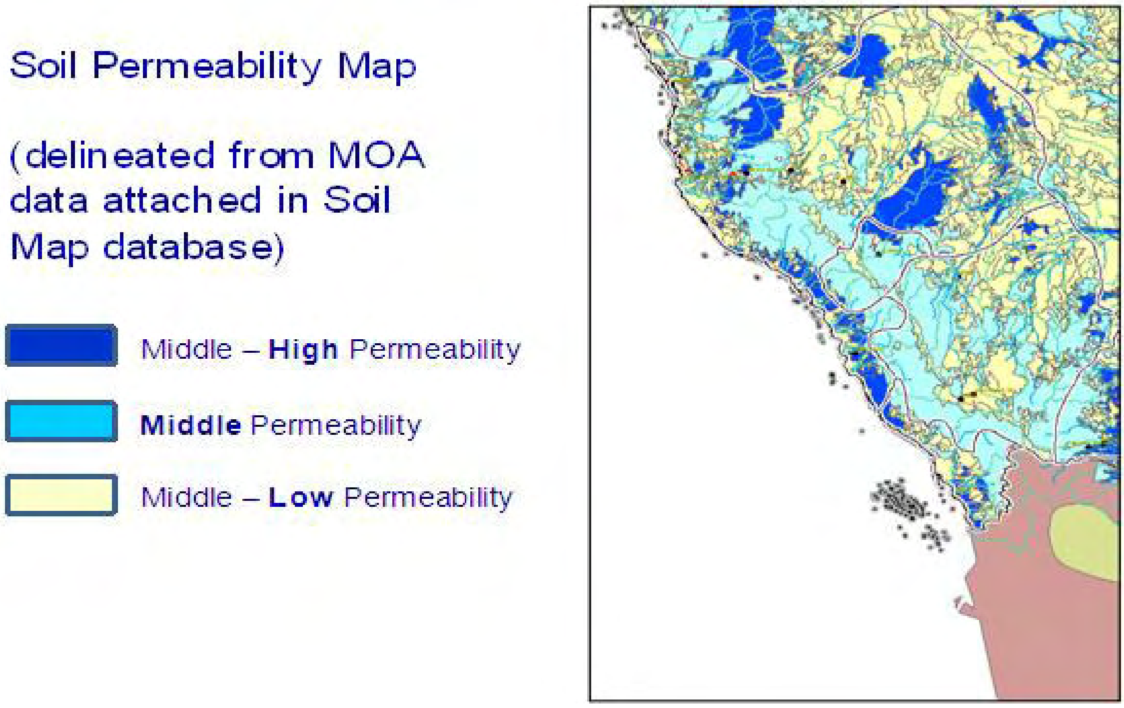


Figure 4-6 Soil Permeability (MOA)

(4) Hydrologic Response Units (HRUs)

The calculation of water balance was based on Hydrologic Response Units (HRUs). HRUs are portions of catchment that possess unique landuse / management / soil attribute. Subdividing the watershed into areas having unique land use and soil combinations enables the model to reflect differences in evapotranspiration and other hydrologic conditions for different land covers/crops and soils.

Hydrologic items of groundwater recharge and runoff were predicted separately for each HRU and routed to obtain the total amount for the watershed. Figure 4-7 shows the calculated catchments, consisting of one to several HRUs, which used to the calculation.

Table 4-1 shows the major water balance items of SWAT output (files) and is processed for respective catchments.

Table 4-1 Major Water Balance Items of SWAT

Variable Name	Definition
PRECIP/ PRECEP	**Precipitation:** Total amount of precipitation falling on the sub-basin during one year (mm H2O), which is showing annual average rainfall applied to SWAT, and is calculated from 38 years (1960-2007) daily records of 128 MOWE and 10 PME stations).
PET	**Potential evapotranspiration (PET):** Potential evapotranspiration from the sub-basin during one year (mm H2O).
ET	**Actual evaporation(ET):** Output of SWAT.
SW	**Soil water contents:** Soil water content (mm). Amount of water in the soil profile at the end of the time period (Dec.31, 2007).
PERC	**Percolation:** Water that percolates past the root zone during one year (mm). There is potentially a lag between the time the water leaves the bottom of the root zone and reaches the shallow aquifer. Over a long period of time, this variable should equal groundwater percolation.
SURQ	**Surface Runoff:** Surface runoff contribution to stream flow during one year (mm H2O).
GW_Q	**Base flow:** Groundwater contribution to stream flow (mm). Water from the shallow aquifer that returns to the reach during one year.
WYLD	**Water Yield:** Water yield (mm H2O). The net amount of water that leaves the sub-basin and contributes to stream flow in the reach during one year. (WYLD = SURQ + LATQ + GWQ – TLOSS – pond abstractions)

Variable Name	Definition
GW_RECHG	**Shallow Aquifer Recharge:** Recharge entering aquifers during time step (total amount of water entering shallow and deep aquifers during time step)
DA_RECHG	**Deep Aquifer Recharge:** The amount of water from the root zone that recharges the deep aquifer during the time step (shallow aquifer recharge = GW_RCHG-DA_RCHG).
REVAP	**Return Flow:** Water in shallow aquifer returning to root zone in response to a moisture deficit during the time step The valuable also include water uptake directly from the shallow aquifer by deep tree and shrub roots.
SA_ST	**Shallow Aquifer Storage:** Amount of water in shallow aquifer at the end of the time step.
DA_ST	**Deep Aquifer Storage:** Amount of water in deep aquifer at the end of the time step.
TLOSS	**Transmission Loss:** Water lost form tributary channels in HRU via transmission through the bed. This water becomes recharge for the shallow aquifer during time step. Net surface runoff contribution to the main channel stream flow is calculated by subtracting.
LATQ	**Lateral Flow:** Lateral floe contribution to stream flow. Water flowing laterally within the soil profile that enters the main channel during time step.
RECHG	**Groundwater Recharge:** Gross amount of groundwater recharge to shallow aquifer calculated from SWATs water balance (groundwater recharge = PRECP – ET – DRCHG - WYLDO). Negative value shows the upward (return) flow from shallow aquifer to surface or roots zone.

Figure 4-7 SWAT Sub-basins

4.3 Model Verification

(1) Sensitivity Analysis and Parameter Calibration

Model calibration was made with 9 records of Rabigh, Al Lith, Hali, Baysh, Jizan, Aqiq, Talabah, Bisha, Ranyah, Marwani basins (refer to Figure 4-8) to determinate the model parameters through the correlation between records and model's outputs. The period of calibration was applied from 1969 to 1885 using with annual and monthly records.

Prior to the calibration, the sensitivity analysis was made to obtain sensitive factors from around 60 parameters as shown in Table 4-2. At the beginning of the analysis, the auto calibration tool was tried to look up a best value as minimum difference between calculated and observed value. Unless the best fitting from the auto calibration was obtained, a manual adjustment was then followed by repeatedly trial runs.

By both of the auto calibration and trial trials, the model parameters were consequently verified within 5 percent error.

In Figure 4-9 and 4-10, the calibration result for 9 basins is indicated. Both figures show the result for 10 to 15 years' period since 1970's. However in some part in particular 1972 and 1973, a difference was large. It is not to be adjusted by handling parameter due to inconsistency of records between precipitation and river discharge. Some records may contain missing records.

For the daily calibration, it was also tried to be adjusted within less than 5 % of error. However, an acceptable result was not obtained due to poor relationship between precipitation and river discharge data. It may be affected by local climatic condition of showery rainfall.

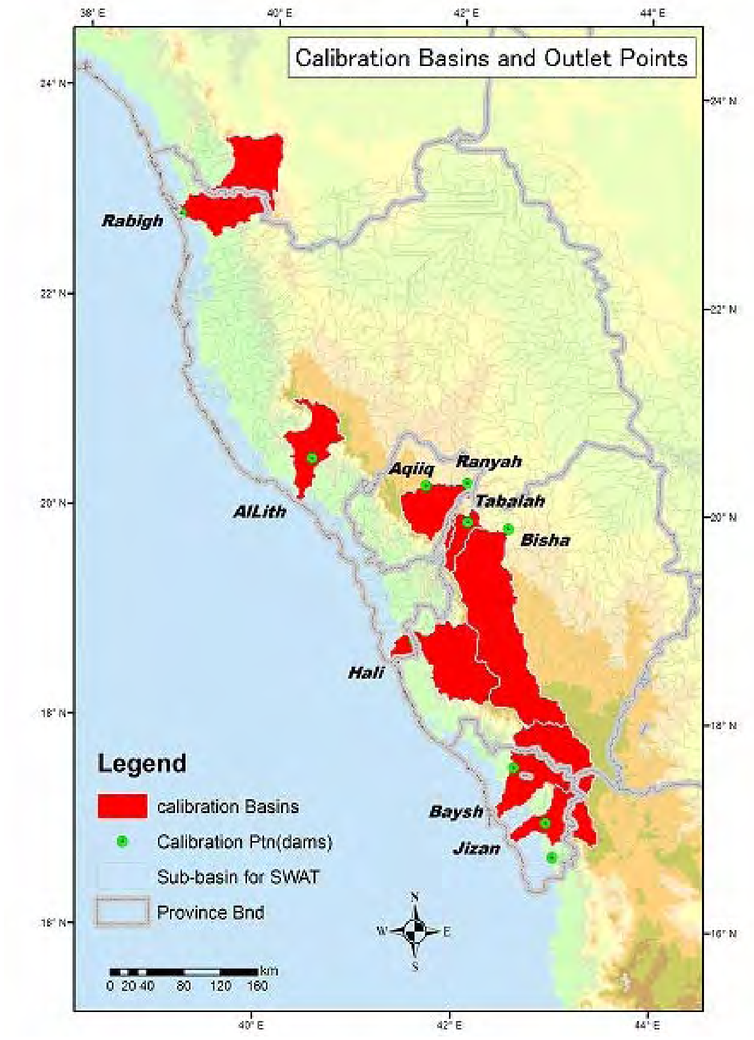


Figure 4-8 Calibrated Basins for Model

Table 4-2 Result of Sensitivity Analysis and Auto Calibration

< Sensitivity Analysis for Al Lith >

Parameters	Order	Parameters	Order	Parameters	Order
CN2	1	surlag	11	ESCO	28
SOL_AWC	2	BIOMIX	12	GW_REVAP	28
GWQMN	3	SLSUBBSN	13	REVAPMN	28
sol_z	4	SLOPE	14	TLAPS	28
sol_k	5	SFTMP	15	GW_DELAY	28
SMTMP	6	SMFMN	16	rchrg_dp	28
canmx	7	CH_K2	17	blai	28
TIMP	8	sol_alb	18	*	
ALPHA_BF	9	ch_n	19	*	
SMFMX	10	epco	20	*	

<Calibration Process for KSA 39 Soil>

Parameters	Sensitivity Order	Parameter decided by ex. Survey	Baysh	Jizan	Hali	Al Lith	Rabigh	Bisha	Tabalah	Ranyah
CN2	1	61	70	90	77	30	80	88	30	70
SOL_AWC	2	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.04	0.42
GWQMN	3	0	0	0	0	500	0	0	100	0
sol_z	4	500	500	500	500	500	500	500	500	500
sol_k	5	33	33	33	33	20	33	33	33	33

＜Explanation of SWAT parameter>

Par	Name	Type	Description	Location
1	ALPHA_BF	Sub	Baseflow alpha factor [days]	*.gw
2	GW_DELAY	Sub	Groundwater delay [days]	*.gw
3	GW_REVAP	Sub	Groundwater "revap" coefficient	*.gw
4	RCHRG_DP	Sub	Deep aquifer percolation fraction	*.gw
5	REVAPMN	Sub	Threshold water depth in the shallow aguifer for "revap" [mm]	*.gw
6	GWQMN	Sub	Threshold water depth in the shallow aguifer for flow [mm]	*.gw
7	CANMX	Sub	Maximum canopy storage [mm]	*.hru
8	GWNO3	Sub	Concentration of nitrate in groundwater contribution [mg N/l]	*.gw
10	CN2	Sub	Initial SCS CN II value	*.mgt
15	SOL_K	Sub	Saturated hydraulic conductivity [mm/hr]	*.sol
16	SOL_Z	Sub	Soil depth [mm]	*.sol
17	SOL_AWC	Sub	Available water capacity [mm H20/mm soil]	*.sol
18	SOL_LABP	Sub	Initial labile P concentration [mg/kg]	*.chm
19	SOL_ORGN	Sub	Initial organic N concentration [mg/kg]	*.chm
20	SOL_ORGP	Sub	Initial organic P concentration [mg/kg]	*.chm
21	SOL_NO3	Sub	Initial NO_3 concentration [mg/kg]	*.chm
22	SOL_ALB	Sub	Moist soil albedo	*.sol
23	SLOPE	Sub	Average slope steepness [m/m]	*.hru
24	SLSUBBSN	Sub	Average slope length [m]	*.hru
25	BIOMIX	Sub	Biological mixing efficiency	*.mgt
26	USLE_P	Sub	USLE support practice factor	*.mgt
27	ESCO	Sub	Soil evaporation compensation factor	*.hru
28	EPCO	Sub	Plant uptale compensation factor	*.hru
30	SPCON	Bas	Lin. Re-entrainment parameter for channel sediment routing	*.bsn
31	SPEXP	Bas	Exp. Re-entrainment parameter for channel sediment routing	*.bsn
33	SURLAG	Bas	Surface rumoff lag time [days]	*.bsn
34	SMFMX	Bas	Melt factor for snow on June 21 [mm H2O/℃-day]	*.bsn
35	SMFMN	Bas	Melt factor for snow on Decemner 21 [mm H2O/℃-day]	*.bsn
36	SETMP	Bas	Snowfall temperature [℃]	*.bsn
37	SMTMP	Bas	Snow melt base temperature [℃]	*.bsn
38	TIMP	Bas	Snow pack temperature lag factor	*.bsn
41	NPERCO	Bas	Nitrogen percolation coefficient	*.bsn
42	PPERCO	Bas	Phosphorus percolation coefficient	*.bsn
43	PHOSKD	Bas	Phosphorus soil partitioning coefficient	*.bsn
50	CH_EROD	Sub	Channel erodibility factor	*.rte
51	CH_N	Sub	Manning's nvalue for main channel	*.rte
52	TLAPS	Sub	Temperature lapse rate [℃/km]	*.sub
53	CH_COV	Sub	Channel cover factor	*.rte
54	CH_K2	Sub	Channel effective hydraulic conductivyty [mm/hr]	*.rte
60	USLE_C	Sub	Minimum USLE cover factor	crop.dat
61	BLAI	Sub	Maximum potential leaf area index	crop.dat

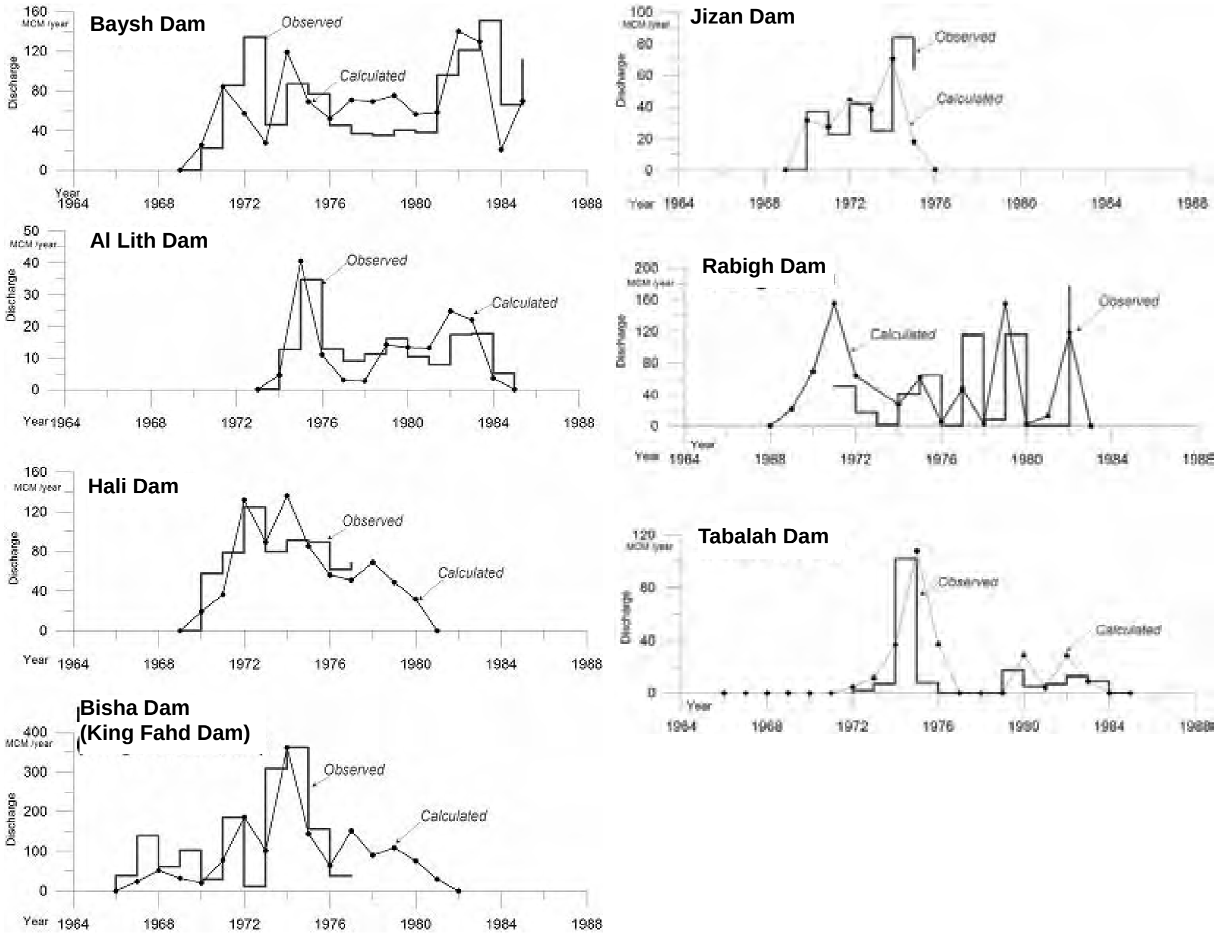


Figure 4-9 Calibration Result (Annual Discharge)

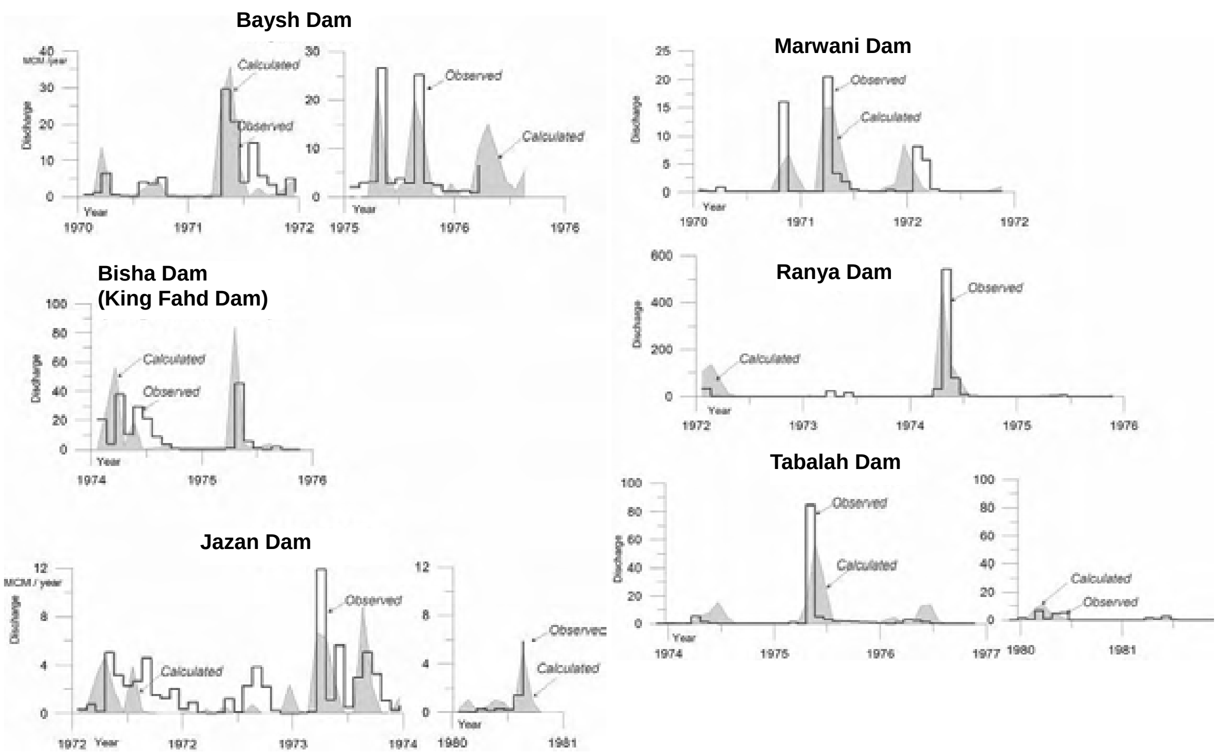


Figure 4-10 Calibration Result (Monthly Discharge)

(2) Area and Application of Model Calibration

SWAT model is basically not applied for evaluating the amount of development resource which is led by a dynamic simulation for facility planning, but is used as a tool for arranging observation data to process the water budget of the vast region. As well, it is applied for preparing the boundary condition of groundwater model, by which estimate the rechargeable water amount.

In order to maintain model's reliability with an effective approach, the interest area for model verification is to be restricted to the productive area which excludes dry (desert) area.

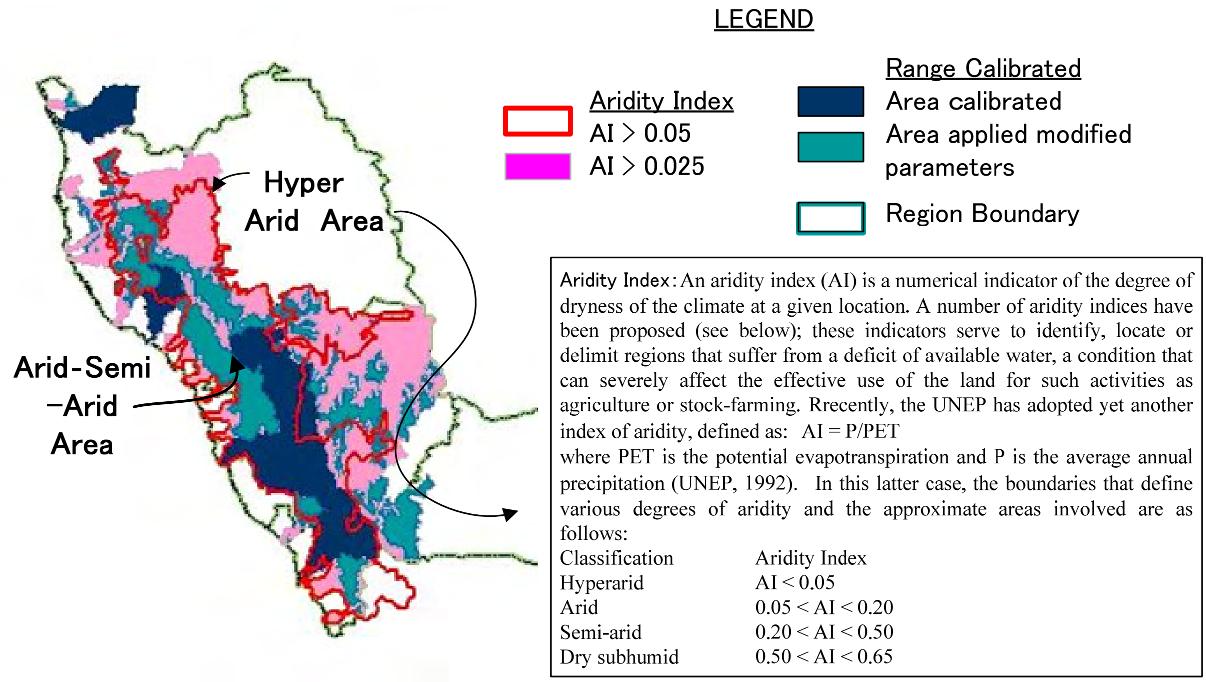


Figure 4-11 Interest Area for Model Calibration and Hyper Arid Area

Prior to the model calibration, the desert area was examined by Aridity Index (AI=Precipitation / Potential Evapotranspiration, UNEP, 1992). By AI < 0.05, Hyper Desert was distinguished from the project area, and 85,000 km^2 of Water Resources Area was extracted as an out-range of Hyper Desert, as shown in Figure 4-11.

At the beginning of model calibration, eight (8) basins of 40,000 km^2 were calibrated as first step with the interpolating process through the comparison with existing records (refer to Sub-section 4.3.1). The area reaches 45 % of 'Water Resources Area', and the extrapolating process was also followed for the range of KSA39[1] with sensitive parameter of CN2[2].

4.4 Model Output

In the project area, groundwater recharge exclusively occurs during floods in the winter season. With

[1] The range of KSA39 (a type of surface condition: mostly rocky mountain) covers the center the project area and ranges up to 70,000 km^2. Totaling the extrapolated area of 70,000 km^2 with 8 interpolated basins of 40,000 km^2, 110,000 km^2 is summed up, and overlapping area of 30,000 km^2 is subtracted from it then 80,000 km^2 comes as net calibrated area. Consequently, 90 % of 'Water Resources Area' is taken into consideration in the calibration process.

[2] As an initial value, 61 of CN2 was given as model default according to landuse classification (i.e. 61 of CN2 is correlative to dried arable land with mixture of grass and shrub). However, higher value was required trough interpolating process for eight (8) basins due to less response of discharge to rainfall, and factual surface condition covering by rocky and bare land. For the selection of CN2, plural alternatives with a zone from 30 to 90 were engaged in the interpolation process for 8 basins. As the most appropriate value for the classification of KSA39, CN2=70 was finally decided.

normal precipitation, it may be intercepted and held in the vegetation canopy or fall to the soil surface, or later lost by evaporation. By the heavy rain, water flows overland as runoff and moves quickly toward a stream channel and contributes to short-term stream response. At the down reach of wadi courses, especially lain by superficial deposits or porous sedimentary rocks, water begins to be infiltrated into the subsurface. Even in held in the soil layer, the water is evapotranspiration and rest of water may slowly make its way to the surface-water system via underground paths. Along with the potential pathways of water movement in the project area, flowing outputs (a)-(f) are selected and post-processed among SWAT's options.

a. Area Rainfall
b. Potential Evapotranspiration
c. Actual Evapotranspiration
d. Soil Content
e. Water Yield (Surface Runoff)
f. Percolation / groundwater Recharge

(1) Area Precipitation

Area rainfall was calculated using with the 85 records. The area precipitation for catchments was obtained as a range form 15 mm/year to 425 mm/year in 30 years' average (1975-2004) for the basin, as shown in Figure 4-12.

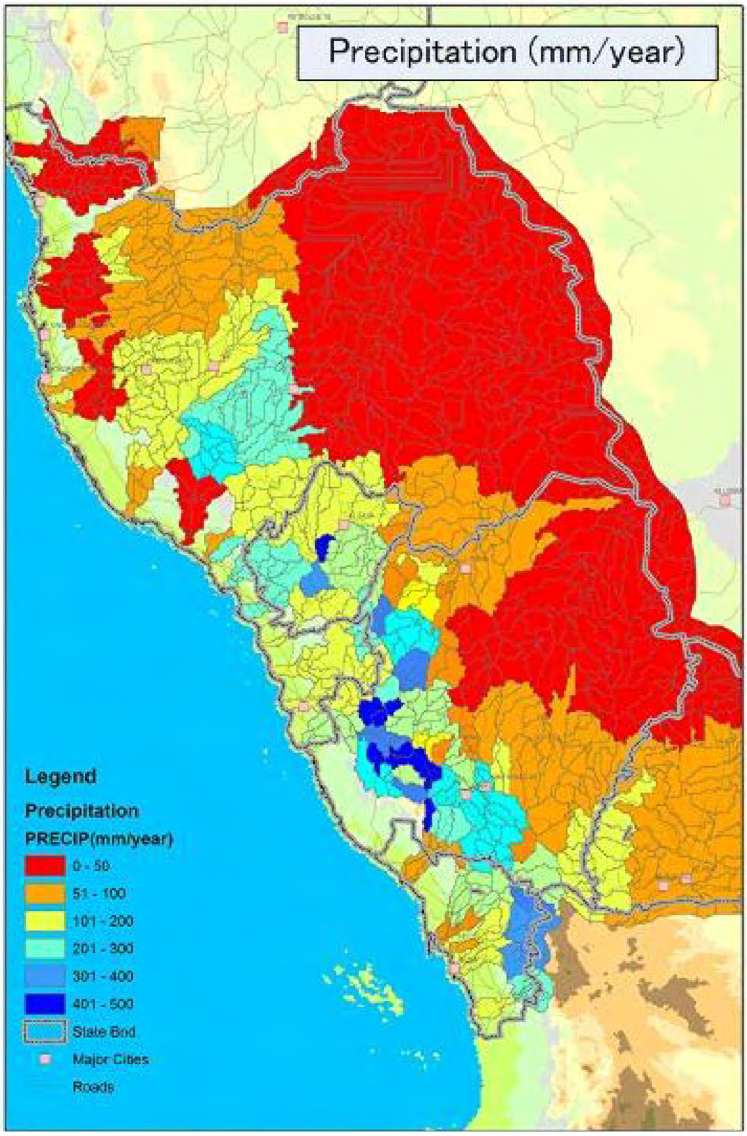


Figure 4-12 Area Precipitation

(2) Potential Evapotranspiration

Potential evapotranspiration is the rate at which evapotranspiration would occur from a large area covered with growing vegetation which has access to an unlimited supply of soil water. The calculation was made with Penman-Monteith method, and a range 660 to over 4,830 mm/year was obtained, as shown in Figure 4-13.

(3) Actual Evapotranspiration

The calculated value of evapotranspiration includes evaporation from rivers and lakes, bare soil, and vegetative surfaces; evaporation from within the leaves of plants (transpiration). The model computed evaporation from soils and plants separately. Potential soil water evaporation was estimated as a function of potential evapotranspiration and leaf area index. Actual soil water evaporation was estimated by using exponential functions of soil depth and water content. Plant transpiration was simulated as a linear function of potential evapotranspiration and leaf area index. As the result of the calculations, 10 to 610 mm/year of actual evapotranspiration was taken, as shown in Figure 4-13.

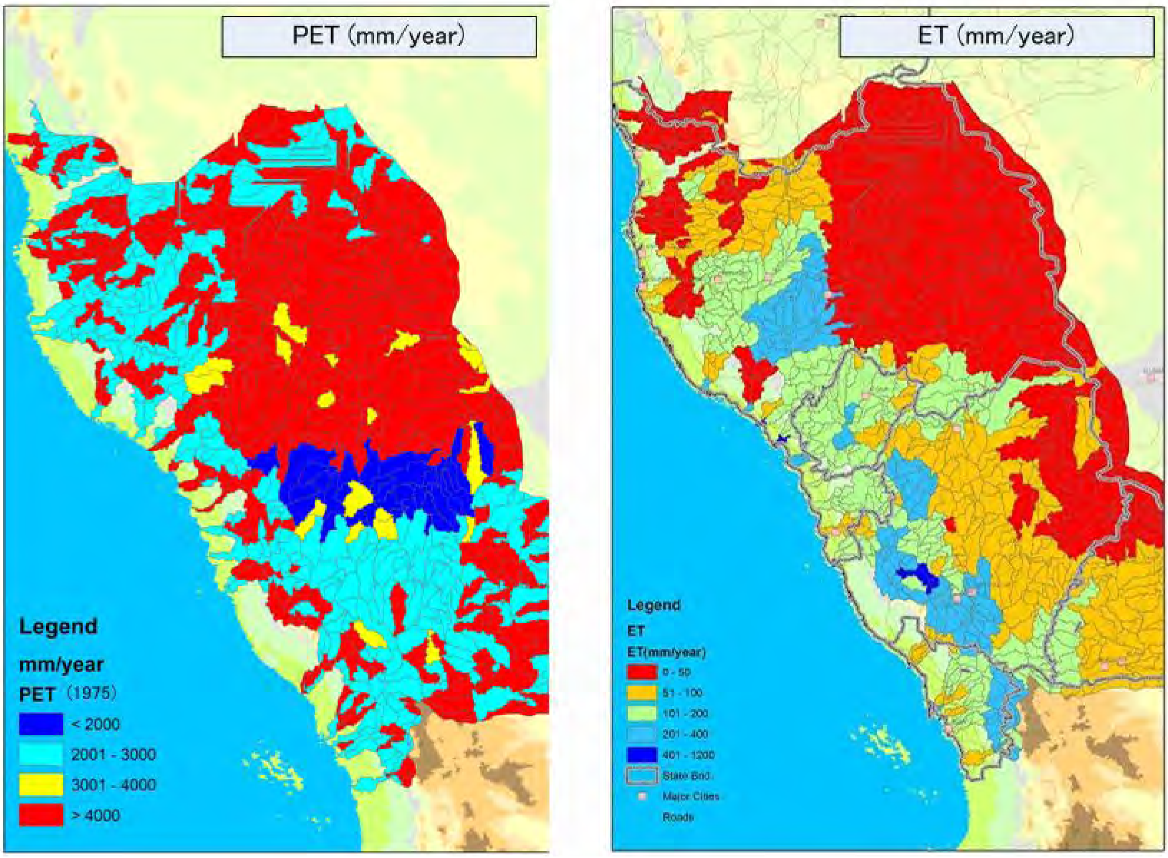


Figure 4-13 Evapotranspiration Potential (PET) and Actual Evapotranspiration (ET)

(4) Soil Water Content

Soil water content was calculated by Green-Ampt and Mein-Larson method. The method is to predict infiltration with an assumption of surface runoff occurring by rain fall. When the rainfall intensity is less than the infiltration rate, all the rainfall will infiltrate during the time period and cumulative infiltration. Inversely, when its intensity is higher than the infiltration, excess water turns to surface runoff.

As water infiltrates into the soil the method assumes the soil above the wetting front At the front, there is sharp break in moisture content and respectively providing different hydraulic conductivity parameters. The result of simulation at 31 Dec. 2004 is given in Figure 4-14.

(5) Water Yield (Surface Runoff)

Flow in a watershed is classified as overland and channelized. The primary difference between the two flow processes is that water storage and its influence on flow rates is considered in channelized flow. Main channel processes modeled by SWAT include the movement of water in the stream net work. Open channel; flow is defined as channel flow with a free surface, such as flow in river or partially full pipe. SWAT uses Manning's equation to define the rate and velocity of flow. Water is routed through the channel network using valuable storage routing method. SWAT treats the volume of out flow calculated with valuable storage routing method as the net amount of water removed from the reach. As transmission losses, evaporation and other water losses for the reach segment are calculated, the amount of outflow to the next reach segment is reduced by amount of the loss. When outflow and all losses are summed, the total amount will equal the value obtained from valuable storage routine method. In Figure 4-14 surface runoff (called as Water yield in SWAT as same meaning of surface runoff of individual catchments) is shown.

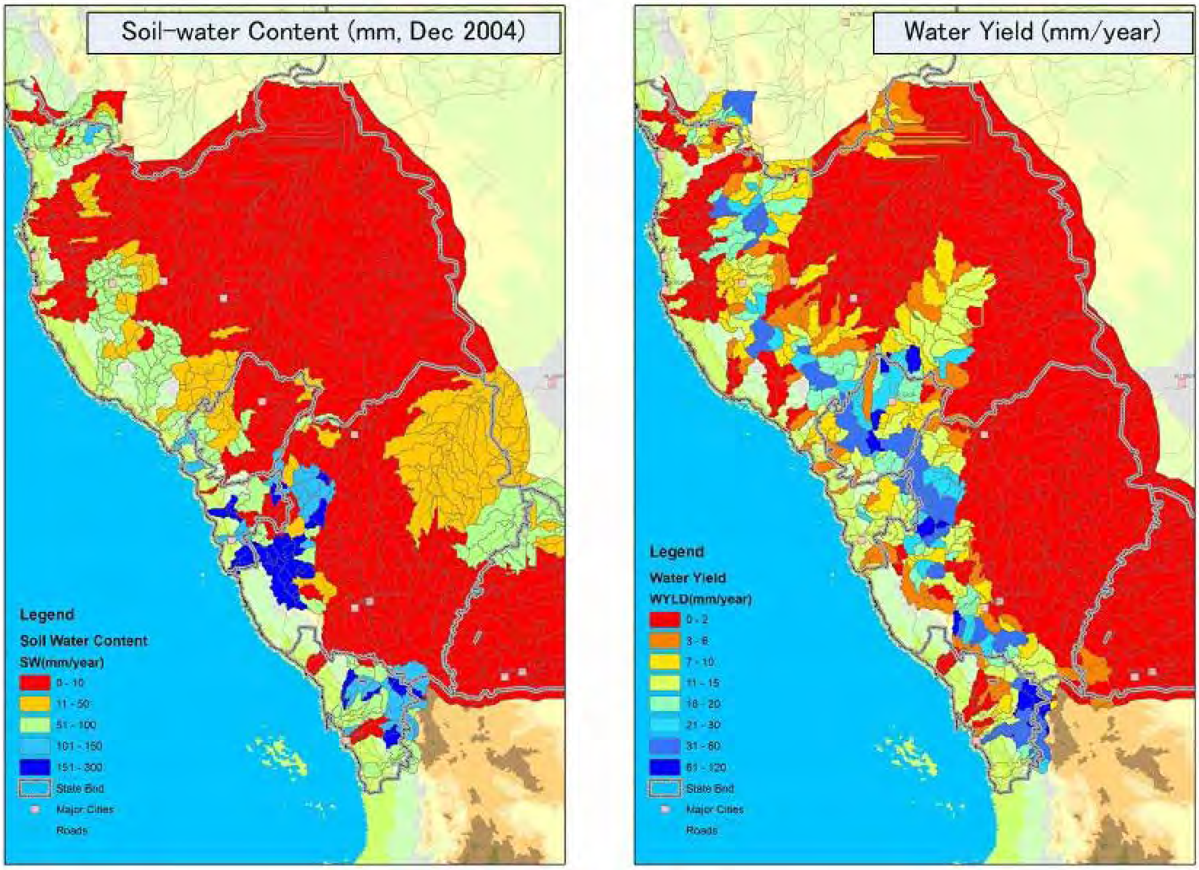


Figure 4-14   Soil Water Contents and Water Yield

(6) Percolation and Groundwater Recharge

Percolation was calculated for a soil layer in the profile. Water is allowed to percolate if the water content exceeds the field capacity water contents for that layer. Water that moves past the lowest depth of the soil profile by percolation enters and flows through the vadose zone in to the shallow aquifer. The lag between the time that water exits the soil profile and enters the shallow aquifer will depend on the depth to the water table and the hydraulic properties of the geologic formations in the vadose zone and groundwater zones. If the time is long enough to move water in to the aquifer like as 30 years as that of the modeling, the amount of percolation water are almost same as groundwater recharge. In the calculation, percolation amount was treated as ground amount water recharge. In Figure 4-15 Percolation is shown.

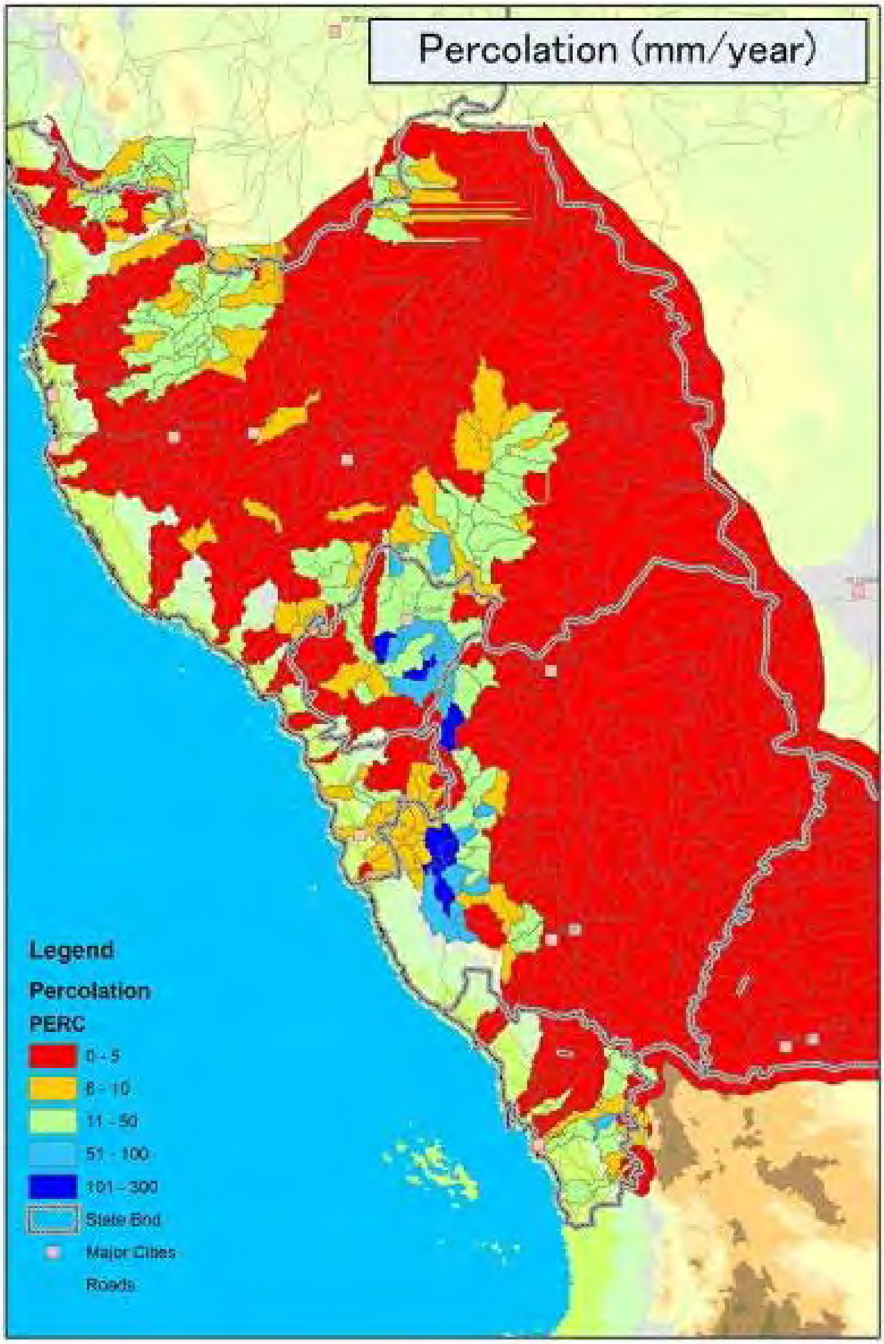


Figure 4-15 Percolation

(7) General Water Balance in Model Area

At an average for 30 year in the model area, 120 mm/year is lost by evapotranspiration out of 130 mm/year of rainfall. Remaining 7 mm is infiltrated into shallow aquifer and stored as groundwater.

In the balance of wet year (1st of 15 years), the area rainfall is 258 mm, and out of this, 154 mm/year is allocated to evapotranspiration. Others of 16 mm/year turn into the subsurface system.

4.5 Water Resources of Wadis

The water balance and river discharge were estimated for 30 years from 1975 to 2004 as is described in sub-section 4.1 to 4.4. Using the same model, the series of monthly discharge was re-calculated and arranged into basin's water balance.

(1) Simulation Period and Wadis

Prior to resume the modeling for basin's water balance, the rainfall data was reviewed with MOWE database[3].

Although 600 or more rain gauge stations in were registered in the database in the project area (of five regions), most of them are temporarily installation only for their project periods. The permanent stations beyond years are limited to 130 stations.

Even as many as 130 stations, most of them are located on Hijaz mountains or stand on the summit of Al Baha-Abha-Jazan mountain.

The observatories are unevenly located on the urban area of Abha and Jazan, While in remote area occupying the major of basin catchments; in particular 'Red Sea coast scarp' and inaccessible slope, the available stations for hydrological analysis is very sparse as shown in Figure 4-17.

The establishment of stations, it had begun from early 1960s'. However, their apparatus had also already superannuated by 1990s and the number of station is decreasing with the peak of 1995.

Moreover, the management on their facility had been also overdue by the ministries restructuring which had separated from MOA in 2002 and integrated with the electric power department in 2003. The missing observation therefore has frequently contaminated (refer to Figure 4-16) in the observation record.

In recent years, as counter measures for this, MOWE has commenced the automating apparatus and registering record to database.

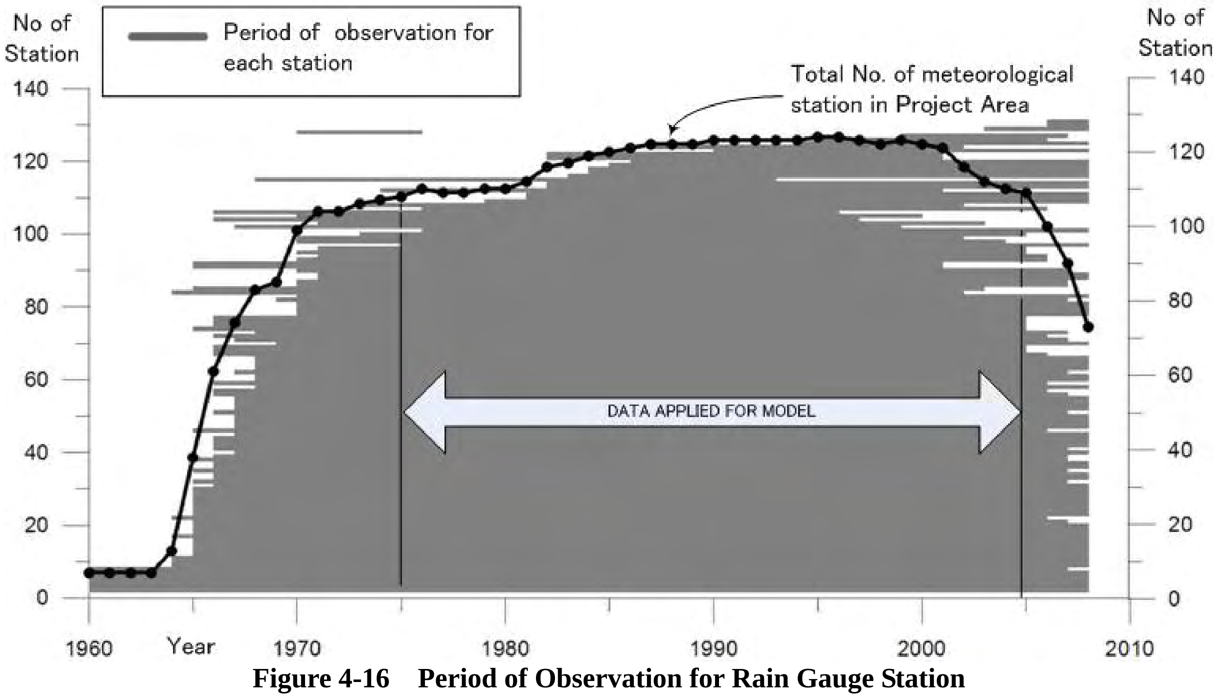


Figure 4-16 Period of Observation for Rain Gauge Station

[3] By 2009, MOWE has begun the establishment of National Water Database and updating the all the related information to water resource, itemized as rainfall, surface water, groundwater, water quality, dam, reclaimed water facility, desalinization plant, water supply network and etc.
The database establishment is conducting by two-year project and has started from 2008. At this moment it is still under construction, the database is however able to be accessible. Through provisional connection to database, additional rainfall data was down-loaded in. this period.

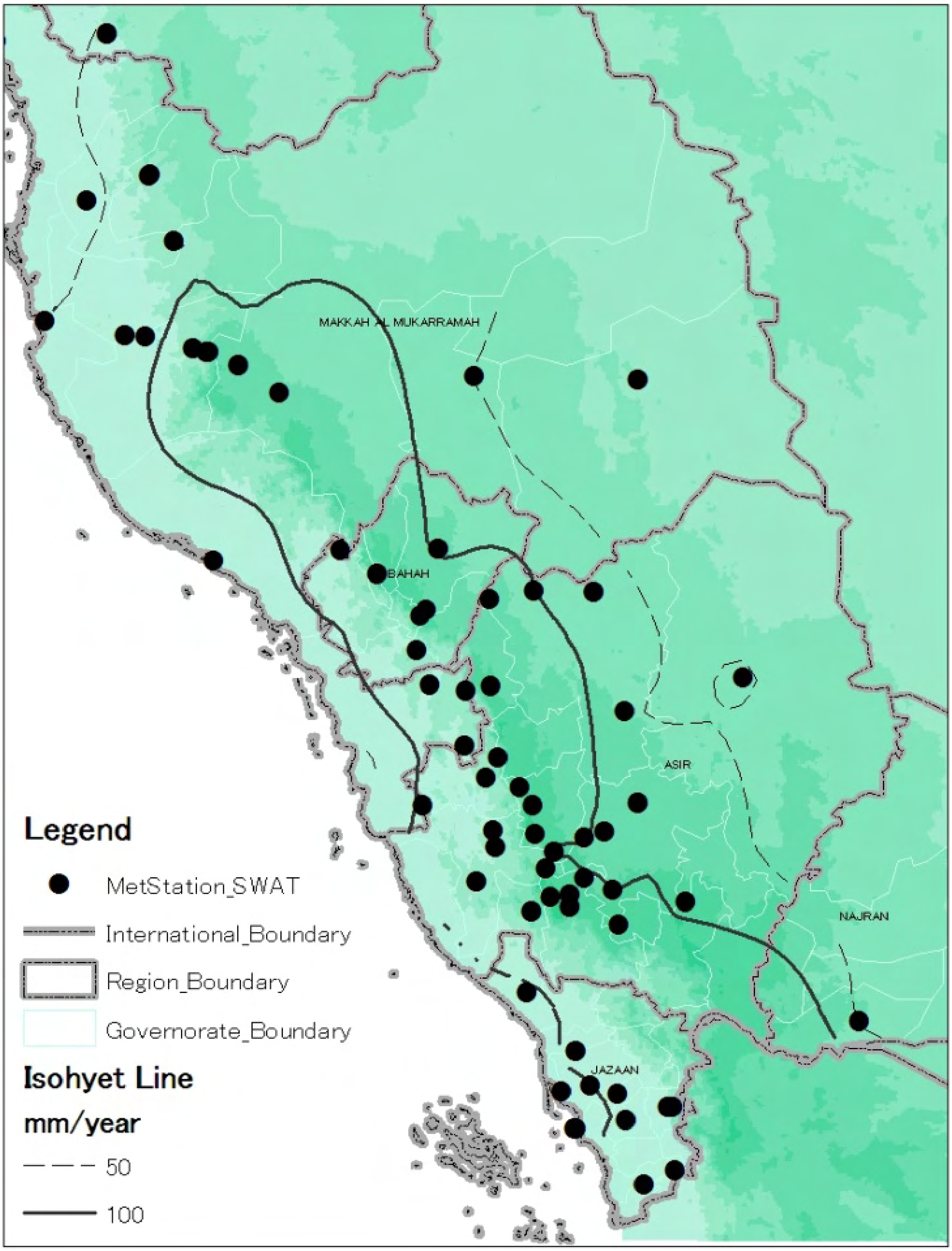


Figure 4-17 Location Map of Rain Gauge Station (Input Data of Model)

As for the requirement of the model, continuous record was substantial to maintain the model accuracy. As well, to make reliable evaluation for hydrologic phenomena, 30 years' record was also requested. Considering both conditions, 85 points of 30 years record from 1975 to 2004 were selected as input data from 130 stations described above.

With 85 points, the density of rain gauge station (as input data) was calculated as 1,800 km^2/point in the 160,000 km^2 of model area. The density, if it compares with WMO criteria (1994) of which is 600 to 900 km^2/point is recommended density of rain gauge possibly to conduct a suitable hydrological analysis, the input data are recognized as the insufficient quantity and quality which requires further information.

Moreover, taking the strong shower of the rain here and its local dependency into consideration, the model has a limitation in accuracy, and requires a consideration on the use of result.

To discern the model accuracy, the calibration result was re-examined. As long as the verified result made ever was referred, there was a validity in use of yearly analysis, but in monthly analysis, discrepancy between model's estimations and observation value was brought partly (for example in coastal area of Makkah and Asir region). Daily trace was not able to be pursued by the model.

Due to the model accuracy, in usage of the model result, an attention was paid for observation points located in Najran, Red Sea side along Asir-Makkah.

BASINS: Applied for SWAT to Estimate Monthly Discharge

Figure 4-18 Model Basin

(2) Summary of Basin Water Balance

31 outlets composed of 21 points of Red Sea coast and 10 points of Najd were used for the estimation of basin water balance. The range of the basins shows in Figure 4-18, and the summary of water balance are shown in Table 4-3.

Table 4-3 Summary of Water Balance

Moutain-Plain (Area 161,150 sqkm)							
Basin					Water Potential (MCM/year)		
No	B_ID	Basin	Area (Sqkm)	Outlet Ptn. at	ER (Mountain+Plain)	Surface Runoff	Ground-water Runoff
1	J5	Khulab	1,568	Jazan	47	1	46
2	J4	Jazan	1,862	Jazan	100	14	85
3	J3	Damad	1,376	Jazan	77	12	65
4	J2	Baysh	6,367	Jazan	98	14	84
5	J1	Itwad	1,972	Jazan	25	1	24
6	M12	Hali	5,659	makkah	99	89	11
7	M11	Yiba	3,346	makkah	91	70	21
8	M10	Yiba_N	2,416	makkah	59	38	20
9	M9	Doquah_S	1,726	makkah	53	41	13
10	M8	Doquah	1,603	makkah	24	18	6
11	M7	Doquah_N	1,578	makkah	16	26	-10
12	M6	Fagh	2,362	makkah	15	36	-21
13	M5	AlLith_Sadiyah	3,338	makkah	17	7	9
14	M4	Naaman	2,513	makkah	8	26	-18
15	M3	Fatimah	4,306	makkah	46	28	18
16	M2	Ghoran	4,916	makkah	51	25	26
17	M1	Ghoran_N	2,355	makkah	16	9	7
18	M0	Khulays	5,462	makkah	100	57	43
19	M1	Qudayd	2,207	makkah	15	7	8
20	M2	Rabigh	6,699	makkah	116	65	52
21	M3	Qahah	3,356	makkah	5	1	4
22	M1	Aqiq	15,485	makkah	47	17	30
23	M2	Turabah	7,786	makkah	154	106	48
24	M2	Ranya	7,885	makkah	144	90	54
25	A1	Bisha	22,303	asir	117	53	64
26	A2	Tathlith	17,237	asir	21	13	8
27	N1	Habana	7,186	Najran	12	1	11
28	N2	Najran	6,999	Najran	28	3	25
29	N2	Mayayn	3,128	Najran	5	1	4
30	N3	Hynah	2,262	Najran	5	0	4
31	N3	Habal	3,891	Najran	3	0	3
Total (on basins)			161,149		**1,614**	**870**	**744**

ER in Table 4-3 is defined as 'Natural renewable resources4' and 1,614 MCM/year totaled with 744 MCM/year of groundwater and 870 MM of surface water is calculated in five (5) regions in the project area.

On the other hand, the applied value for the master plan (M/P) is referred as 'Exploitable water resources5', which is different from 'Natural renewable resources' and shall consider with the human

[4] These are defined as the average manual flow of rivers and recharge of aquifers generated from precipitation. It distinguishes between the natural situation (natural renewable resources), which corresponds to a situation without human influence, and the current or actual situation（FAO/BRGM, 1996）.

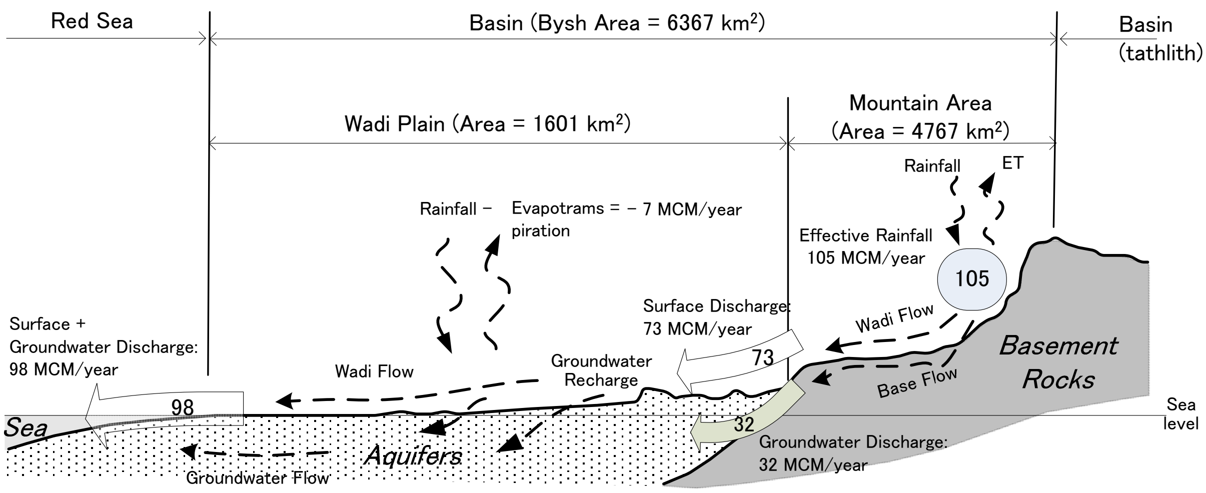
[5] Exploitable water resources (manageable water resources or water development potential) considers factors such as: the economic and environmental feasibility of storing floodwater behind dams or extracting groundwater; the physical possibility of catching water which naturally flows out to the sea; and the minimum flow requirements for navigation, environmental services, aquatic life, etc（FAO/BRGM, 1996）.

factors' such as existing facilities, the economic and environmental and the physical possibility of catching water which naturally flows out to the sea. The value shall be taken from the contents of development plan. Its evaluation process therefore describes in other sectors such as Water Resources Development and Management along with the formulation of M/P.

(3) Water Balance in Major Wadi s

In addition to 31 outlets, internal outlets were set along the mountain border between mountains and plain areas and created total 64 divisions (31 plain catchments and 34 mountain catchments). For divisions, monthly discharge and water balance were calculated for 30 years. In Figure 4-19 (1) ~ 4-19 (6) shows the summary of water balance for respective divisions and its expiations referred as below.

Explanation of Balance Items（Figure 4-19 (1) ~ 4-19 (6))



Explanation: The balance items used in the Figure 4-19 (1) ~ 4-19 (6)) is explained with Baysh basin's result shown in Figure 4-19(1). Baysh basin has an area of 6,367 km^2 divided in to the 4,767 km^2 of the mountain area and 1,601 km^2 of the wadi plain. The mountain area has 200 mm, and 90 % of it is lost by the evapotranspiration and the rest of 22 mm (105 MCM/year) is flowing in the mountain wadis. At the mountain foot, of 105 MCM/year, 73 MCM/year is delivered in to wadi channels and 32 MCM/yea is turn into a baseflow and a groundwater. In the wadi plain extending from mountain foot to the sea, 120 mm of rainfall is received. However, a higher evapotranspiration from surface and even groundwater's causes a negative balance of 7 mm. Finally at the end of wadis, the 98MCM/year of ground water released to the sea as groundwater run-off, which is reduced 7 mm from 105MCM/year of ER.
Note: Values (balance item) marked by underline is also indicated in Figure 4-19 (1) ~ 4-19 (6).

(a) Red Sea Coast (Jazan Area)

Jazan area is regarded as 'wet area' in the project area indicating as 180 to 300 mm/year of basin rainfall. At the southern part, Khurab, Jazan, Damad basin lain on and were calculated as high as 270 mm/year of area rainfall, and 32 to 57 mm of height of runoff (37 to 82 MCM of flow discharge, 0.001~0.002m^3/sec/km^2 of specific discharge) at the outlets of mountain border.

However, since the rainfall record is lacking at the upper parts of their basins near/in Yemen territory, the model input had to be extrapolated by Saudi's observatories. While in Baysh and Itwad basin, by both reasons of fewer rainfall and lager area of basin, they show less rainfall of 179 mm/year and 19 mm of flow discharge (6,271km^2 of catchment area, flow discharge of 119 MCM, specific discharge 0.0003m^3/sec/km^2 as shown in Figure 4-19 (1).

(b) Red Sea Coast (Asir-Makkah-Al Baha Area)

The area consists of the Red Sea coast of Asir region, Itwad basin of Jazan region, and Yiba basin of the Makkah region. There are Quaternary basalt and Precambrian rocks, and extrude nearby the Red Sea coast and forming coastal hills. Therefore, the alluvium plain limitedly develops within the narrow strip between hills.

In Hali basin, as large as 5,659 km^2 of catchment area, although it once flows east in the mountain in Asir region, it is barred by basaltic hills and consequently turn its flow north at the mountain foot.

On the north side of a Hali, Yiba and Dawqah basin are standing parallel in a row, and flow into Alluvial plain with recharging a part into Alluvial deposit before reaching Red Sea.

The mean rainfall of three basins was calculated as 191 mm/year, and 19 mm of flow discharge (9,303 km^2 of catchment area, flow discharge of 192 MCM, specific discharge 0.0002m^3/sec/km^2.

In the area, the groundwater is highly extracted by the shallow wells, consequently a salinization is observing in some wells far from wadi courses. As well, seawater intrusion is also reported at wells located near the seashore.

Hali basin conveys the largest water potential estimated as over 100 MCM/year, and Yiba basin follows as the second largest wadi (Figure 4-19 (2)).

(c) Red Sea Coast (Al Baha−Makkah Area)

The area consists of six basins. They are three(3) of Dawqah basins which is located in Al Baha region and Al Lith, Fagh and a Naaman basin in the Red Sea coast of Makkah region.

In the area, the flood water produced in the mountains flashes into the plain. During flooding, a part of surface water converts into groundwater, and the remaining is directly discharged as surface water to Red Sea.

Three (3) of Dawqah basins (in Al Baha) lie on hilly terrain which forms Tertiary formation. Controlling by geologic condition, their channels are in places strangulated.

Moreover, the length of Alluvial plain is shorter (20 km) than the other basins. While, other three basins (in Makkah) have the large alluvial plains with 30 km wide and tributaries also develop nearby the seashore.

157 mm/year of basin rainfall and 23 mm of flow discharge (8,296 km^2 of catchment area, flow discharge of 188 MCM, specific discharge 0.0001 m^3/sec/km^2 was calculated. In general, aridity is higher and outflow is fewer toward the north. In the area, Dawqah basin has the highest water potential, and the amount of outflows was estimated as about 50 MCM/year (Figure 4-19 (3)).

Figure 4-19 (1) Summary of Water Balance (Red Sea Coast: Jazan Area)

Figure 4-19 (2) Summary of Water Balance (Red Sea Coast: Asir-Makkah-Al Baha Area)

Figure 4-19 (3) Summary of Water Balance (Red Sea Coast: Al Baha–Makkah Area)

(d) Red Sea Coast (Makkah)

The area adjoins to the northern part of the region of Makkah and includes the southern part to Fatimah, Ghoran, and Khalays (Marawani), Qudayd, Rabigh and Qahah basin. Among them, the mountain part of Rabigh and Qahah basin is located in Madinah region.

Tertiary basalt also spreads in the north of the area and Marawani-Ghoran basin. The geologic feature acts as a pervious zone at the surface and accelerates the groundwater recharge even in the mountain area. To the seashore, the Alluvial plain develops between basalt hills.

There are few rainfalls of 74 mm/year and low 11 mm of flow discharge (20,643 km^2 of catchment area, flow discharge of 221 MCM, specific discharge 0.00005 $m^3/sec/km^2$ behaves as an arid zone. Since a big flood occurs at intervals of 10 years from several years, the amount of basin outflow which exceeds 100 MCM/year at the Marawani and Rabigh basin is estimated.

At the flood on November 26, 2009, 90 mm/4hrs of heavy rain was recorded (Figure 4-19 (4)).

(e) Eastern Slope to Najd (Makkah Region)

The area lain on the eastern slope of Makkah to Asir region, and includes Aqiq, Turabah, Ranyah and Bisha basin from the north.

All are large basins. The biggest one is Bisha basin and occupies 13,000 km^2. King Fahd Dam (biggest dam in KSA, catchment area of 7,600 km^2, storage of 325 MCM with reservoir area of 18 km^2 in Saudi Arabia) is located at the middle stream of the basin.

Although the basins in the area are wide, they lie in the arid zone indicating as low as 100 mm/year of rainfall. As is the east or to the downstream of basins, evaporation rate is higher.

By the actual measurement from 1975 to 1996, the pan-evaporation rate is reported as 10.1 mm/day as yearly average (MAW, aluminum-Qahtany, 1998).

Effective rainfall at the Turabah dam is as large as 150 MCM, and 117 MCM at Bisha (King Fahd Dam). The average rainfall of the area is 135 mm/year, and flow discharge is 5 mm (37,127 km^2 of catchment area, flow discharge of 191 MCM, specific discharge 0.00003 $m^3/sec/km^2$ as shown in Figure 4-19 (5).

(f) Eastern Slope to Najd (Asir-Najran Region)

The area includes Tathlith, Habawnah, Najran, Hynah, Habal and Myayn basin. Of these, Three (3) basins of Tathlith, Habawnah and Najran extend Nejid-Hijaz mountain area. Other two (2) basins of Hynah and Habal are located on Paleozoic Aquifer (mainly Permian Wajid Aquifer). At the southern end, Myayn basin adjoins to Yemen territory.

In the area, amount of rainfall is supposed to be larger as is closer to Yemen, while is fewer toward the northeast where are near Tathlith, Hynah and Habal basin.

Although the inflow from Yemen is expected to be high at Habawnah, Najran and Mayayn basin, the calculation was not done with in-situ data due to the lack of observation data.

As for the average rainfall, 99 mm/year was estimated and flow discharge was calculated as 0.1 mm (41,083 km^2 of catchment area, flow discharge of 18 MCM, specific discharge 0.000002 $m^3/sec/km^2$ as shown in Figure 4-19 (6).

Figure 4-19 (4) Summary of Water Balance (Red Sea Coast: Makkah Area)

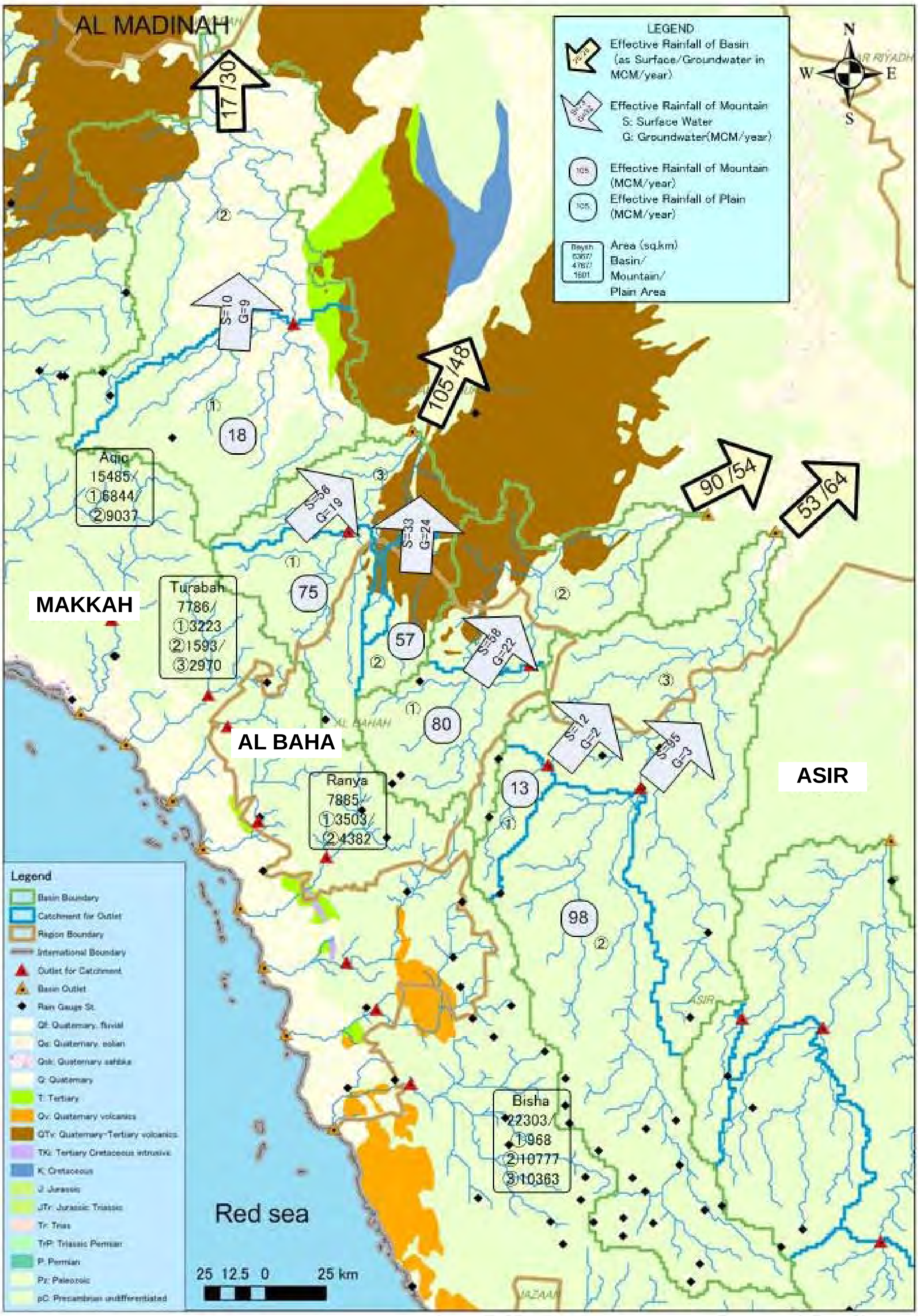


Figure 4-19 (5) Summary of Water Balance (Najd-Ad Dahna: Makkah Area)

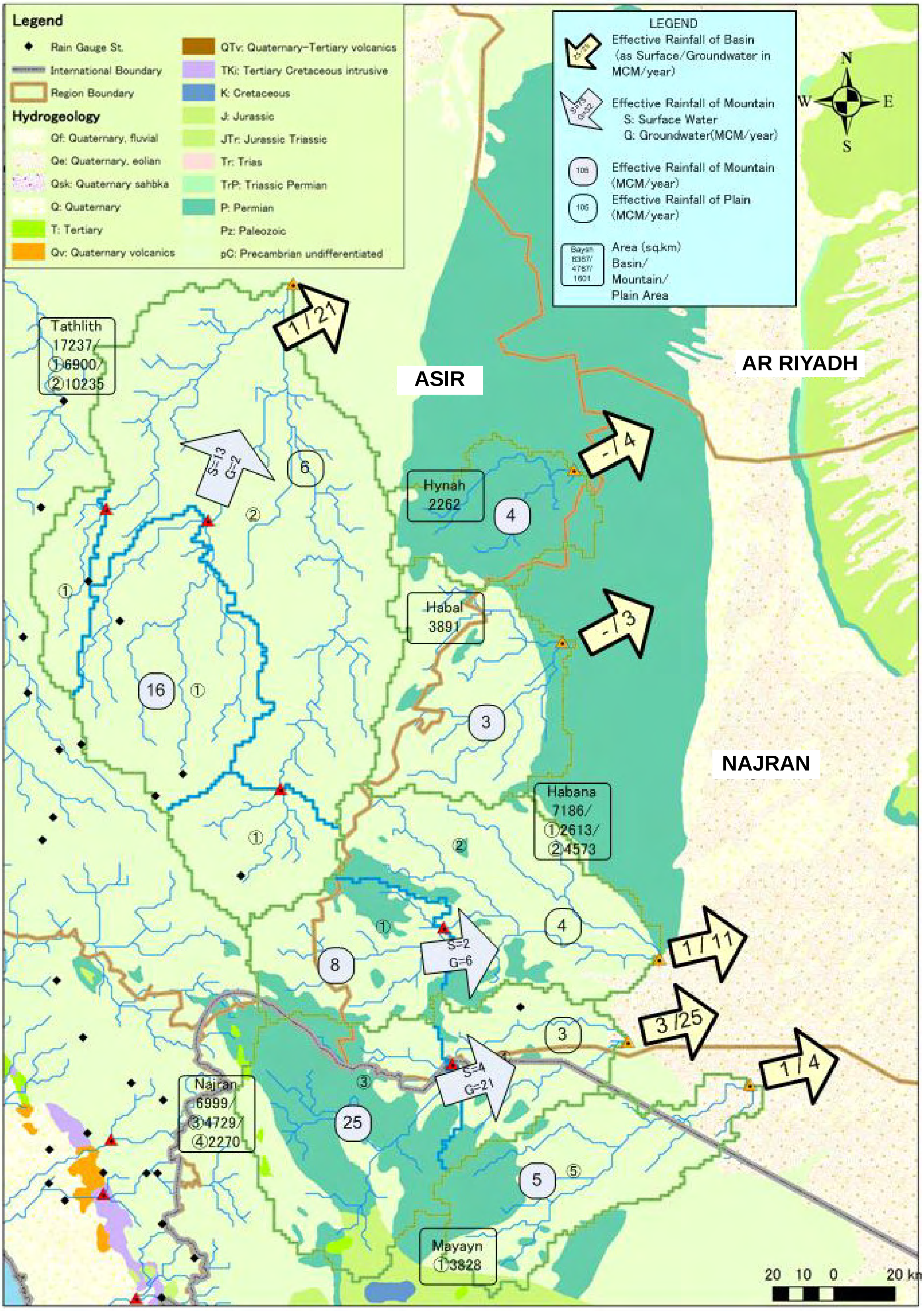


Figure 4-19 (6) Summary of Water Balance (Najd-Ad Dahna: Asir-Najran Area)