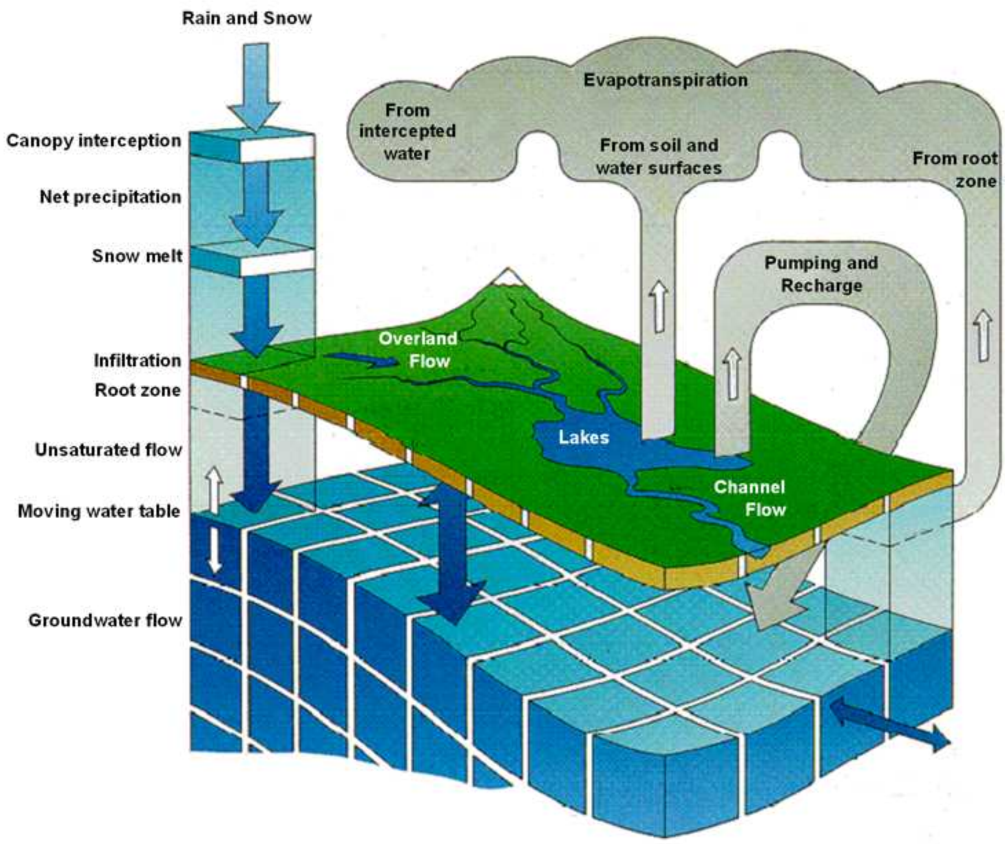
CHAPTER 5 ESTABLISHMENT OF HYDROLOGICAL CYCLE MODEL FOR URMIA LAKE BASIN

5.1 Establishment of MIKE-SHE Model

To elaborate a hydrological simulation engine for the ULRP decision support system, the distributed hydrological model (hereinafter called as "the model") was established by MIKE-SHE based on collected information and examination results discussed in the previous chapter-3 and chapter-4.

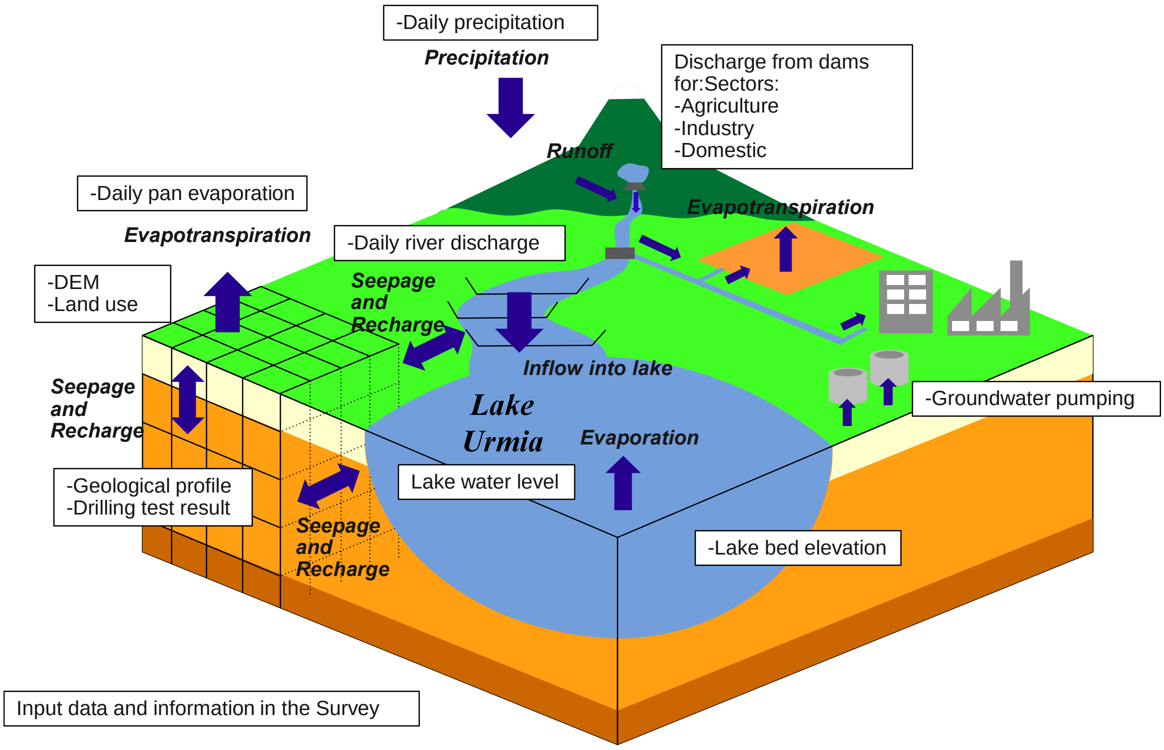
5.1.1 Outline of MIKE-SHE Model

MIKE-SHE is a mesh-based model, in which the entire basin is divided horizontally into orthogonal meshes, and vertically into multiple columnar soil layers. Each divided block is given with observation values including precipitation, and parameter values including permeability coefficient to analyze water flow among the entire basin. Furthermore, optional tools are prepared for the process of pre- and post-calculation, digitizing of paper-based information, interpolation of data, graph drawing and animations of the results, etc. The source code, however, is not open to the public. In the Survey, Figure 5.1.1 and Figure 5.1.2 present conceptual diagrams of the model and applied input data and information, respectively.



*Source: DHI

Figure 5.1.1 Conceptual Diagrams of the Model



*DEM: Digital Elevation Model

Figure 5.1.2 Applied Input Data and Information for MIKE-SHE Modeling

5.1.2 Cooperation on Decision Support System

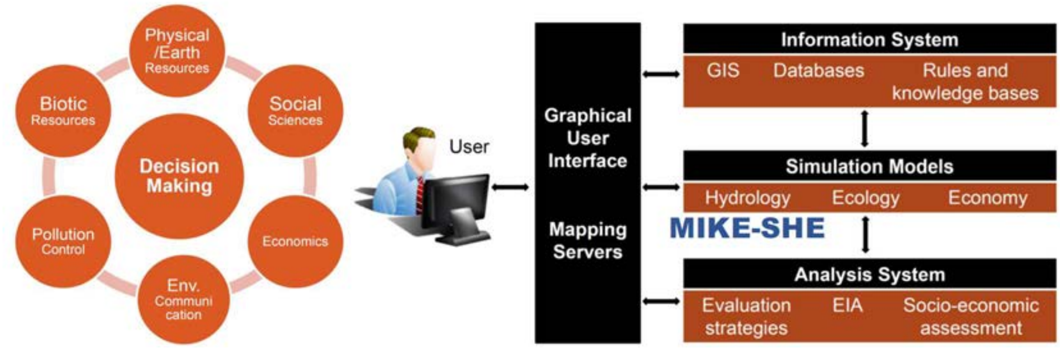
(1) Outline

ULRP presents the 25 solutions to restore the Urmia Lake Basin. Establishment of a Decision Support System (DSS) is mentioned as one of the solutions in the program B.12 "Developing a Decision Support System (DSS) for Integrated Management of Urmia Lake Watershed in No.15 Design and Implementation of an Integrated Decision Support System for integrated management of Lake Urmia Basin" Tasks for DSS, which consist of three part (Phase Zero, Phase I and Phase II), started from the second quarter of 2017 and scheduled to be completed in the second quarter of 2020.

The Phase Zero aimed at establishment of "Urmia Lake Database (ULRPDB)" which is like a platform to store reports, paper documents, books, maps/GIS layers, time-series data/tables, videos, images/photos and letters. Phase I aimed at construction of "Spatial Data Infrastructure (ULSDI)" which enables users to access a data server which is connected to web/GIS servers through user interface. The users can access data stored in the servers and make individual/grouped database rooms in the web server. The tasks for Phase I was just finished at March 2018. After that, ULRP takes actions to complete DSS which will involve hydrological cycle models as well as other models related to physical and social conditions as shown in Figure 5.1.3 (see Left figure).

Through the steps as described above, the DSS will be established along with the approaches, namely, a) Integrated Modeling Approach, b) Scenario Analysis and c) Shared Vision planning, which are very important principles to quantitatively evaluate scenarios prepared by stakeholders. The image of DSS and its components are expressed by ULRP as shown in Figure 5.1.3.

As of May 2020, the DSS system is not completed due to waiting for all of engines for the above-mentioned approaches.



Source: ULRP

Figure 5.1.3 Social and Physical Systems (Left) and Components of a DSS (Right)

(2) Application of hydrological cycle model to DSS

In accordance with ULRP, the roles and manner of utilization of the water cycle model in DSS are as follows:

- Policy makers who plan countermeasures for the restoration of Urmia Lake need to comprehensively analyze the respective results obtained from simulation modules (for example, hydrological cycle model) such as hydrological conditions, environmental impacts, and economics.
- Collaboration with other fields as shown Figure 5.1.3 can be concluded through discussions with policy makers, and optimal solutions cannot be easily obtained. The policy makers do not operate the simulation modules in each field by themselves. Therefore, the operator of the water cycle model should be a specialist in hydrology, where it is important to give the applicable information to the policy makers. In other words, it is important how to apply the specific calculation conditions obtained from the policy draft to the hydrological cycle model and calculate under the appropriate conditions.
- In the hydrological cycle model constructed in the Survey, simulations based on the countermeasures of several Urmia lake restoration programs were carried out. The quantitative outputs obtained by the hydrological cycle model are the river discharge and the water level of Urmia Lake. The analysis results using the discharge and water level will be input to the DSS center, and will be evaluated by policy makers.

Therefore, it is important to change various condition settings in order to evaluate the effects of the measures considered in the DSS after the completion of the Survey. As shown in the conditions of the model in this Chapter 5, the main components of the hydrological cycle model constructed by this model are as shown in the Figure 5.1.2, and the prerequisites for Urmia Lake restoration program considered in DSS are as shown in Table 5.1.1.

It is necessary for the operator to properly convert various condition settings into the MIKE-SHE data format. The output results of the MIKE-SHE data format must be appropriately converted and provided to policy makers. An example of data items and MIKE-SHE file format is shown in Table 5.1.2.

Table 5.1.1 Summary of Major Condition in Hydrological Cycle Model

Classification	Input Item	Prerequisites considered in DSS
Meteorological condition	Lake surface evaporation	- Improved estimation of lake surface evaporation - Change in evaporation of lake surface due to environmental changes such as global warming
	Land evapotranspiration	- Improved estimation of evapotranspiration - Change in evapotranspiration due to environmental changes such as global warming
	Precipitation	- Change in precipitation due to environmental changes such as global warming
Topography	Ground surface elevation	- Large-scale topographic change
	Lakebed elevation	- Secular changes such as sediment

Classification	Input Item	Prerequisites considered in DSS
		- Implementing measures such as dredging
Land use	Surface roughness	- Large land use changes due to environmental changes and development
Natural conditions	River network	- Detailed river specification data (implementation of cross-section survey) - Implementation of measures for river improvement (widening, dredging, etc.)
	River cross section	- Detailed river specification data (implementation of cross-section survey) - Implementation of measures for river improvement (widening, dredging, etc.)
Water use structure	Dam	- Construction of new dam - Implementing measures such as dam operation improvement
Water use	River water intake	- Implementation of measures such as changes in irrigation efficiency and demand for agricultural water
	Groundwater intake	- Implementation of measures such as changes in irrigation efficiency and demand for agricultural water

Table 5.1.2 Summary of MIKE-SHE Input / Output Data Format

Classification	Extension	Input Data	Output Data
Time Series	.dfs0	Lake evaporation, Precipitation, Dam outflow River water intake, Groundwater intake	Discharge Water level
Spatial Distribution	.dfs2	Land evapotranspiration, Ground surface elevation, Lakebed elevation, Land use data (Converted to Surface roughness [Manning N]), Others (Geological distribution, Infiltration fraction)	-
Boundary	.shp	Delineated area for areal precipitation	-
River network / structure	.nwk	River network River structure (Dam, Weir)	-
River cross section	.xns	River cross section	-

5.2 Basic Features of MIKE-SHE

MIKE-SHE basically consists of (i) precipitation, evapotranspiration, and snowmelt; (ii) land use (transpiration from plants and irrigation); (iii) surface and river flow; (iv) unsaturated flow; and (v) saturated flow, which express almost the complete process of water circulation considering their mutual interaction by simultaneous calculation of water movement. Not only each process can be individually calculated, but also the calculation is carried out with selected time steps to meet the most appropriate time scale for each process. Furthermore, all calculated results are updated at certain common time points. Thus, calculation can effectively be carried out even for long-term calculation. The water circulation process is modeled as follows.

(1) Precipitation, Evapotranspiration, and Snowmelt

Precipitation is handled as input data. When unsaturated flow is activated, evapotranspiration is handled as “evapotranspiration”. It is handled as “evaporation” when unsaturated flow is inactivated. When unsaturated flow is activated, actual transpiration is calculated by multiplying crop index with input base evapotranspiration by setting leaf area index (LAI) and root depth for land use parameters.

Snowmelt is calculated by degree-day method. In addition to input precipitation and temperature, rain/snow determination temperature and snowmelt coefficient are referred.

(2) Land Use

For land use, when unsaturated flow is activated, leaf area index (LAI) and root depth can be set according to the vegetation. LAI and root depth can also be applied as time series data.

In addition, for impermeable areas such as urban area, runoff coefficient and storage volume can be set for each calculation grid. Furthermore, irrigation can also be considered, by setting supply and demand volume in temporary and spatially distributed manner for irrigation area.

(3) Surface Flow and River Flow

Surface flow and river flow are described with diffusion wave model which is a simplified St. Venant Equation, and continuous equation (For river flow, dynamic wave model is also applicable.). Surface flow is two-dimensional (2-D), and river flow is one-dimensional (1-D). In surface flow analysis, the process of flowing toward river channels with water evaporation and seepage is incorporated. In most cases, area of river channels is much smaller than the area of the entire basin; river channels are handled as lines embedded along the grid edges.

(4) Unsaturated Flow

Since recharge of groundwater and exchange of surface and groundwater occur within an unsaturated layer, the calculation of unsaturated flow is the critical part of the model. Water flow in an unsaturated soil layer is expressed by one-dimensional (1-D) Richards Equation. In addition, for the surface layer where roots grow, water absorption to roots from the soil is also incorporated.

(5) Saturated Flow (Subsurface water Flow)

Subsurface water flow calculation is the significant part which has a great influence to the water circulation process. Two-dimensional (2-D) model is applied for single aquifer, whereas three-dimensional (3-D) model is for multiple aquifers. For complete three-dimensional (3-D) flow, the aquifer is divided three-dimensionally. When the flow is approximated to two-dimensional (2-D) (or quasi three-dimensional (quasi-3-D)), the aquifer is divided according to the geological structure. When deploying quasi-three-dimensional (quasi-3-D) model, quasi-horizontal flow is assumed. Thus the vertical variation of water head is not considered. In the groundwater analytical model, water exchange between unsaturated aquifer and river flow, water uptake and pouring at wells, water drainage through embedded pipes, etc., are modeled. Heterogeneity of the aquifer and anisotropy of permeability coefficient are also able to be incorporated.

5.3 The Governing Equation of MIKE-SHE

MIKE-SHE consists of basin model (land surface layer, unsaturated layer, and underground layer), and river model (MIKE 11). Modeled area is divided into grids to calculate horizontal and vertical water flow, as well as water exchange with river channels (one-dimensional (1-D) unsteady flow model). The fundamental governing equations for basin model (precipitation, ET, land surface layer, unsaturated layer, and underground layer) and river model are shown below. As for detailed description of mechanism of MIKE-SHE, refer to the User Manual.

- ✓ Precipitation: correction with elevation
- ✓ Snowmelt: degree-day method
- ✓ Air temperature: correlation with elevation
- ✓ Land surface layer model: two-dimensional horizontal diffusion wave model
- ✓ Unsaturated layer model: one-dimensional Richard’s equations
- ✓ Saturated layer model: two-dimensional horizontal / three-dimensional groundwater flow model
- ✓ River channel model (MIKE 11): one-dimensional dynamic wave / diffusion wave / kinematic wave model

(1) Precipitation

As described above, MIKE-SHE is the distributed hydrological model which requires input data into delineated calculation grids. Point-observed information, e.g., climatological data, is to be interpolated and applied into the model. Due to difficulty in climatological observation, observation network is insufficient especially in mountainous area with high precipitation. Therefore, precipitation is spatially corrected with elevation.

Precipitation varies linearly with evaluation. Similarly, precipitation varies spatially across the catchment, but the amount of local precipitation is also a function of the elevation. However, the different areas will have precipitation-elevation relationship. Thus, the elevation corrected precipitation in a cell, when the precipitation is greater than zero, is

$$P_{cell} = P_{ref} + (H_{cell} - H_{ref}) \cdot \beta_p$$

Where; P_{cell} is the precipitation in the cell, P_{ref} is the measured precipitation at a weather station, H_{cell} is the elevation of the cell, H_{ref} is the elevation of the weather station, and β_p is the elevation-correction factor (lapse rate) for precipitation.

(2) Snowmelt

Snowmelt is an important phenomenon that can dramatically affect the spring runoff timing and volume. Therefore, a realistic description of the snow melt process is important. With precipitation and air temperature, snowmelt amount is evaluated using degree-day method. The melting coefficient accounts for the energy content or the rain.

$$M_{rain} = C_{rain} \cdot P \cdot (T_{air} - T_0)$$

Where; M_{rain} is the melting rate, C_{rain} is the melting coefficient due to the energy content of the rain, P is the precipitation rate, T_{air} is the current air temperature, and T_0 is the Threshold Melting Temperature.

(3) Air Temperature

Air temperature varies linearly with elevation. Snow typically accumulates at higher elevation, but the temperature measuring network is rarely dense enough to present the spatial variation of temperature that is known to exist in the catchment. Furthermore, the change in temperature with elevation depends on the relative humidity. Thus, the elevation corrected temperature in a cell, under dry conditions, is

$$T_{cell} = T_{ref} + (H_{cell} - H_{ref}) \cdot \beta$$

Where; T_{cell} is the air temperature in the cell, T_{ref} is the measured air temperature at a weather station, H_{cell} is the elevation of the cell, H_{ref} is the elevation of the weather station, and β is the elevation correction factor (lapse rate).

(4) Evapotranspiration

In this context that different approach is applied to deal with evapotranspiration in the Survey, explanation in this sub-sub-section refers to default concept on evapotranspiration in MIKE-SHE. MIKE-SHE calculates the Crop Reference ET rate prior to calculations of actual ET.

$$ET_{rate} = ET_{crop} = ET_{ref} \cdot k_c$$

Where; ET_{rate} is Crop Reference ET rate, ET_{ref} is the reference evapotranspiration, and k_c is the Crop Coefficient with different vegetation types.

When soil is well-saturated, ET from surface layer is estimated by:

$$ET_{UZ} = ET_{rate} \cdot F_{ETUZ}$$

Where; F_{ETUZ} is 1.0 when the water table is in the root zone and decreases linearly from 1.0 to zero when the water table is below the root zone, but above the extinction depth.

ET is only removed from the upper unsaturated zone (UZ) layer. However, as the water content of the root zone decreases, plants will find it harder to remove water, especially in such a dry condition as Iran. Finally, when the wilting point is reached, ET will stop. However, the reduction in ET does not occur immediately. Plants will remove ET from the root zone at the maximum rate until water content reaches a specified point, at which the rate of ET removal will be restricted. In the 2-Layer Water Balance method, this phenomenon is accounted for by a plant specific deficit fraction. ET will be removed at the maximum rate until this deficit fraction is reached, then linearly reduced to zero as the water content falls to the wilting point. ET from UZ layer is estimated by the following equation.

$$ET_{UZ} = ET_{rate} \cdot F_{ETUZ} = ET_{rate} \cdot \frac{min(\theta_{act}, \theta_p) - \theta_{min}}{\theta_p - \theta_{min}}$$

Where θ_p is water content when ET begins to be restricted given by

$$\theta_p = \theta_{min} + F_p \cdot (\theta_{max} - \theta_{min})$$

Where; θ_{act} is the current water content in the upper layer, θ_{min} and θ_{max} are the minimum and maximum water contents as shown in Figure 5.3.1.

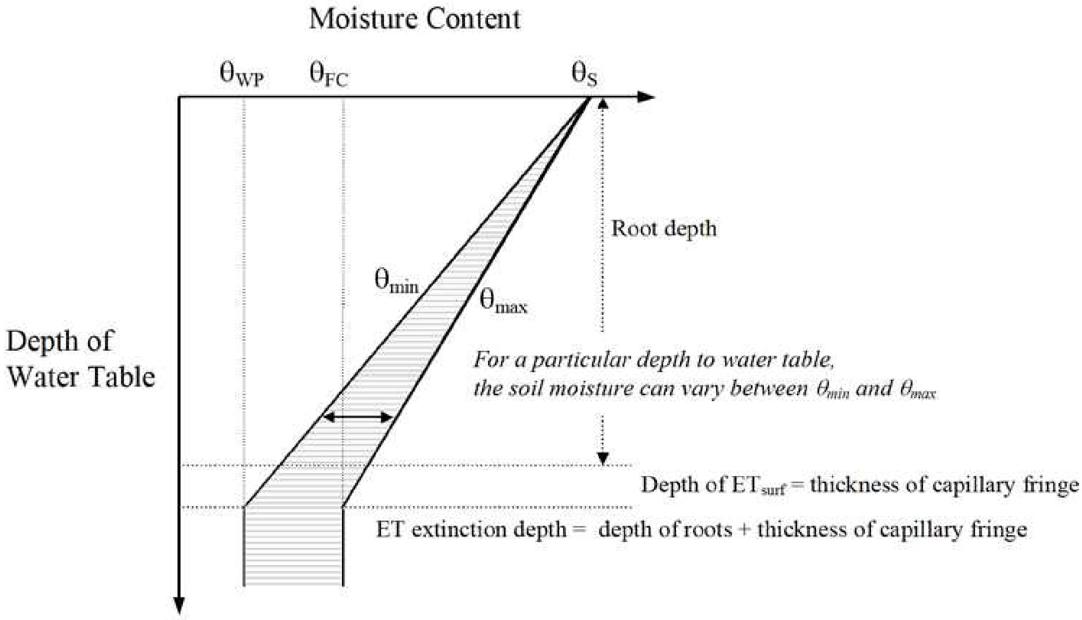


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Figure 5.3.1 Allowable Range for Soil Moisture in the Upper ET Layer

(5) Surface Layer Model

In the surface layer model, surface flow is described by two-dimensional (2-D) horizontal diffusion wave model, which is the simplified St. Venant Equation, and continuity equation. The governing equations for surface layer model are shown below. When precipitation is larger than the permeability of unsaturated layer, surface flow emerges and thus evaporation and seepage along the flowing process through river channels are considered.

① Continuity Equation

$$\frac{\partial h}{\partial t} + \frac{\partial}{\partial x}(uh) + \frac{\partial}{\partial y}(vh) = i \qquad (5.1.1)$$

② Equations of Motion in x direction

$$S_{fx} + \frac{\partial}{\partial x}(Z_g + h) = 0 \qquad (5.1.2)$$

$$S_{fx} = \frac{u^2}{K_x^2 h^{4/3}} \qquad (5.1.3)$$

③ Equations of Motion in y direction

$$S_{fy} + \frac{\partial}{\partial y}\left(Z_g + h\right) = 0 \tag{5.1.4}$$

$$S_{fy} = \frac{v^2}{K_y^2 h^{4/3}} \tag{5.1.5}$$

Where;

Z_g	:	ground elevation (m)
h	:	water depth(m)
u, v	:	water velocity in x, y directions (m/s)
i	:	inflow per unit area [precipitation – seepage] (m/s)
S_{fx}, S_{fy}	:	friction slopes in x, y directions
K_x, K_y	:	roughness coefficients in x, y directions (m-1/3s)

The water level for the next time step is calculated based on the water balance with the 4 surrounding grids as shown in Figure 5.3.2. Outflow between grids are calculated by the equation (5.1.10).

$$\frac{\partial}{\partial x}(uh) \cong \frac{1}{\Delta x}\left\{(uh)_{east} - (uh)_{west}\right\} \tag{5.1.6}$$

$$\frac{\partial}{\partial y}(vh) \cong \frac{1}{\Delta y}\left\{(vh)_{north} - (vh)_{south}\right\} \tag{5.1.7}$$

$$\Delta h = h(t + \Delta t) - h(t) = \frac{I + \Sigma Q \Delta t}{\Delta x^2} \tag{5.1.8}$$

Where;

$$I = i\Delta x^2, \quad \Sigma Q = Q_N + Q_S + Q_E + Q_W \tag{5.1.9}$$

Additionally, for x direction,

$$Q = \frac{K\Delta x}{\Delta x^{1/2}}\left(Z_U - Z_D\right)^{1/2} h_u^{5/3} \tag{5.1.10}$$

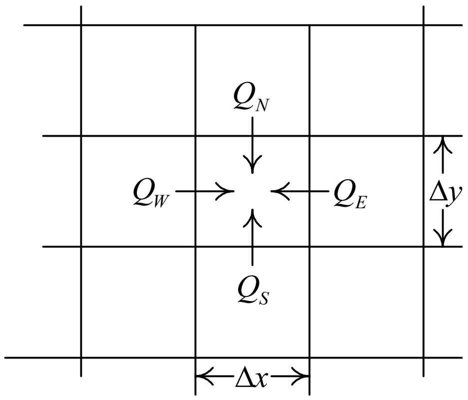


Figure 5.3.2 Water Balance for the Control Volume

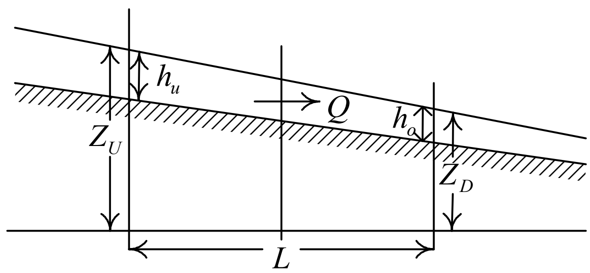


Figure 5.3.3 Outflow between Grids

(6) Unsaturated Layer Model

Water flow in the unsaturated layer is expressed by one-dimensional (1-D) Richards Equation. Unsaturated flow is primarily vertical since gravity plays the key role during infiltration. Therefore, unsaturated flow in MIKE-SHE is calculated only vertically in 1D, which is sufficient for most applicants. The governing equation is shown below. In addition, for surface layer where roots grow, water absorption to roots from the soil is also incorporated.

$$C\frac{\partial \psi}{\partial t} = \frac{\partial}{\partial z}\left(K\frac{\partial \psi}{\partial z}\right) + \frac{\partial K}{\partial z} - S \qquad (5.1.11)$$

$$C = \frac{\partial \theta}{\partial \psi} \qquad (5.1.12)$$

Where; θ : volumetric water content ratio
ψ : absorption pressure (cmH_2O)
K : permeability coefficient for unsaturated layer (m/s)
S : absorption volume to roots (l/s)
C : specific water content volume

(7) Saturated Layer Model

Water flow in the saturated layer is expressed by two-dimensional (2-D) horizontal or three-dimensional (3-D) groundwater flow model. Two-dimensional (2-D) model is applied to single-layered aquifers, where three-dimensional (3-D) model is applied for multi-layered aquifers.

Since both shallow and deep groundwater flow are the calculation targets in the modeled basin, three-dimensional (3-D) groundwater flow model is applied. In aquifers, water recharge from unsaturated layer, outflow to river channels, seepage from river channels, and water uptake are incorporated.

The governing equation of three-dimensional (3-D) groundwater flow model is shown below.

$$\frac{\partial}{\partial x}(K_{xx}\frac{\partial h}{\partial x}) + \frac{\partial}{\partial y}(K_{yy}\frac{\partial h}{\partial y}) + \frac{\partial}{\partial z}(K_{zz}\frac{\partial h}{\partial z}) - Q = S\frac{\partial h}{\partial t} \qquad (5.1.13)$$

Where; K_{xx}, K_{yy}, K_{zz} : permeability coefficient in x, y, z directions (m/s)
S : specific storage coefficient
h : water head in the aquifer (m)
Q : groundwater flow per unit area (such as water recharge, water uptake etc.) (m/s)

In MIKE-SHE, groundwater flow model is solved by differential method. In this method, partial differential equations are approximated with difference equations which are specially and temporally discretized. For a micro control volume stretching from the top to the bottom of an aquifer, 4 inflows (outflows) from (to) surrounding micro grids and water uptake (recharge) from the upper grid are assumed. By applying Continuity Equation and Darcy's Equation and considering the water balance, Continuity Equation (5.1.14) is derived. Continuity Equation of a grid means the outflow (inflow) between control volumes is equal to the temporal change of the storage in the grid. This infinite difference approximation based on water balance leads to the equation below.

$$q_{p,i-1} + q_{p,i+1} + q_{p,j-1} + q_{p,j+1} + q_{p,k-1} + q_{p,k+1} - q_{out} = \frac{\Delta w}{\Delta t} \qquad (5.1.14)$$

Where; q_p : inflow to domains i, j, k 、 q_{out} : outflow from the domains、 Δw : storage volume

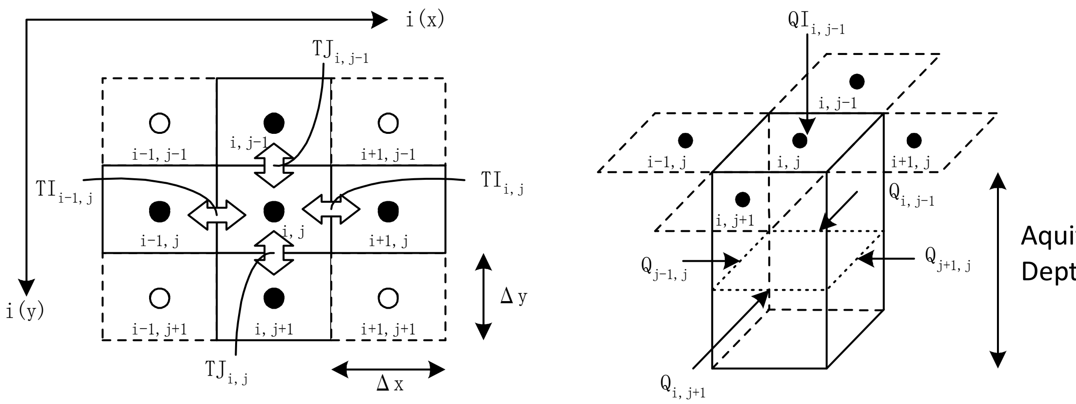


Figure 5.3.4 Water Balance at a Control Volume

(8) River Channel Model

The river channel model was coupled with MIKE-SHE model, which can be selected from one-dimensional (1-D) dynamic wave/diffusive wave/ kinematic wave models. The governing equations for river channel model are shown below.

① Continuity Equation

$$\frac{\partial A}{\partial t} + \frac{\partial}{\partial x}(Au) = q_L \tag{5.1.19}$$

② Equations of Motion

$$S_f + \frac{\partial}{\partial x}\left(Z_o + h\right) = 0 \tag{5.1.20}$$

$$S_f = \frac{u^2}{K^2 h^{4/3}} \tag{5.1.21}$$

$$Au = K\left(-\frac{\partial Z}{\partial x}\right)^{1/2} Ah^{2/3} \tag{5.1.22}$$

Where,
A : cross-sectional area (m^2)
u : velocity (m/s)
q_L : inflow per unit length (m^2/s)
S_f : friction slope
Z_o : river bed elevation (m)
h : water depth (m)
K : roughness coefficient ($m^{-1/3}s$)

5.4 Model Setting and Input Data Processing

The basic ideas of model setting are summarized as below.

Table 5.4.1 Summary of Model Setting (MIKE-SHE)

Classification	Item	Description
Modeled Area		Surface water basin boundary: In addition to the boundary of the Lake Urmia Basin provided by IWRM Co., catchment area of Nazulo Chay River Basin was extended outward to the neighboring country based on basin-topographic condition. Groundwater basin boundary: Ditto
Areal Delineation		Based on topological condition and land use, area for 64 sub river basins were delineated. Furthermore, irrigated area was identified for differentiating water use.
Mesh size		2-km-mesh was employed, considering required resolution for modeling topographic and land use conditions, and calculation time.
Calibration period		10 years (2005 – 2014)
Verification period		5 years (2000 – 2004)
Required time for 15-years simulation		Following time was required for each time step of MIKE 11 (1D hydraulic model): ΔT=5min : 10 hours ΔT=3min : 15 hours
Meteorological condition	Lake surface evaporation	Evaporation estimated by RSRC with DeBruin-Keijman method from 2000 to 2016 was applied with spatial distribution. The data was modified by following ways: - For adjusting simulated lake water level with observed one, evaporation was multiplied by 1.05. - Evaporation data in 2011 was substituted with that of 2010's - Water area captured by RSRC based on satellite image was expanded to the area to the status in 2010's where wetland possibly exists.
	Land evapotranspiration	Actual ET estimated by RSRC with METRIC (2000-2016) (hereinafter referred to as "RSRC-ET") is applied with spatial distribution. Correction was applied by multiplying numerous factors to adjust runoff from mountainous area.
	Precipitation	The potential influence of missing data was solved by preparation of Thiessen polygon by the day without the missing values. The average precipitation in each sub-basin was applied. The average precipitation was calculated using the observed precipitation data (242 stations) by the Thiessen method. Precipitation was corrected with 2-20%/100m of Lapse Rate, which was determined based on relationship between precipitation and elevation of the observation stations meshed precipitation provided by IRMO.
Geological condition	Geological Model	Based on collected geological information/data such as boring log, horizontal geological distribution and aquifer distribution, 3D geological model was constructed by ULRP with help of the Survey Team. The maximum thickness of the total alluvium (lake deposit a river and talus deposit) is 200 to 300 m. The marginal zone of aquifer is surrounded by the river and talus deposit which has the thickness of 100 to 150 m.
	Parameters of the layer (permeability coefficient, etc.)	Referring the guidelines (draft) published by the Ministry of Land, Infrastructure, Transport and Tourism, Japan, the values corresponding to actual geological parameters were initially applied and calibrated.
Topography	Ground surface elevation	2-km-mesh of ground elevation data was prepared by MIKE-SHE based on the 90m-DEM provided by IWRM Co.
	Lakebed elevation	Meshed lakebed elevation data was created by MIKE-SHE based on the DEM data obtained from 2010 bathymetry survey result of Urmia Lake.
Land use	Surface roughness	Based on the land use data of 2007 provided by IWRM Co., the dominant land use type in each mesh was selected with the area. Roughness coefficient in each land use were given into the grid.
Natural conditions	River network	Considering irrigation module in MIKE-SHE, main river channel in each basin was modeled based on the collected river channel data. Rectangle-shaped cross sections

Classification	Item	Description
		on the channels were prepared with elevations of riverbeds referred to the elevation of the ASTER GDEM.
Water use structure	Dam	Dam lake was created with river cross section and regulator tool in MIKE-11 to dam up river water coming from upstream. Operation records (outflow) of following 5 dams; Bukan dam (2000-2014), Mahabad Dam (2000-2014), Hasanlu Dam (2002-2014), Sahar Chay Dam (2006-20014) and Alvian Dam (2010-2014) were inputted into model as point source data.
Ground water	Initial condition	In MIKE-SHE, meteorological data from 1993 to 1999 (precipitation, lake surface evaporation, and ET) were placed into the model. The calculation results by MIKE-SHE when the lake water levels at some points had high similarities with the observed data in 1999 were applied for the initial condition.
Water use	River water intake	Based on RSRC-ET, aerial average ET for irrigated area was converted into irrigation water demand using irrigation efficiency, whose average value is approximately 0.36 for southern part. Intake points were identified based on satellite image or specified at upstream of irrigated area.
	Groundwater intake	The water amount of the wells permitted by IWRM Co. in the grid of 2-km-mesh were summed up and was found to be 1.1 times more than collected amount. (1.1 was the ratio of the water demand described in 2013 Master Plan to the permitted amount between 2012 and 2014) Seasonal proportion of groundwater uptake was referred to that of river water intake amount.

5.4.1 Model Input Specification

(1) Modeled Area

The main objectives of modeling for ULRP are: (i) to analyze the behavior of surface water and groundwater around Urmia Lake, and (ii) to simulate the change in lake surface area and lake water level. Therefore, the target area was determined as Urmia Lake Basin shown as Figure 5.4.1 based on following basic premises:

- Although it was not determined whether the boundary of groundwater basin matches that of surface water, according to interview with hydrology experts in ULRP, no interaction of groundwater outside the boundary of Urmia Lake has occured. As such, the behavior of groundwater outside the basin boundary was not considered in modeling.
- It was not necessary to model the water cycle outside the basin since there was no interchange of water with other neighboring basins.

In the Survey, in the context of improvement of the hydrological model constructed in the previous survey is one of main objectives, it is necessary to correctly estimate river discharge. Nazlo Chay is an international river, and Nazlo Chay has the catchment area not only in Iran but alos within Turkey's administrative area. Therefore, in addition to the boundary of Urmia Lake Basin provided by IWRM Co., the catchment area data of Nazulo Chay River Basin was extended outward to neighboring country (Turkey) based on basin-topographic condition (see Figure 5.4.2).

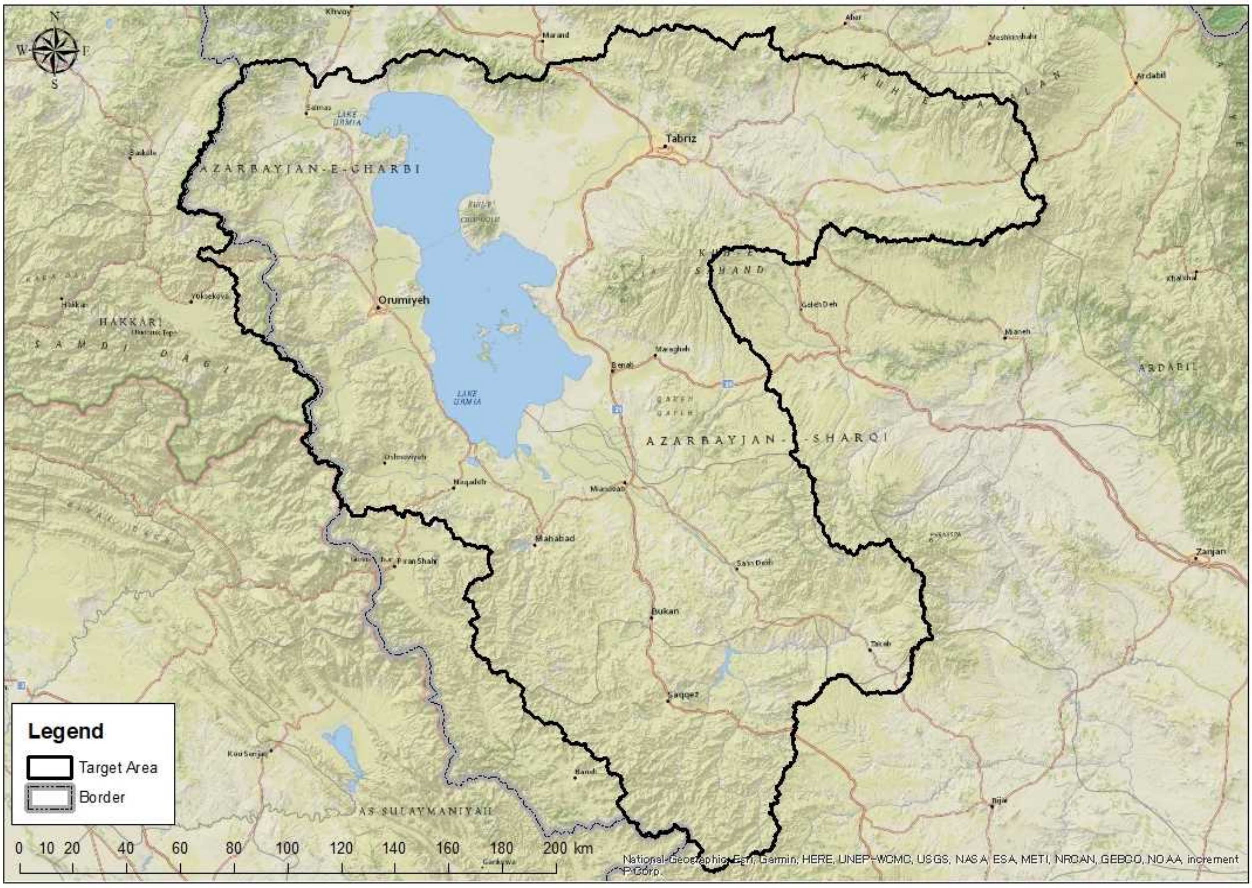


Figure 5.4.1 Target Area

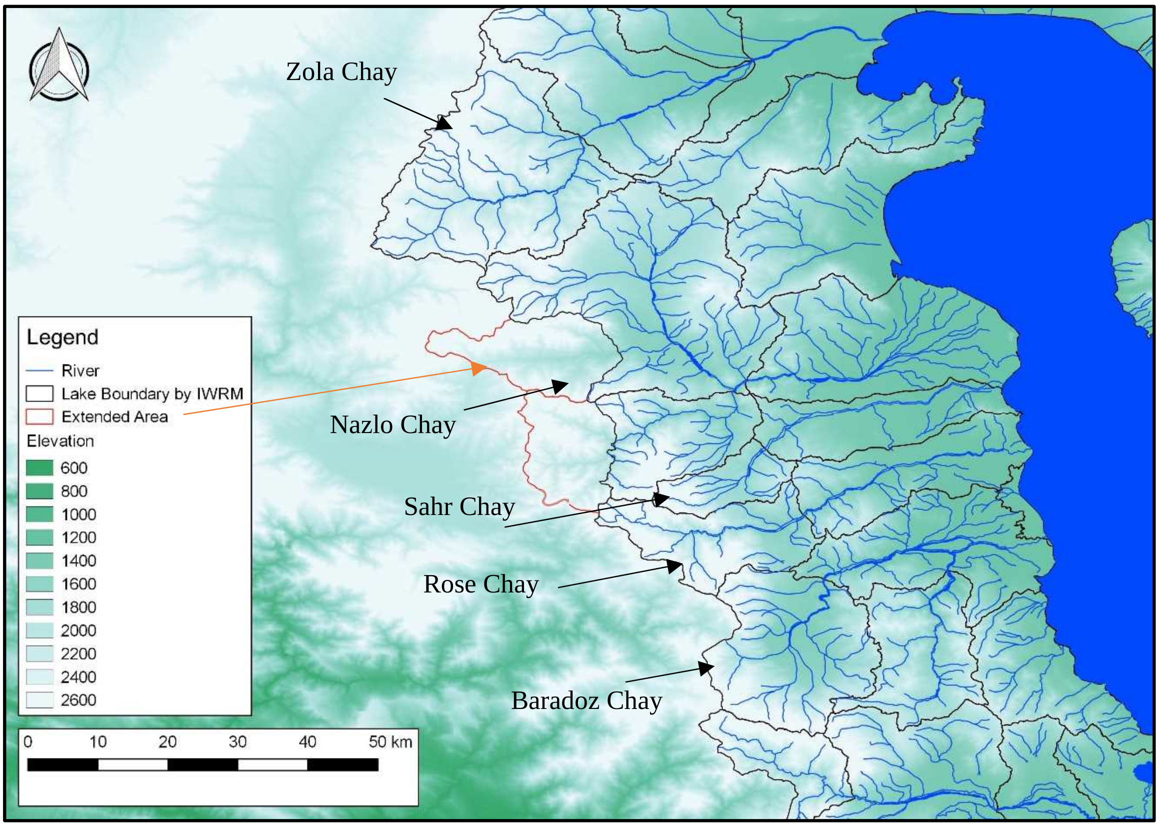


Figure 5.4.2 Outward-Extended Area in Western Part for Modeling

(2) Areal Delineation for Sub-River Basin

This survey aims at the evaluation of hydrological characteristics that is spatially and temporally distributed in the lake basin. Considering the basin scale with more than 50,000km^2 of catchment area, in order to incorporate some input data, averaging their characteristics in sub-river basin scale does not disrupt their accuracy. Sixty-four (64) sub-river basins were prepared by the areal delineation with topological condition to evaluate meteorological condition, e.g., precipitation trend (see Figure 5.4.3).

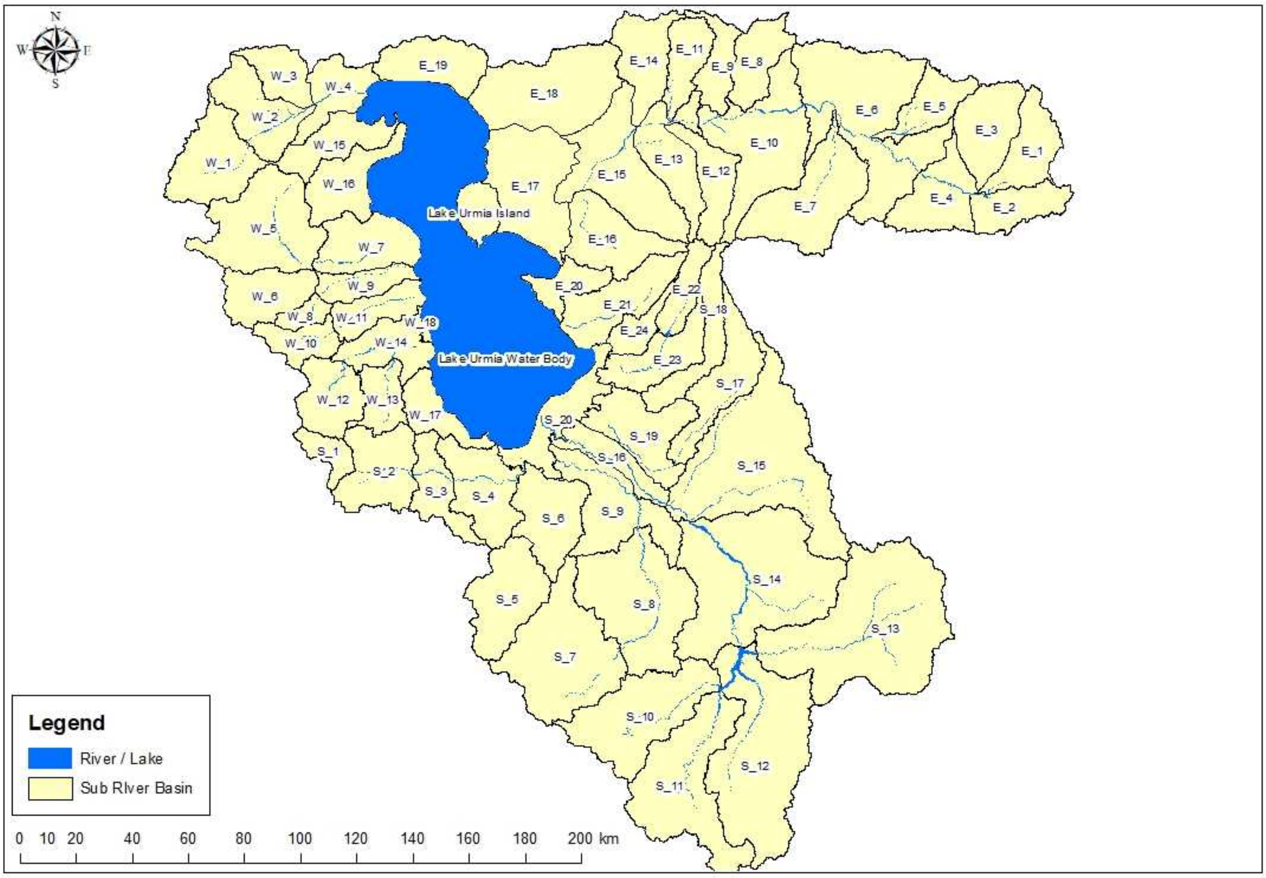


Figure 5.4.3 Sub River Basin Delineation

Table 5.4.2 Summary of Sub River Basins of the Urmia Lake Basin

■Southern Part

No.	Basin Name	Area (km^2)	No.	Basin Name	Area (km^2)		
S_1	Gedar Chay Up	217	S_11	Zarineh Rud	1,433		
S_2	Gedar Chay Mid1	709	S_12	Khor Khoreh Chay	1,967		
S_3	Gedar Chay Mid2	445	S_13	Sarough Chay	2,404		
S_4	Gedar Chay Low	720	S_14	Zarineh Rud Mid1	2,257		
S_5	Mahabad Chay Up	809	S_15	Zarineh Rud Mid2	2,211		
S_6	Mahabad Chay Low	698	S_16	Zarineh Rud Low	375		
S_7	Simine Rud Up	1,453	S_17	Lilang Chay UL	699		
S_8	Simine Rud Mid	1,449	S_18	Lilang Chay UR	498		
S_9	Simine Rud Low	881	S_19	Lilang Chay Low	739		
S_10	Saghez	1,191	S_20	Residual south	551	**Sub Total (km^2)**	**21,706**

■Western Part

No.	Basin Name	Area (km^2)	No.	Basin Name	Area (km^2)		
W_1	Zola Chay Up	787	W_10	Sahar Chay Up	325		
W_2	Zola Chay Mid1	653	W_11	Sahar Chay Low	387		
W_3	Zola Chay Mid2	369	W_12	Baradoz UL	533		
W_4	Zola Chay Low	450	W_13	Baradoz UR	350		
W_5	Nazlo Chay UL	1,181	W_14	Baradoz Low	479		
W_6	Nazlo Chay UR	530	W_15	Residual 1-2	488		
W_7	Nazlo Chay Low	637	W_16	Residual 1-1	572		
W_8	Rose Chay Up	145	W_17	Residual 2	375		
W_9	Rose Chay Low	313	W_18	Residual west	37	**Sub Total (km^2)**	**8,610**

■Eastern Part

No.	Basin Name	Area (km^2)	No.	Basin Name	Area (km^2)	No.	Basin Name	Area (km^2)
E_1	Aghmiun Chay	521	E_11	Gomanab Chay	404	E_21	Gale Chay R Up	699
E_2	Vanagh Chay	441	E_12	Lighavan Chay	455	E_22	Sufi Chay L Up	311
E_3	Tajyar Chay / Razligh Chay	643	E_13	Aji Chay Mid3	637	E_23	Sufi Chay L Low1	549
E_4	Aji Chay Up1	636	E_14	Varkash Chay	578	E_24	Gale Chay L Low2	235
E_5	Chekeh Chay	420	E_15	Aji Chay Low1	1,150			
E_6	Aji Chay Mid1	1,906	E_16	Aji Chay Low2	702			
E_7	Ojan Chay	1,066	E_17	Aji Chay Residual	1,110			
E_8	Par chay	462	E_18	Residual 3-1	1,253			
E_9	Nahand Chay	349	E_19	Residual 3-2	587			
E_10	Aji Chay Mid2	1,238	E_20	Residual4	299		**Sub Total (km^2)**	**16,650**

■Urmia Lake

No.	Basin Name	Area (km^2)		
-	Urmia Lake Island	260		
-	Urmia Lake Water Body	4,976	**Total Area (km^2)**	**52,203**

(3) Mesh Size

The target area was modeled with 2-km-mesh based on the following reasons. The principle idea follows that of the previous survey as described below:

- In the Survey, it was required to simulate the lake surface area and lake water level that were affected by the change of water withdrawal from surface/ground waters. Therefore, it was necessary to model the target area with sufficient resolution to simulate change of the lake water surface of Urmia Lake.
- The resolution was required so that spatial distribution of elevation and land use are represented as clear as possible.
- The balance between resolution and calculation time was considered. The established model with 2-km-mesh requires approximately 10 hours for 15-year simulation (in the case of ΔT=5min of 1D hydraulic model). In case of 1-km-mesh is applied, simulation time would be four times as that of 2-km-mesh.

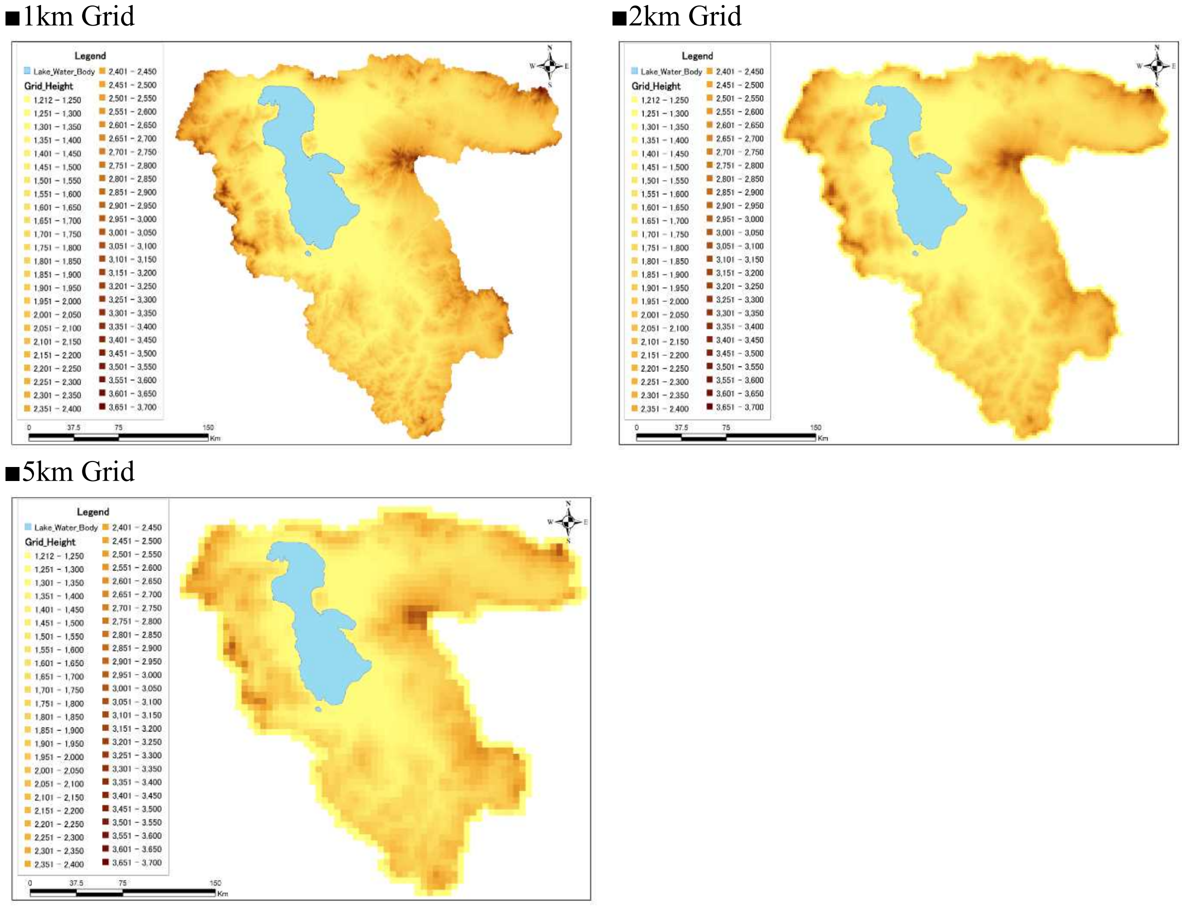


Figure 5.4.4 Difference of Topologies with Mesh Size

(4) Calibration and Verification Periods

Taking the required calculation time and availability of observed hydrological data into account, 10 years between 2005 and 2014 was determined as calibration period. This determination was agreed between ULRP and the Survey Team and prepared based on the fact that IWRM Co. authorized hydrological data until 2014, according to ULRP.

Five years between 2000 and 2004 was applied for verification period in addition to the above-mentioned calibration period in the Survey, in the context that RSRC provided the actual ET by METRIC from 2000 to 2016.

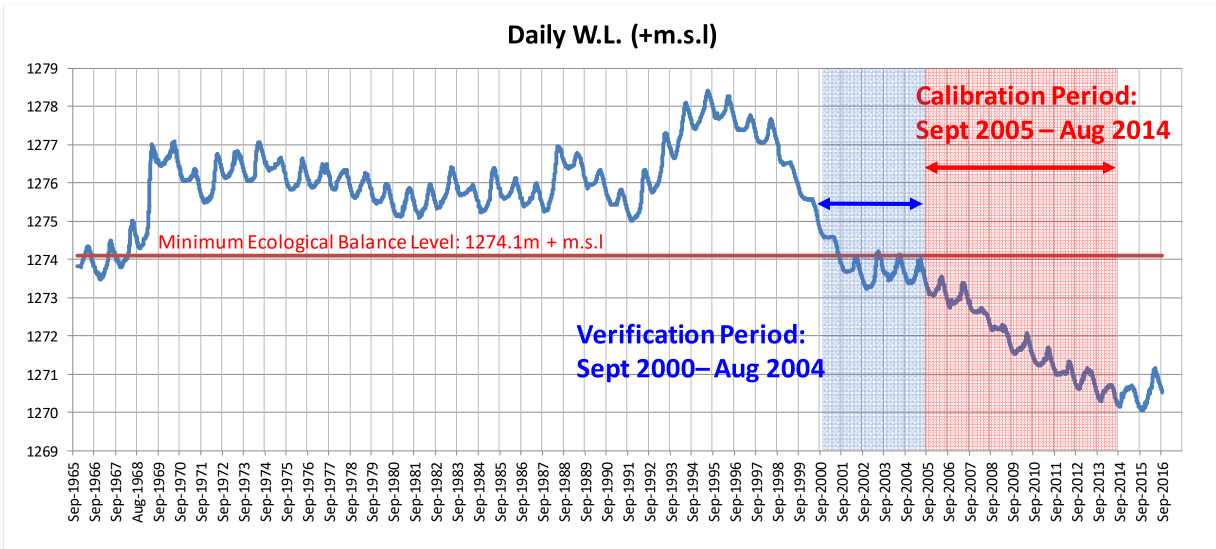


Figure 5.4.5 Temporal Change in Lake Water Level and Calibration and Verification Period

(5) Meteorological Condition

(a) Precipitation

The precipitation data observed at 163 rainfall gauging stations (as shown in Figure 5.4.6) were given into the model as the data sets for average precipitation which was calculated by Thiessen Method. MIKE-SHE requires time series data set with spatial distribution for the input. It was confirmed that the precipitation data includes a lot of missing values; therefore, the data sets were prepared by means of the Thiessen Method with the selection of stations day by day. The data set of precipitation was given to each sub-basin (See Figure 5.4.6) which were processed day by day, separately with the MIKE-SHE module.

Figure 5.4.7 shows spatial distribution of average annual precipitation issued by WorldCLIM, the isomap provided by IRMO and location of rainfall gauging station. Mountainous area of western part with high precipitation tends to less density of gauging network. For securing water balance under the lack of precipitation gauging network and uncertainty of ET in mountainous area, rainfall correction with elevation was applied for some river basins based on try-and-error, which ranges 2-20% as show in Figure 5.4.8. It tends that high rates (10-20%) show at western mountainous area. For eastern part, 1-4% was applied for adjustment. Besides, no correction has been conducted for southern part because of the sufficiently dense rainfall gauge network which enables to capture precipitation at the high place of mountainous area. Appendix 5-1 shows rainfall correction applied for each sub-river basin.

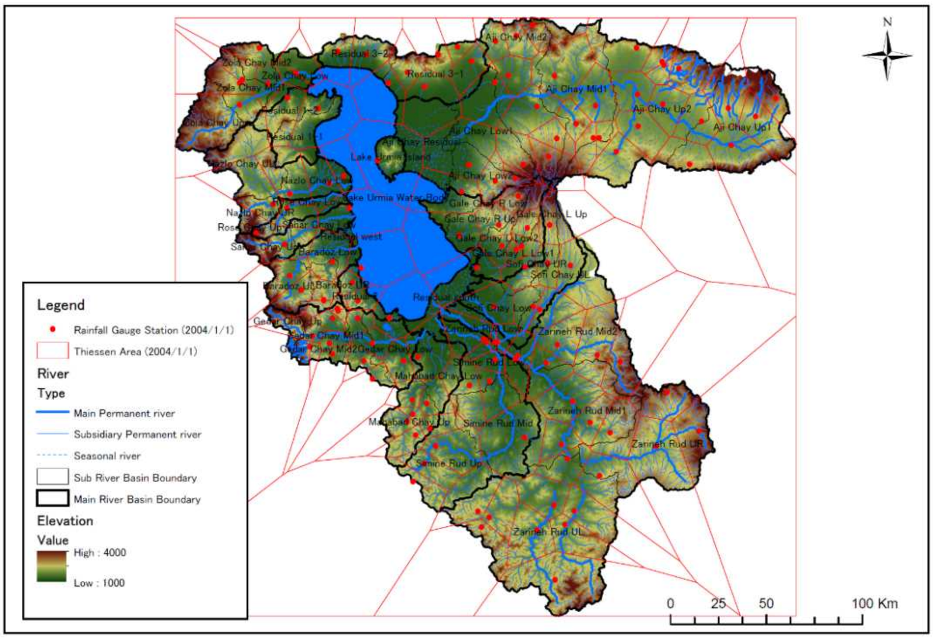


Figure 5.4.6 Location of Rainfall Gauging Station and Example of Thiessen Polygon

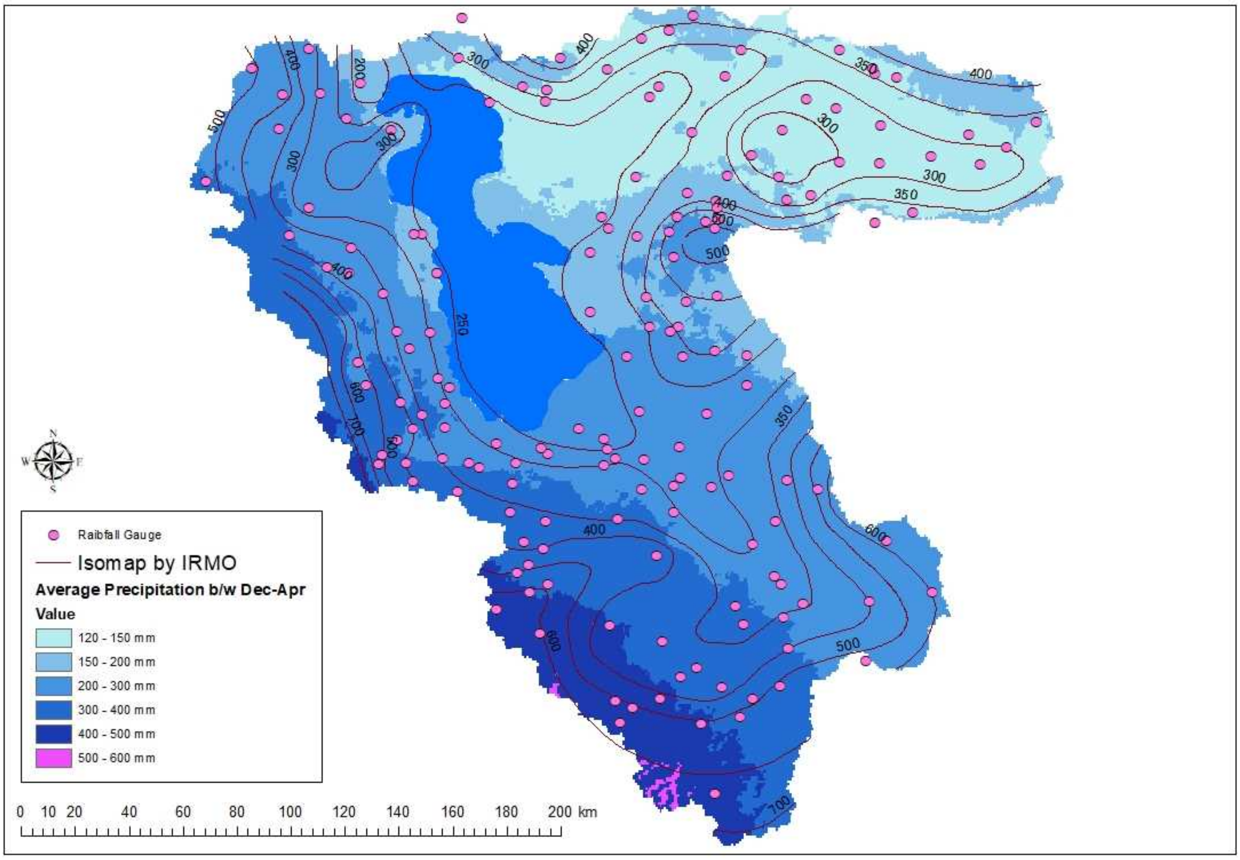


Figure 5.4.7 Spatial Distribution of Annual Precipitation retrieved from WorldClim, Isomap of Annual Precipitation provided by IRMO and Rainfall Gauging Station.

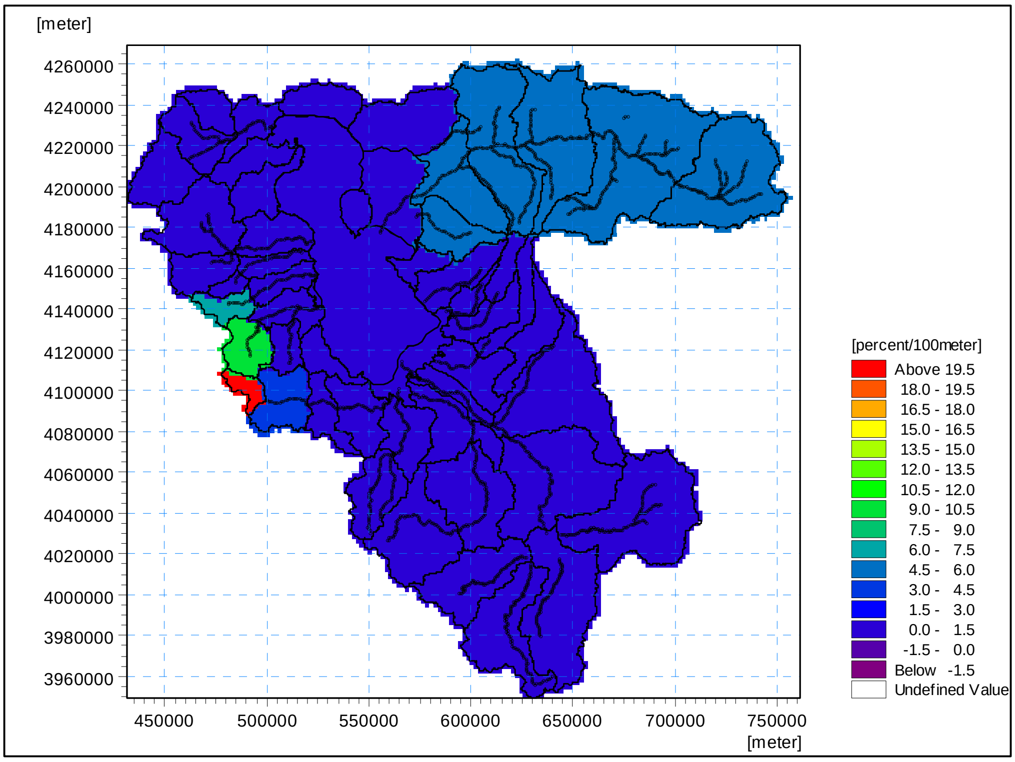


Figure 5.4.8 Spatial Distribution of Rainfall Correction in MIKE-SHE

(b) Snowmelt Estimation

Snowmelt estimation is essential for improving the accuracy of the runoff simulation in Urmia Lake Basin, especially for response of river discharge to precipitation in the mountainous area of the basin. Snowmelt was simulated by means of the Degree-Day method mounted as default module in MIKE-SHE, based on precipitation, air temperature, and parameters (threshold air temperature and melting coefficient). While melting coefficient is fixed with 1.6 mm/day/℃, threshold snow melt temperature was adjusted by try-and-error approach so that calculated discharge agrees to that observed. Figure 5.4.9 shows spatial distribution of applied values of threshold snow melt temperature. Appendix 5-2 shows their applied value for each basin.

Applied air temperature was also corrected with elevation difference between neighboring climatological stations and average temperature value of sub river basins. As a result, 0.6˚C/100m was applied for correction coefficient.

Air temperature data at the stations shown in Figure 5.4.10 were collected from IRMO in the previous survey between 1992 and 2010 and extended to 2016 with the daily data retrieved from National Climatic Data Center of National Oceanic and Atmospheric Administration (NOAA)[3], whose agreement and availability into the model by the extension has been confirmed by plotting these data as shown in Figure 5.4.11.

Figure 5.4.12 shows an example of snowmelt simulation by MIKE-SHE, which can simulate snow storage and snowmelt with spatial distribution, respectively.

3 Metadata of data set is available at http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NCDC/.DAILY/.GLOBALSOD/ and data was retrieved from ftp://ftp.ncdc.noaa.gov/pub/data/gsod

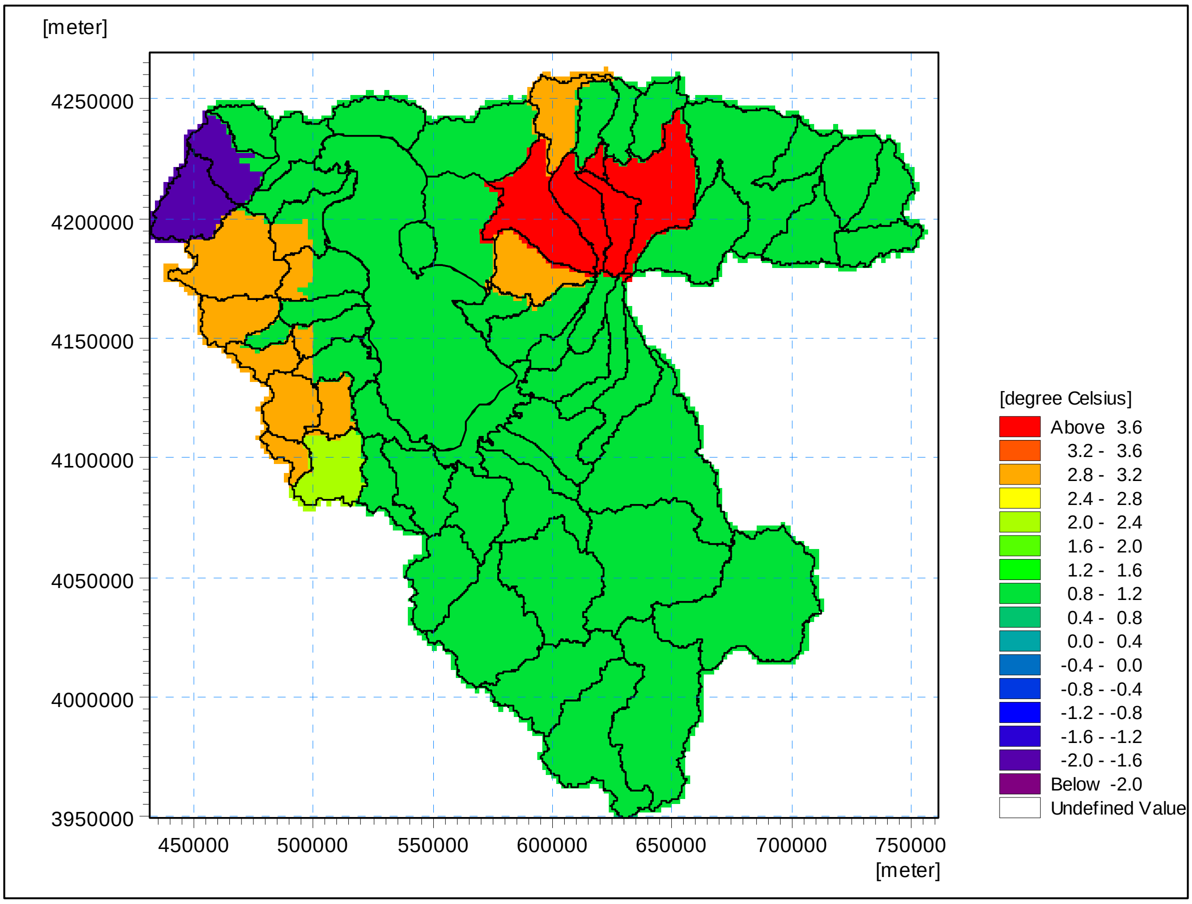
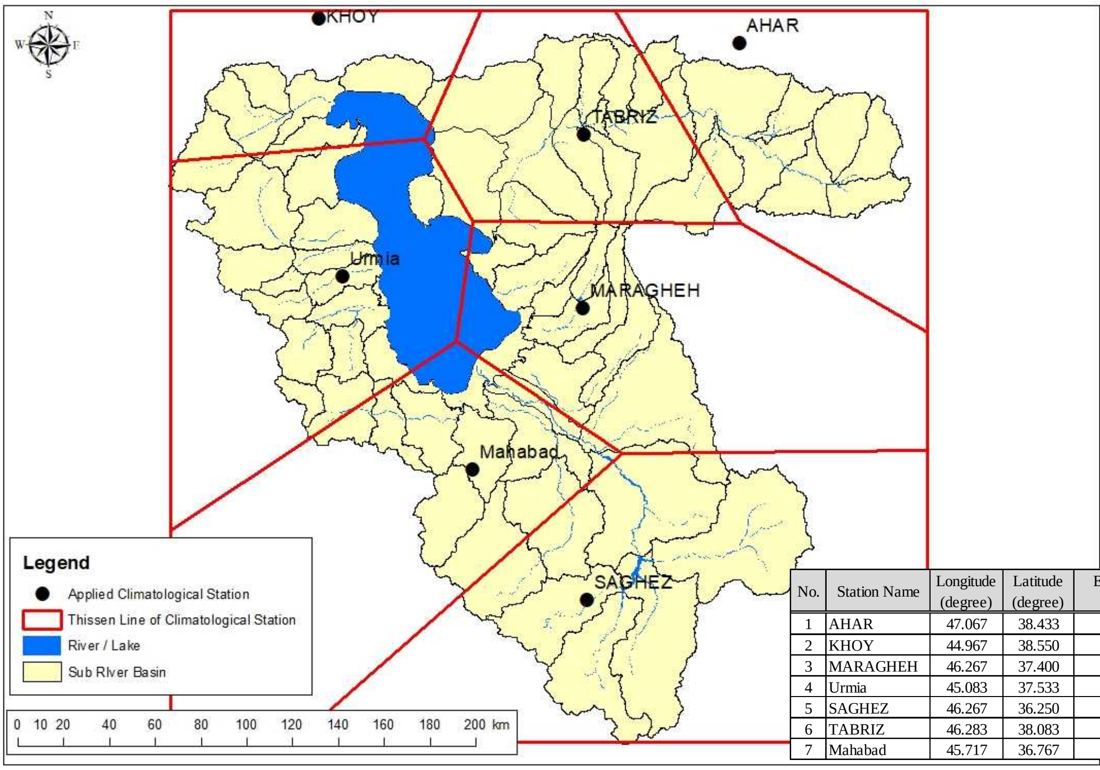


Figure 5.4.9 Applied Threshold Snowmelt Coefficient



No.	Station Name	Longitude (degree)	Latitude (degree)	Elevation (m)
1	AHAR	47.067	38.433	1,390
2	KHOY	44.967	38.550	1,107
3	MARAGHEH	46.267	37.400	1,476
4	Urmia	45.083	37.533	1,312
5	SAGHEZ	46.267	36.250	1,493
6	TABRIZ	46.283	38.083	1,361
7	Mahabad	45.717	36.767	1,385

Figure 5.4.10 Location of Applied Climatological Station

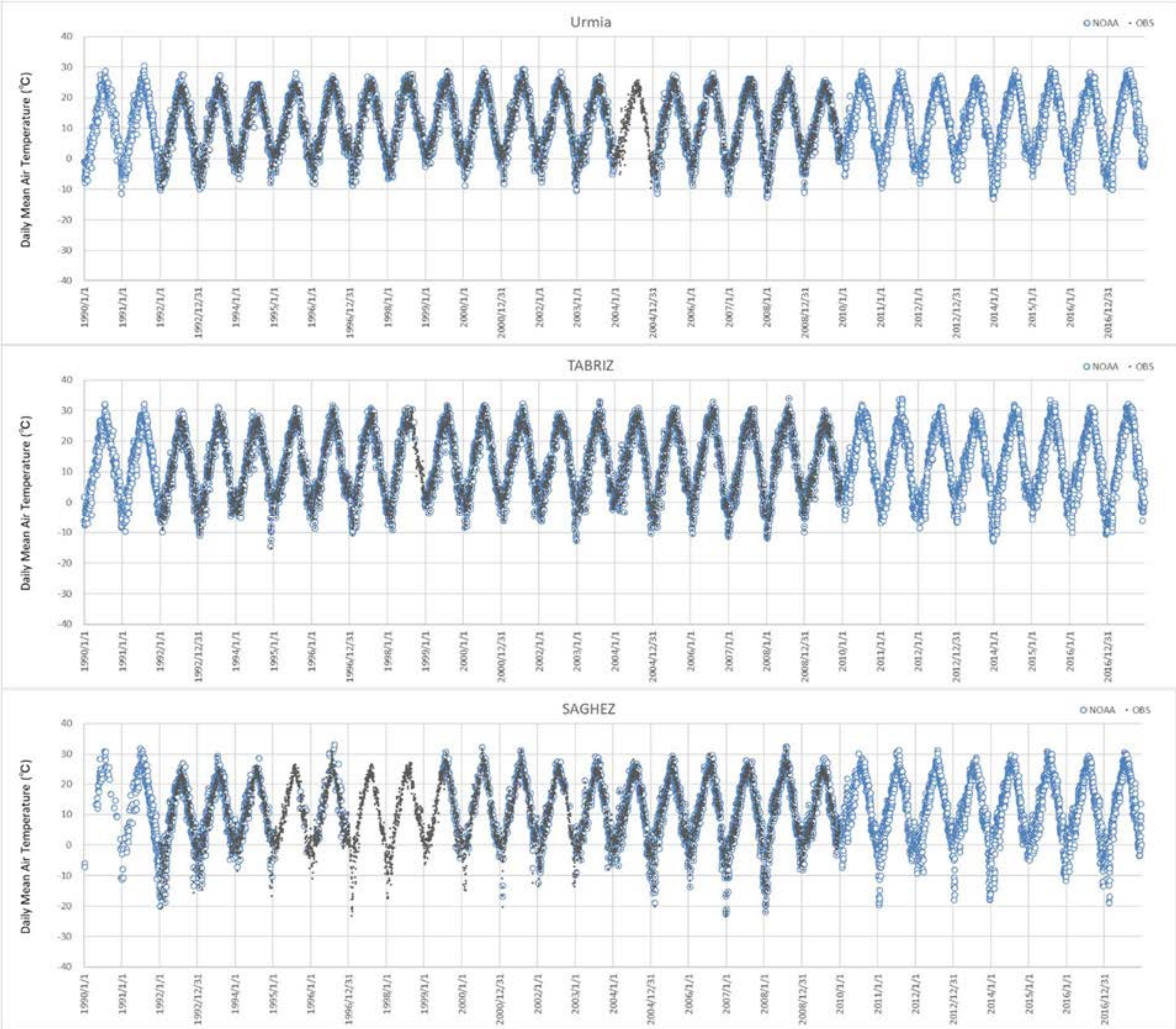


Figure 5.4.11 Trend Comparison of Air Temperature between Provided by IRMO and NOAA data (1)

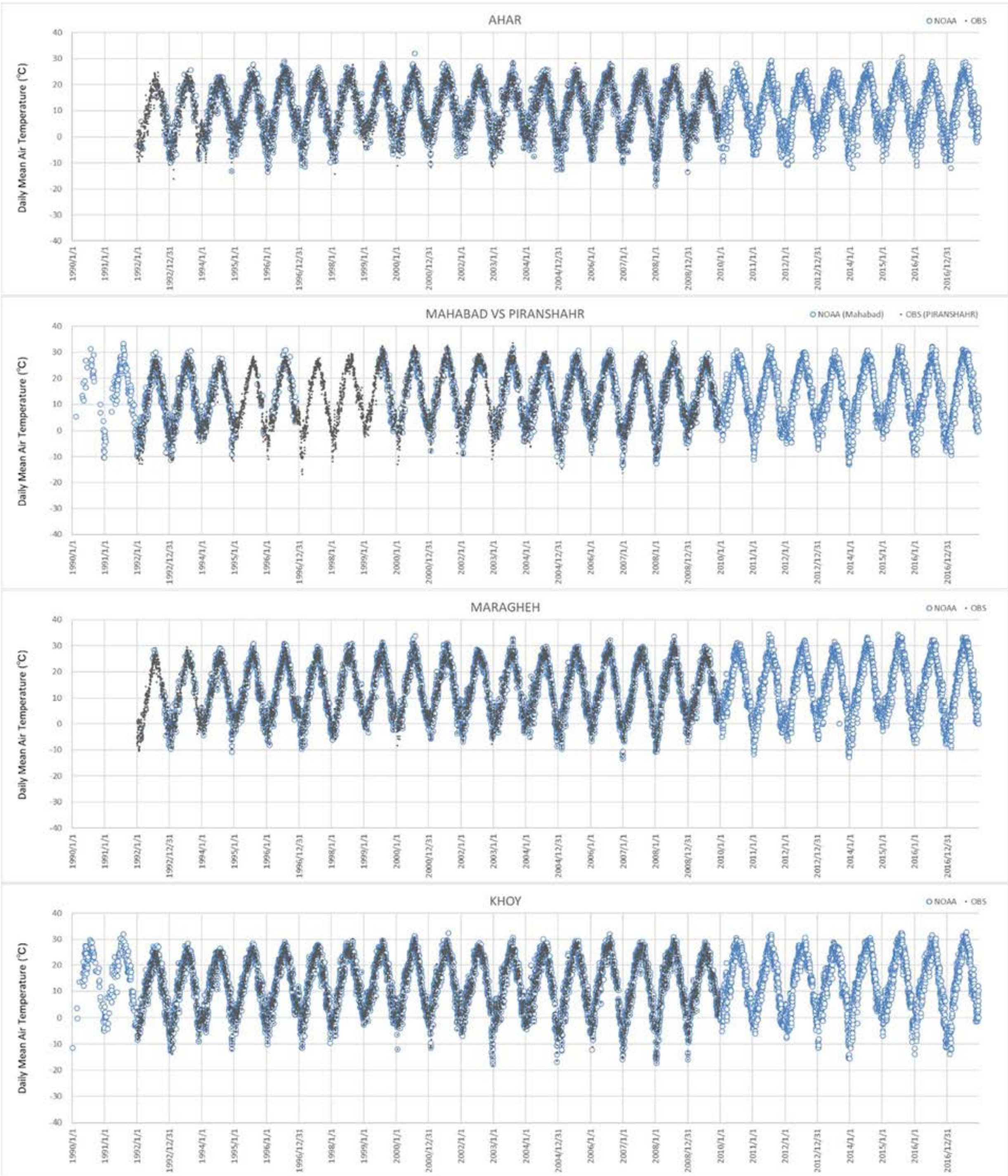


Figure 5.4.11 Trend Comparison of Air Temperature between Provided by IRMO and NOAA data (2)

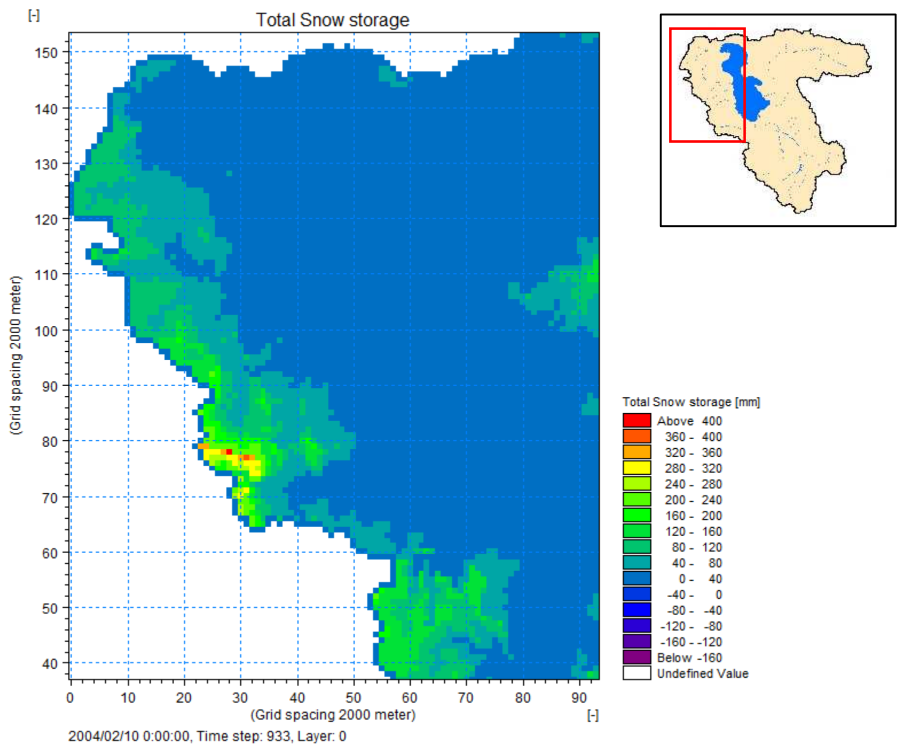


Figure 5.4.12 Example of Simulated Snow Storage (MIKE-SHE Output)

(c) Actual Land Evapotranspiration

ULRP and the Survey Team agreed to apply RSRC-ET as input data for MIKE-SHE model. Prior to application, the Survey Team confirmed applicability of the actual ET (RSRC-ET) into the established MIKE-SHE model by visualizing spatial distribution and comparing basin-average actual ET and precipitation with annual basis (Refer to spatial distribution of monthly ET and charts comparing annual ET and precipitation for each sub-basin in Appendix 5-3 and Appendix 5-4, respectively).

In this item, approaches to convert RSRC-ET into available format in MIKE-SHE and maximize its utilization are described based on the fact and assumption as follows.

(i) Preparation of Actual ET Data for MIKE-SHE Format

Since RSRC-ET was provided with monthly basis, daily actual ET data needed to be prepared. By multiplying ET_{ref} with excel format and ET_{frac} as GeoTIFF format, that were provided by RSRC, spatially-distributed actual ET data with daily basis was prepared and incorporated into MIKE-SHE data set (.dfs2) (Figure 5.4.13). This preprocess enables input data with more detailed spatial resolution, which was requested by ULRP. However, as described in Section 3.3, uncertainty of RSRC-ET accuracy remains especially at mountainous area, in which pixel values were substituted with "0mm" due to cloud effect. In the Survey, in the context of necessity of calibration with ET in mountainous area, cells with value of 0mm were converted into 0.1mm.

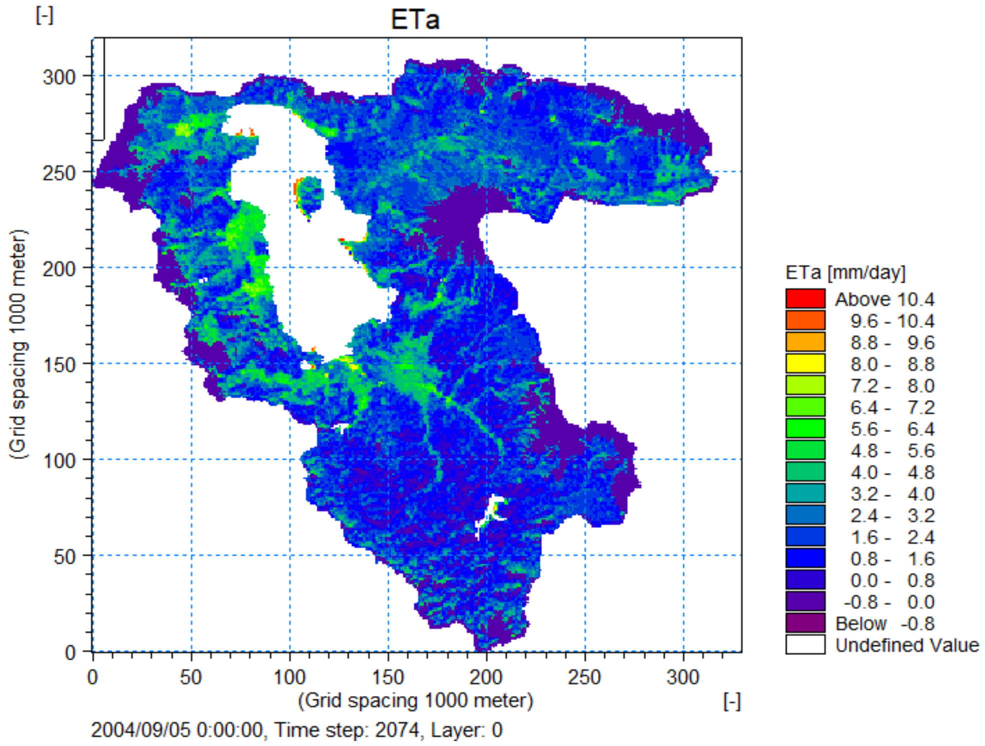


Figure 5.4.13 Prepared .dfs2 Dataset of Daily Evapotranspiration for MIKE-SHE

(ii) Application of RSRC-ET into MIKE-SHE

In the calculation process of water movement in UZ zone, MIKE-SHE needs to calculate actual ET in UZ module based on ET_{ref} and the k_c, which is directly input into the model or estimated based on other measured/estimated information of vegetation (e.g. LAR, root depth and crop efficiency). In this context MIKE-SHE cannot apply actual ET data itself.

For maximum utilization of actual ET map provided by ULRP, RSRC-ET was substituted as Crop Reference ET rate in the established model as described in (4) of Subsection 5.3. Actual ET was calibrated by multiplying the k_c as numerical factor (normally the value is 1.0 but if necessary used as modification ratio) so that simulated river discharge in upstream area of agree with observed one, as described in (iii).

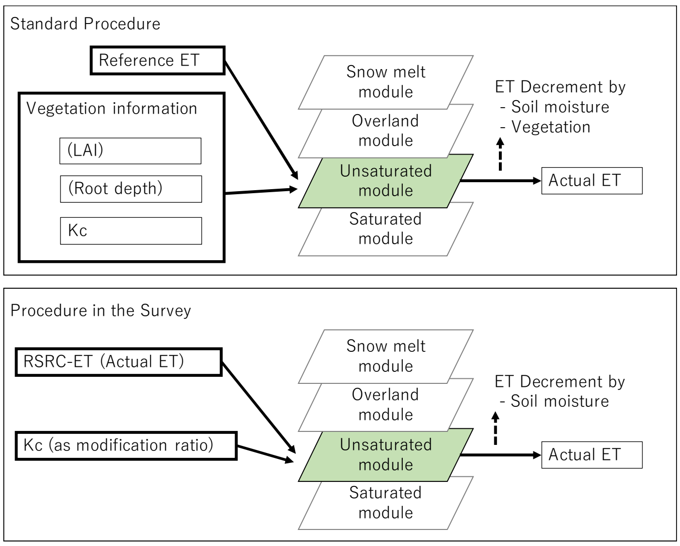


Figure 5.4.14 Schematic Diagram for Application of RSRC-ET into MIKE-SHE

(iii) Modification of RSRC-ET for Applying into MIKE-SHE

Taking the uncertainty especially in mountainous area into account, for using RSRC-ET as MIKE-SHE input, it would be inevitable to modify the product by several approaches. Prior to inputting into MIKE-SHE, the actual ET is modified with the basic concept described as follows.

- ET_{frac} values exceeding 1.0 are replaced with 1.0 (in case actual ET exceeds ET_{ref})
- ET at mountainous area is modified with applying numerical factor (k_c is applied) so that simulation result of river discharge agrees with observed one.

Figure 5.4.15 and Figure 5.4.16 show simulation results of river discharge with/without the initial modification which replaced the ET_{frac} values exceeding 1.0 into 1.0, respectively. It was confirmed that, while simulation result without modification tends to underestimate surface water due to exploitation by ET, that with modification shows better agreement of simulated discharge with observed one. This result indicates that further calibration is necessary for securing more accuracy of the established model, which include modification of the actual ET by RSRC.

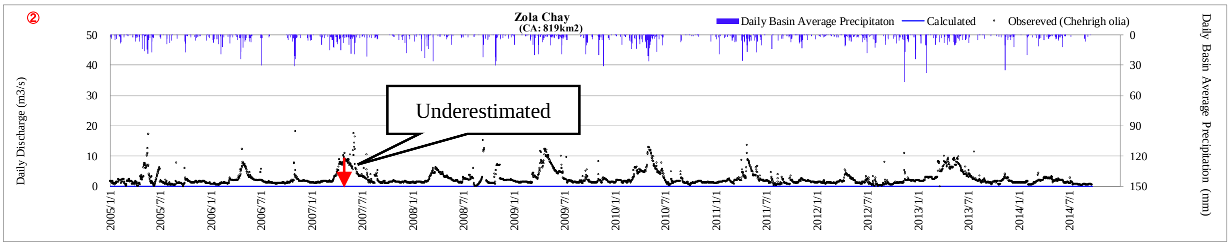


Figure 5.4.15 Example of Comparison of Simulation Result without ET Modification and Observed River Discharge (at Mountainous Area of Western Part)

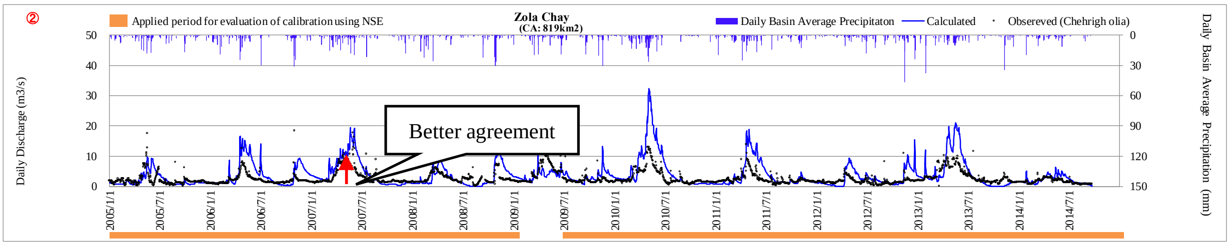


Figure 5.4.16 Comparison of Simulation Result with initial ET Modification and Observed River Discharge (at Mountainous Area of Western Part)

(d) Lake Surface Evaporation

Lake evaporation was estimated by RSRC and provided to the Survey Team as dataset of the monthly ET_{frac} combined with RSRC-ET, which was calculated using DeBruin-Keijman method. For inputting into the model, daily evaporation data was calculated by multiplying RSRC's ET_{frac} with daily ET_{ref} at Urmia climatological station and applied into the model with spatial distribution. Accumulated monthly lake evaporation is shown as Figure 5.4.17.

When incorporating into the model, the data was modified as described below.

Lake evaporation for the period is substituted with that of 2009's: Comparing with ET_{ref} at Urmia climatological station (see Figure 5.4.18), annual lake evaporation in hydrological year 2010 (2010 September – 2011 August) is approximately 20% less than other years, while ET_{ref} at Urmia climatological does not show such a trend.

To prevent underestimation of lake evaporation, water area after 2011 identified by RSRC was expanded to the status in 2010's where wetland possibly exists: As shown in Figure 5.4.19, drastic shrinking of lake water area has occurred after 2010. RSRC identified lake area based on satellite image and gave the estimated value evenly into identified lake area. Outer of the lake area is identified as dry area with extremely low evaporation. As described in (c), MIKE-SHE calculates actual evapotranspiration based on the value multiplying ET_{ref} by ET_{frac} which also takes into account conditions such as soil moisture. In the case that RSRC's water area after shrinking was incorporated into the model, the evaporation from wetland might be underestimated, even where surface soil is saturated.

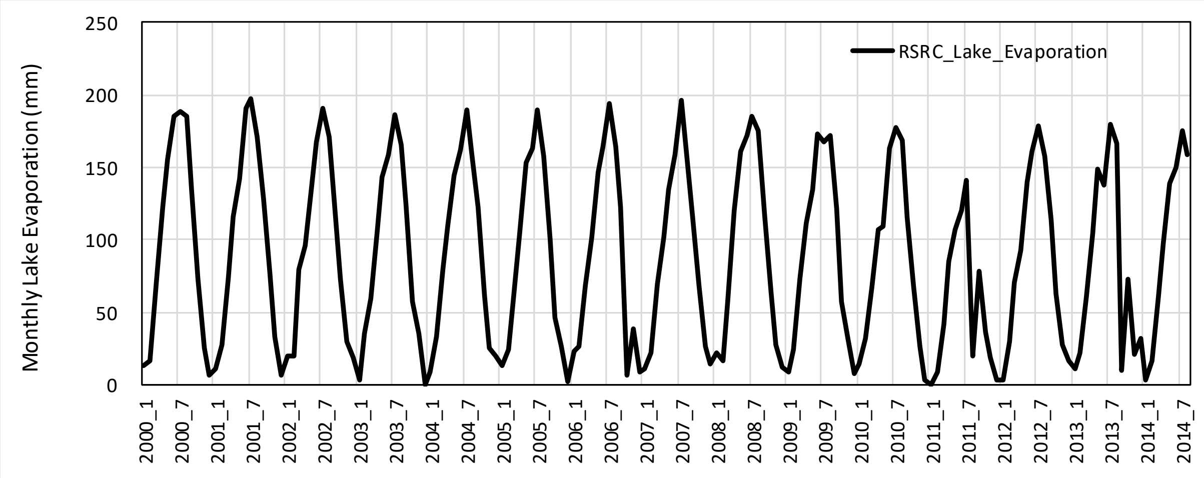
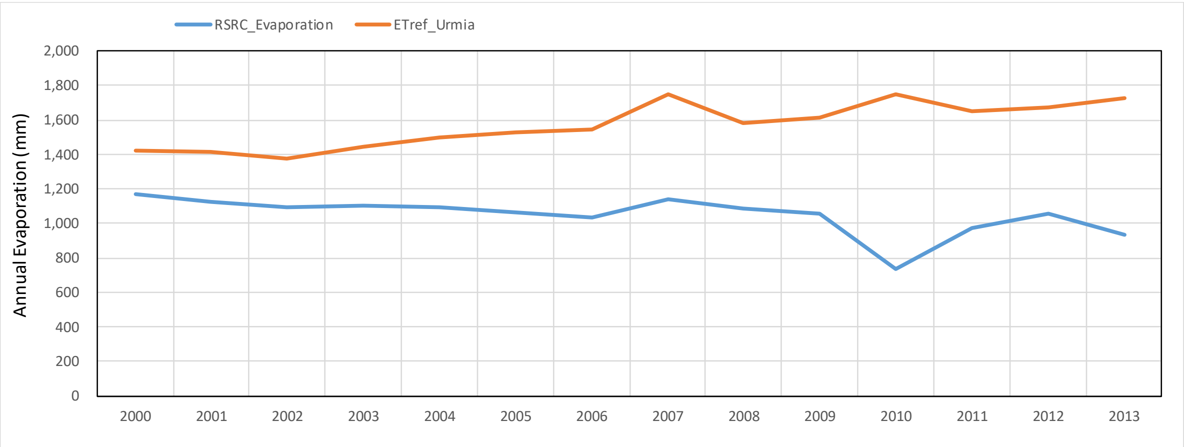


Figure 5.4.17 Monthly Lake Evaporation Estimated by RSRC



*Aggregation period is the period between September to next year's August

Figure 5.4.18 Comparison of Annual Lake Evaporation between ET_{ref} at Urmia Climatological Station

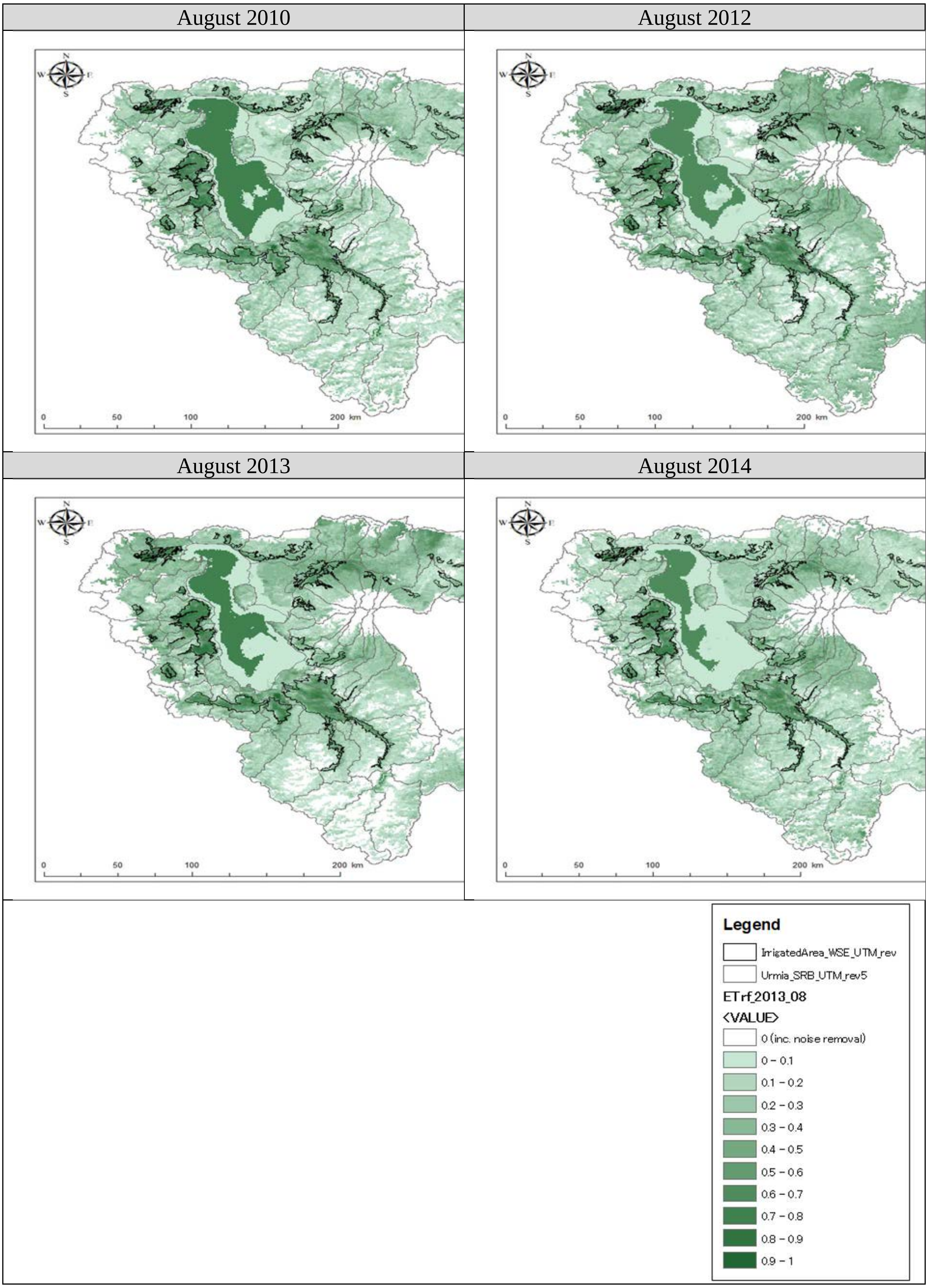


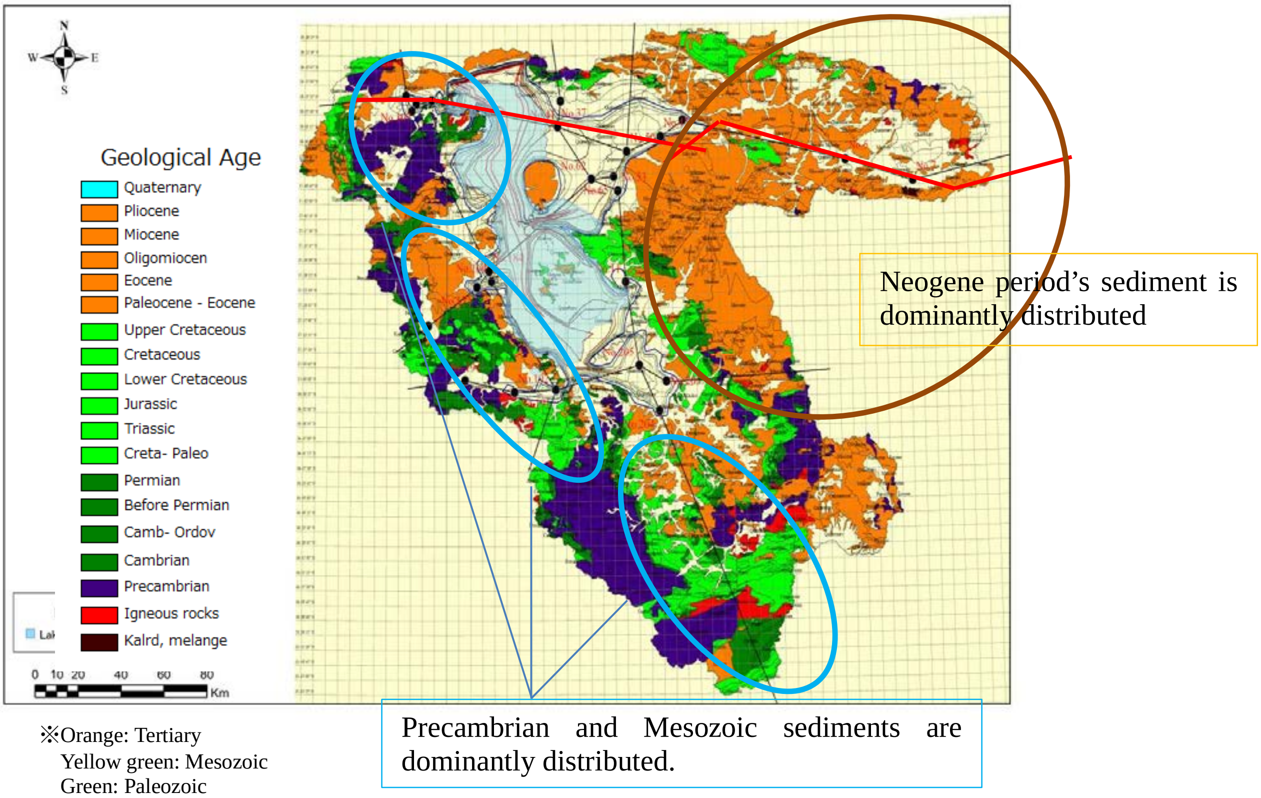
Figure 5.4.19 Transition of Spatial Distribution of ET_{frac} in Lake Area

(6) Geological Condition

(a) Geological Structure

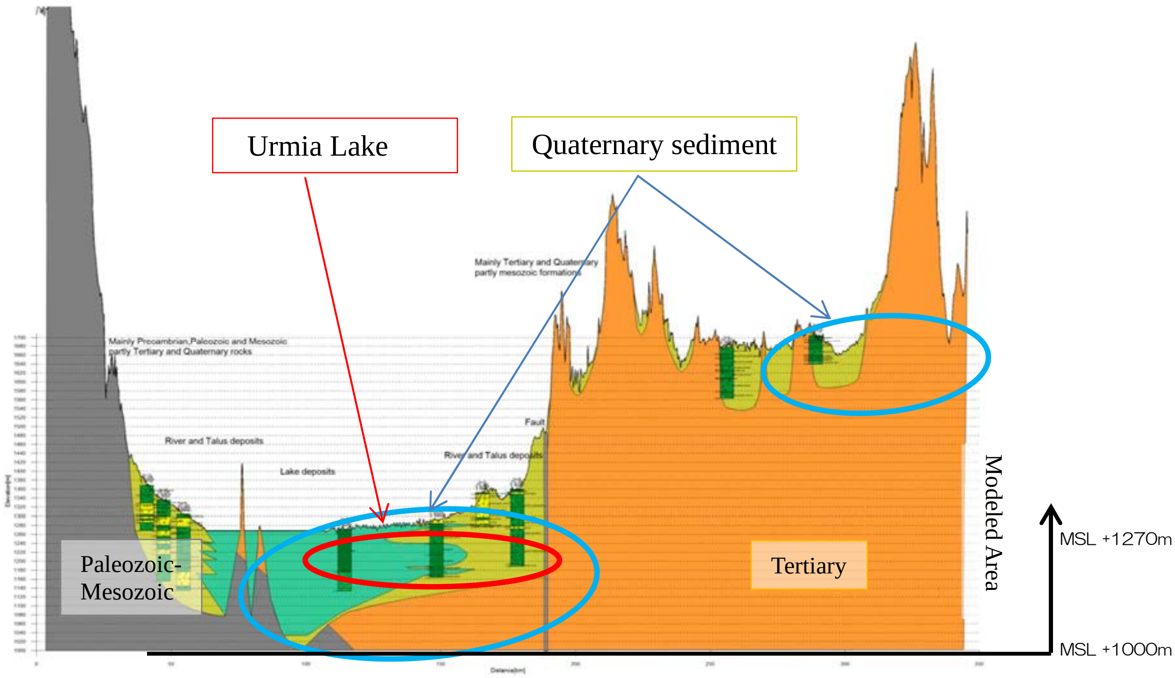
The geological structure of Urmia Lake Basin consists of the old strata of the Pre Mesozoic (Pre Cambrian to Mesozoic) in the southwest region of the main basin and old strata of the Tertiary in the eastern region. Moreover, relatively new geology of Quaternary was found in the areas along the river valleys and the lake. Location of these geological features are shown below in horizontal and longitudinal view (See Figure 5.4.20 and Figure 5.4.21).

Since these geological features were established in different era, parameters such as permeability coefficient can differ significantly. Therefore, geological features of different age groups are modeled to have different parameters.



※Orange: Tertiary
Yellow green: Mesozoic
Green: Paleozoic
Purple: Pre-Cambrian
Yellow grid : Quaternary period

Figure 5.4.20 Geological Planar map of the Urmia Lake Basin



*In this figure, columnar diagram indicates that the boring survey was done at that point
*The left side of the figure is the West, the right side is the East.

Figure 5.4.21 Geological Cross-Sectional View of the Urmia Lake Basin

(b) 3-D Geological Model

Based on collected geological information/data such as boring log, horizontal geological distribution and aquifer distribution, 3-D geological model was constructed by ULRP with the help of the Survey Team. With limited boring log reaching bed rock and soil profile, distribution of river/lake deposit and embedded bed rock distribution were interpolated.

Figure 5.4.22 shows the final version of the fact data and interpolation data about the thickness of the lake deposit, river and talus deposit. The final model data is formatted as ASCII. The 3-D image and longitudinal profile of the model are shown in Figure 5.4.23 and Figure 5.4.24.

The maximum thickness of the total alluvium (lake deposit a river and talus deposit) is 200 to 300 m. The marginal zone of aquifer is surrounded by river and talus deposit which has the thickness of 100 to 150 m. The central part of the Urmia Lake area is almost occupied by lake deposits, and river and talus deposits in this area are rather thin or absent in the northern center part.

Bedrock is usually covered by weathered layer which has a certain degree of permeability, and the thickness of this layer varies according to the weathering progress so that it is possible to consider the permeable layer on the surface of bedrock depending on the necessity of simulation software.

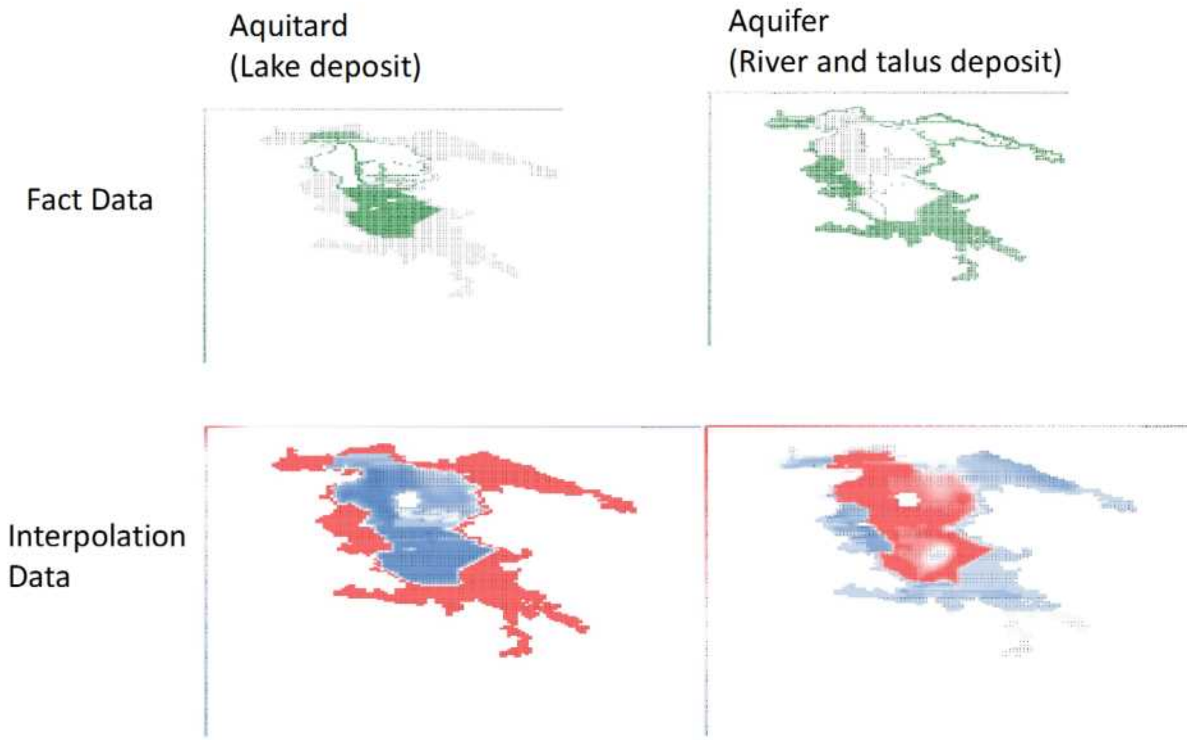


Figure 5.4.22 Constructed 3D Geological Model

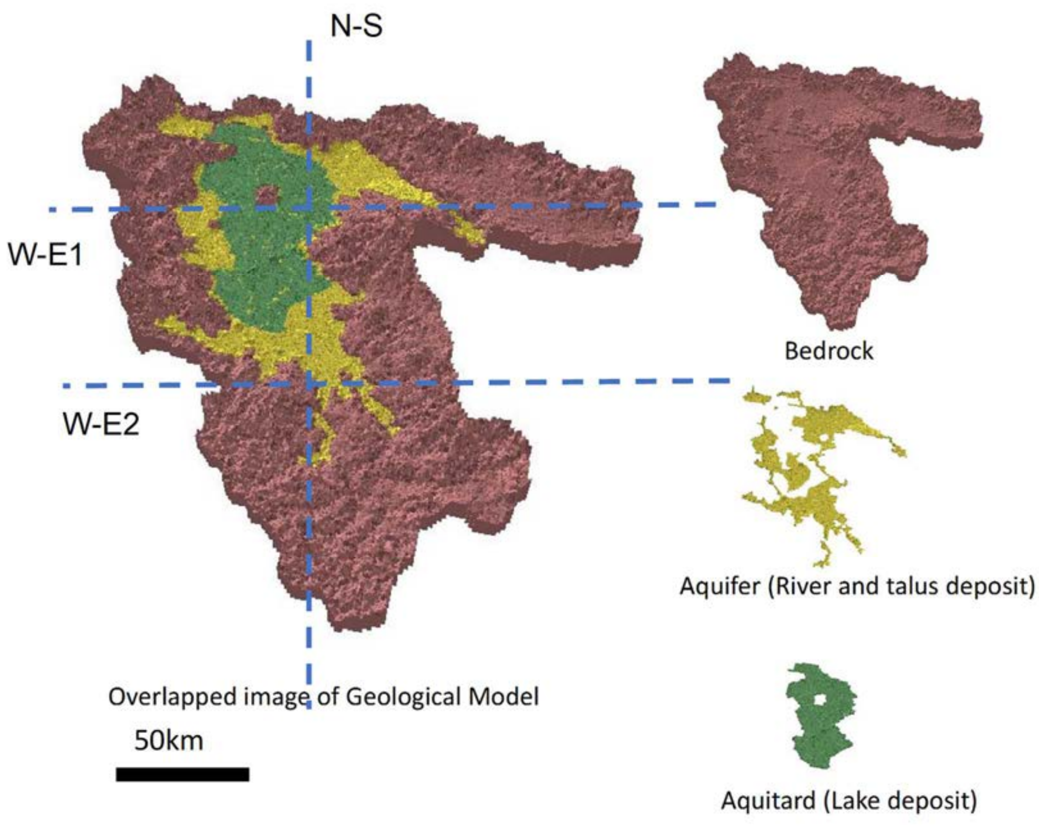


Figure 5.4.23 3D Image of Constructed Geological Model

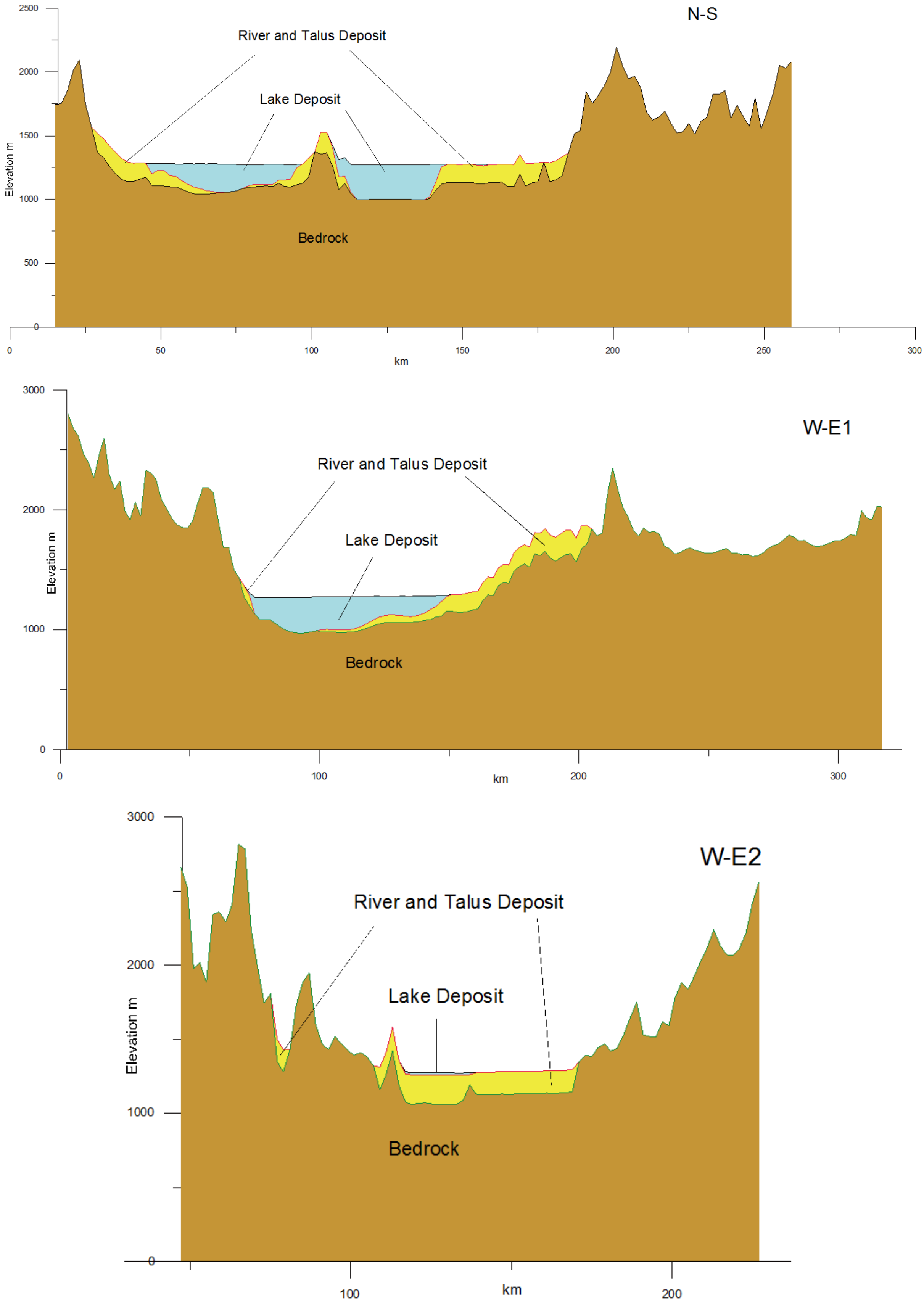


Figure 5.4.24 Longitudinal Profiles of Constructed Geological Model (along the lines drawn in Figure 5.4.23)

(c) Concept of Geological Parameter Setting

In the model, it is necessary to set the geologic parameters as shown below. (See Table 5.4.3)

Table 5.4.3 Geological Parameters

Classification	Item
Geological features	Conductivity
	Specific yield
	Specific storage

When calculating groundwater flow, permeability coefficient was to be determined based on geological features. In the Urmia Lake Basin, it was considered that the quaternary deposits exist on top of the paleogene, mesozoic and paleozoic layers. Further, weathered rocks and fresh rocks constitute the geological foundation besides the above deposits. The geological parameter was set for each type of deposit.

(7) Topographic Condition

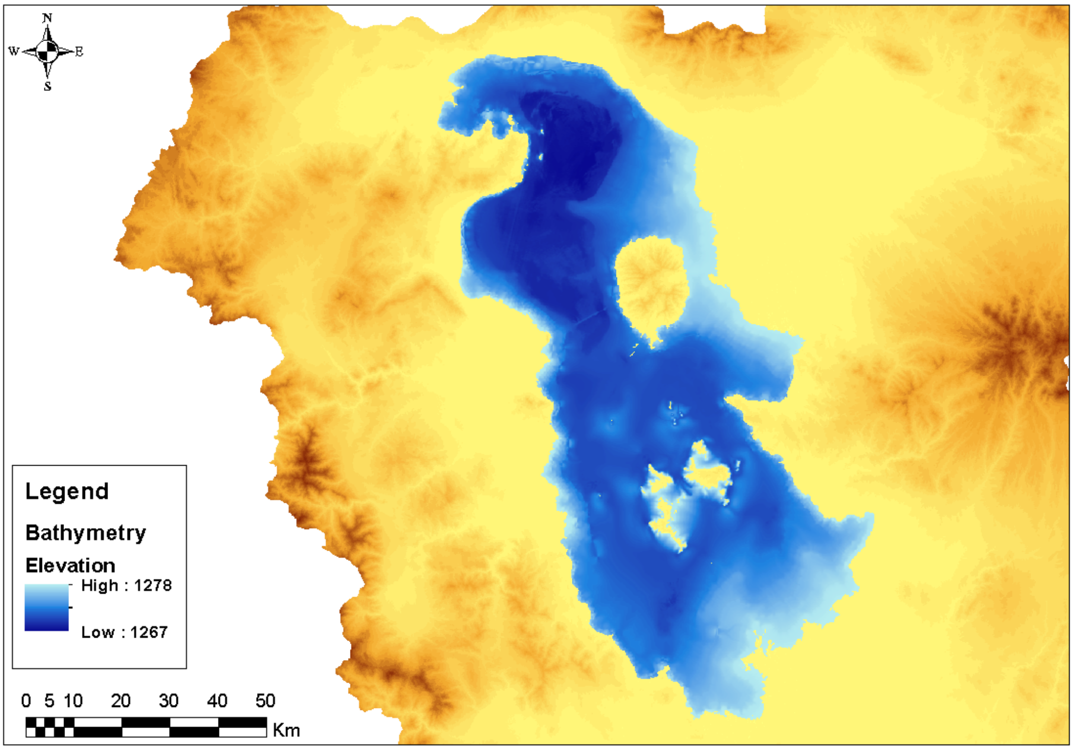
(a) Ground Surface Elevation

Ground surface elevation data of 2km mesh was prepared from the 90m-DEM data provided by IWRM.Co and established using the MIKE-SHE module.

(b) Lakebed Elevation

The lakebed elevation was incorporated into ground surface elevation in this year, which was same one as the previous survey.

The lakebed elevation data was prepared from DEM data established from bathymetry survey results of Urmia Lake. The 2km mesh of lakebed elevation data was created using MIKE-SHE (See Figure 5.4.25).

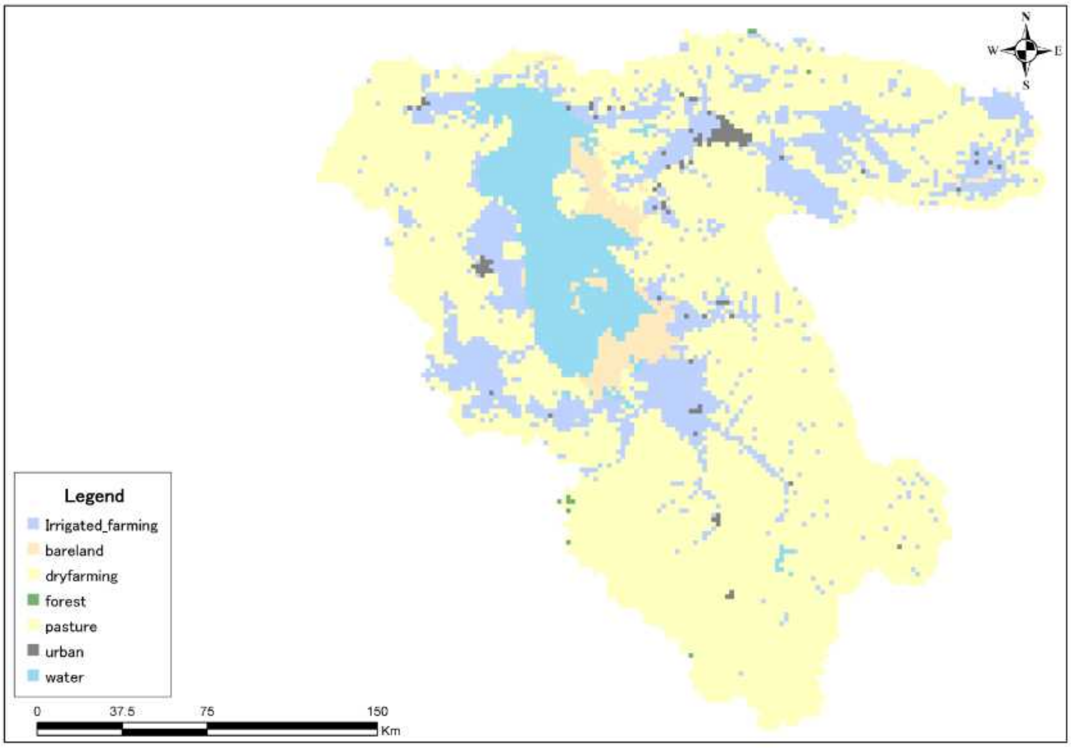


Source: Iran Water Research Authority

Figure 5.4.25 Lakebed Elevation

(8) Land Use

In calculating surface flow, roughness coefficient (Manning's N) is the key factor determined for hydraulic phenomenon of surface water flow. Land use in 2007 collected in the previous survey was applied for 2km-mesh data (see Figure 5.4.26). The roughness coefficients were set based on the commonly used value of roughness coefficients for different land uses listed in Table 5.4.4. With these values applied as initial value, the model was calibrated so that runoff discharge agrees with observed one.



*Map was prepared based on the land use map provided by IWRM Co.

Figure 5.4.26 Land use in 2007 (processed by 2-km-mesh)

Table 5.4.4 Applied Roughness Coefficient with Land Use

Land Use	Manning's Runoff Coefficient (n)	N (1/n)
Range Land	0.05	20
Dry Farmland	0.06	17
Orchard	0.035	29
Bare Soil	0.025	40
Forest	0.160	6.25
Urban	0.025	40
Water	0.040	25

Reference:
https://www.wcc.nrcs.usda.gov/ftpref/wntsc/H&H/HecRAS/NEDC/lectures/docs/Manning%92s%20n-values%20for%20Kansas%20Dam%20Breach%20Analyses%20-%20Adopted%20071216.pdf

(9) River Channel

(a) Concept of River Channel Modeling

Distribution of river network and basin boundaries within the Urmia Lake Basin are shown in Figure 5.4.27. Although river channel networks are densely distributed across the basin, some of them only seasonally exist and these are quite small. In consideration of this situation, river channels were modeled by following the ideas below. The water flow in un-modeled river channels which actually exist was modeled as surface runoff flowing on the ground surface or as a seepage into the ground which contributes to groundwater recharge.

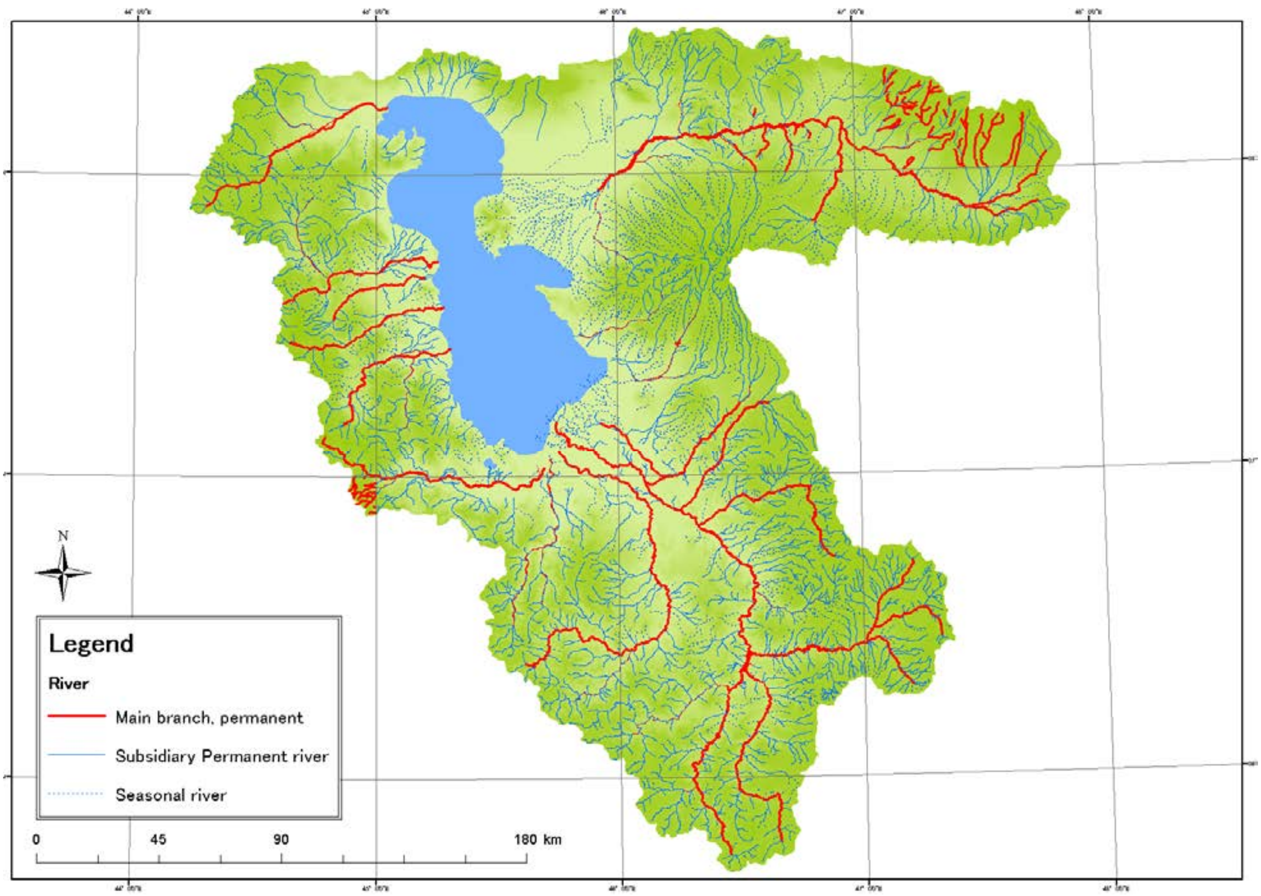
The modeled river channel network are shown in Figure 5.4.28 and summarized in Table 5.4.5, whose total length is approximately 2,200km.

- Main river channels in the river basin were modeled (Main Branch)

  Based on the information provided by WRMC, the river channel defined as “Main Branch” was selected for modeling. As for the river basins which do not have main river channels, the longest river network was selected.

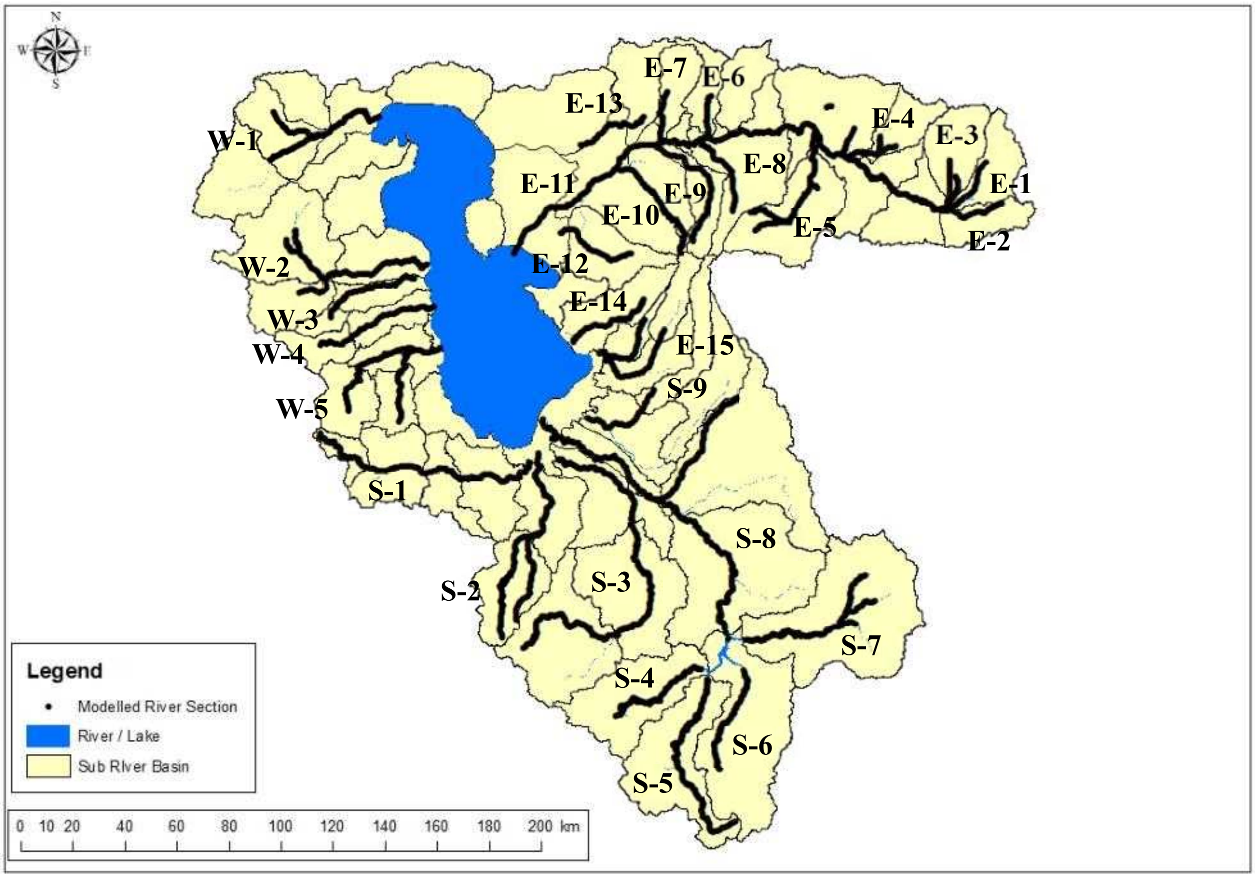
- River channels on which dam (s) exist were modeled

  As for dams located in neighboring main river channel, though they were not modeled, outflow data of the dams was input on the main rivers, directly.



Source: IWRM Co.

Figure 5.4.27 Distribution of Basin Boundaries and River Channel Network



*Described numbers are referred to "No" in Table 5.4.5

Figure 5.4.28 Modeled River Channel Network

Table 5.4.5 Summary of Modeled River Channel

No.	River	River Length (km)	No.	River	River Length (km)
S-1	Gedar chay	85	E-1	Aghmiun Chay	25
S-2	Mahabad chay	141	E-2	Vanagh Chay	29
S-3	Simineh rud	182	E-3	Tajyar Chay	20
S-4	Saghez	66	E-4	Chekeh Chay	30
S-5	Zarineh Rud Up	111	E-5	Ojan Chay	64
S-6	Khor khoreh	65	E-6	Nahand Chay	18
S-7	Sarough chay	111	E-7	Gomanab Chay	23
S-8	Zarrineh rud	221	E-8	Lighavan Chay	56
S-9	Mardugh chay	39	E-9	Zinjenab Rud	48
W-1	Zola chay	82	E-10	Saiid Abad Chay	36
W-2	Nazlu chay	107	E-11	Aji Chay	257
W-3	Rose chay	44	E-12	Azar Shahr Chay	36
W-4	Shahr chay	60	E-13	Varkash Chay	32
W-6	Baranduz chay	102	E-14	Ghaleh chay	39
			E-15	Sufi chay	75
				Total	**2,204**

(b) Modeling of Cross Section

The cross-sections of the river channels were modeled based on the following concepts (See Table 5.4.6).

Table 5.4.6 Concept of Modeling of River Channel and Cross-Section

Item	Concept of modeling
Modeled river channels	Modeled for main river channel in each basin
Cross-sectional shape	Cross sections were modeled based on DEM as rectangle with 20-100m wide, which were processed by GIS software.
Cross-section interval	Basically 1km (cross section was interpolated for model stability)

(10) Applied Information on Dam Operation into the Model

(a) Concept of Dam Modeling

Dams in the Urmia Lake Basin are classified into four: “In Operation”, “Proposed”, “Under Study” and “Under Construction”, according to IWMR Co. In the model, based on field investigation and interview survey, in order to evaluate the current condition in Urmia Lake Basin, only the dams in operation during the calibration period were considered, namely, the 5 dams listed in Table 5.4.7 with approximately 1,379 MCM of dam storage. Since there is no H-V rating curve of dams, dam lakes were created with river cross section in MIKE-11, and regulator function to dam up the water of rivers and observation record for these dams were input into the model as dam released discharge (see Chapter 3).

Table 5.4.7 Dams Input into the Urmia Lake Basin Model

No.	Province	Dam	Storage Volume (MCM)	River Basin	Province	Duration of Daily Data for as Input （Year/Month）
1	West Azerbaijan	Shahid Kazemi Bukan- Zarine Rud (Bukan Dam)	825*	Zarine Rud	West Azerbaijan	2000/1～2014/9
2	West Azerbaijan	Mahabad Dam	190	Mahabad Chay	West Azerbaijan	2000/1～2014/9
3	West Azerbaijan	Hasanlu Dam	94	Gadar Chay	West Azerbaijan	2002/3～2014/9
4	West Azerbaijan	Sahr Chay Dam	213	Shahr Chay	West Azerbaijan	2006/5～2014/9
5	East Azerbaijan	Alavian Dam	57	Sufi Chay	East Azerbaijan	2000/1～2014/9

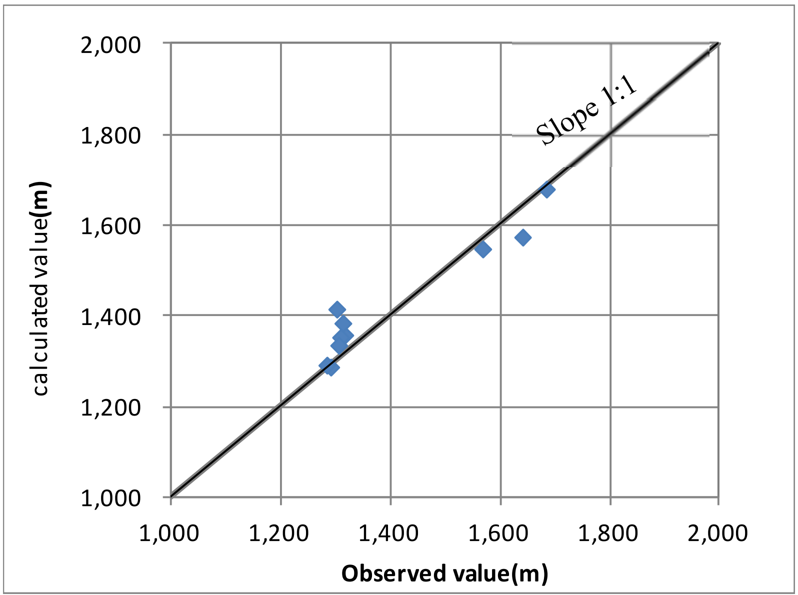
Source: IWRM Co.
*According to IWRM Co., 486MCM of dam storage was reported. However, it was commented that the volume is 825 in the P/R2 seminar held at Urmia University in March 2018.

(11) Setting of Initial Condition of Piezometric Head

For the initial condition used at the start of calculation time, it was preferred that calculated values of lake water level and groundwater level agree with those of observed data. The observed data of the lake water level were gathered since collected observed groundwater level was limited. In case that spatial distribution of groundwater level is prepared using only observed data, low accuracy shall be obtained for initial condition for model simulation, and there will be a high possibility of instability of model calculation. Instead, the initial condition was prepared based on calculation by MIKE-SHE.

In order to obtain the initial condition of the model starting from January 1, 1999, calculation was carried out under the climatological and hydrological condition from 1993 to 1999 (by inputting data of precipitation, lake surface evaporation, and land evapotranspiration). Calculated value of the lake water level (1,276.52m) that matches the observed lake water level on January 1, 1999 (1,276.49m) was selected for the initial condition of the model simulation.

The calculated and observed data of groundwater level on the same date were compared as shown in Figure 5.4.29. The observed and calculated initial groundwater levels were compared at the locations shown in Table 5.4.8. In the context that collected observed piezometric head is limited, with observed data, it was confirmed that the calculated groundwater level well matches that of observed in 1999.



*Prepared by JICA Survey Team

Figure 5.4.29 Comparison of Groundwater Level between Calculated and Observed

Table 5.4.8 Location of Extracted Point of Groundwater

City	Lon (degree)	Lat (degree)	Observed*	Simulated
Maragheh	37.382	46.226	1302.3	1415.8
Ajabshir	37.448	45.906	1292.2	1285.4
Azar shahr	37.742	45.981	1316.1	1355.4
Tabriz	38.080	46.300	1313.5	1382.9
Sahand (Tabriz)	37.945	46.122	1641.9	1573.7
Bilverdi	38.281	46.798	1567.7	1548.1
Sarab	37.938	47.578	1686.3	1680.0
Shabestar	38.165	45.788	1311.8	1350.7
Tasuj	38.309	45.388	1307.3	1336.1
Malekan	37.131	46.098	1285.3	1289.7
Salmas	38.195	44.773	1356.5	1359.0
Qalqachi	38.111	45.194	1296.0	1296.7

* Observe data is representative groundwater level in cities provided by IWRM Co.

(12) Water Use

(a) Basic Idea of Estimation of Water Use in Irrigated Area

Irrigation demand for each identified irrigation area was calculated by the following equation.

$$W_{demand} = (ETa \,/\, IE) \,/\, 1000 \times A \times 10^{6} \,/\, 86400$$

Where,

W_{demand}	: Irrigation demand (m^3/s)
ETa	: *Actual* evapotranspiration (RSRC-ET, mm/day)
IE	: *Irrigation* efficiency
A	: *Irrigated* Area (km^2)

The agricultural water demand for each irrigated area was calculated by the above-described equations (see Figure 5.4.30 and Appendix 5-5) and given to the model as input in irrigation module and automatically retrieved from water source, e.g., river channel. Return flow from irrigated area was considered as the base flow calculated based on behavior of groundwater and remained water overland.

Irrigation efficiency is obtained by multiplying two efficiencies, conveyance efficiency (ec) with field application-efficiency (ea). These three types are defined as follows:

- **Conveyance Efficiency (ec)** which represents the efficiency of water transport in canals
- **Field Application Efficiency (ea)** which represents the efficiency of water application in the field.
- **Irrigation Efficiency (IE)** = ec x ea

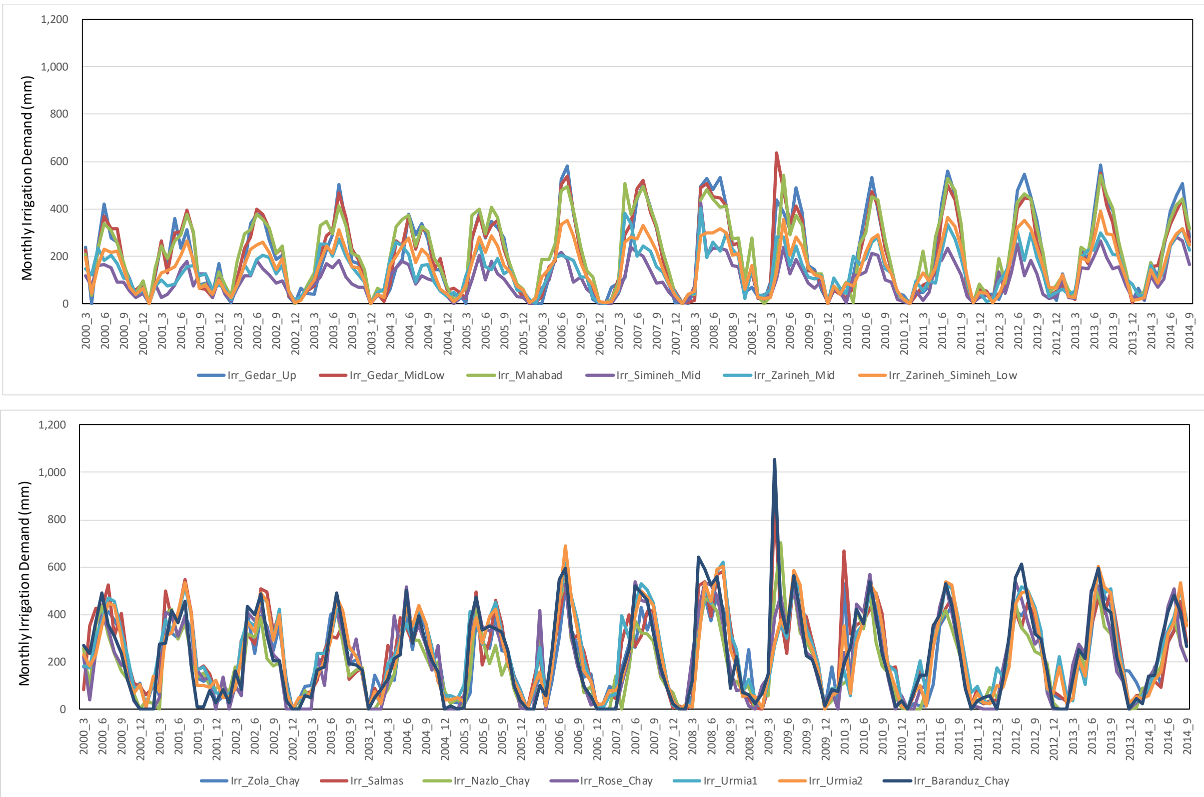


Figure 5.4.30 Calculated Agricultural Water Demand for each Irrigated Area (1)

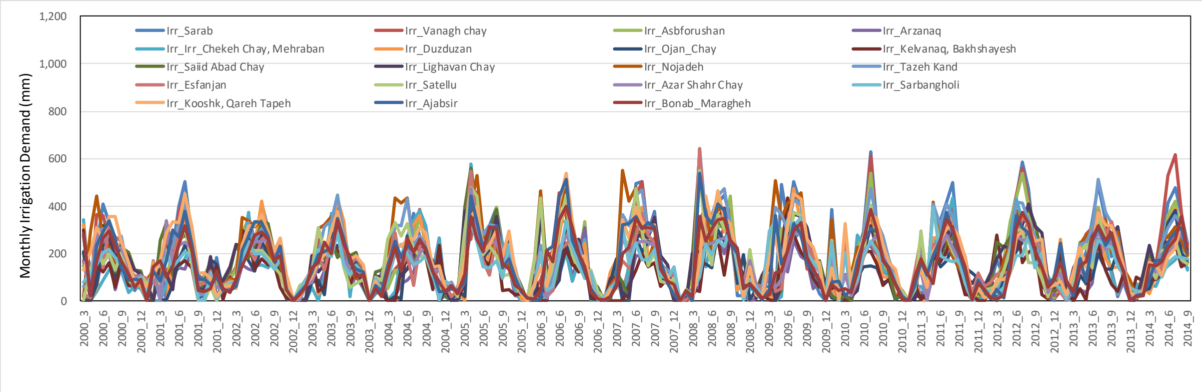


Figure 5.4.30 Calculated Agricultural Water Demand for each Irrigated Area (2)

(b) Identification of Irrigated Area of Urmia Lake Basin

Based on satellite image (see Figure 5.4.32) and information of irrigation channel provided by ULRP (see left figure in Figure 5.4.31), 4,245 km^2 of irrigated area was identified in Urmia Lake Basin as shown in Figure 5.4.33 and summarized in Table 5.4.9 with given irrigation efficiency. Since information of only southern part was obtained (described in Subsection 3.2.8), irrigation efficiency in southern part was calculated by averaging with the area of irrigated area. As for western part and eastern part, without concrete information of irrigation efficiency, ULRP indicates that 0.3 of irrigation efficiency is applied for each irrigated area, which is the value equivalent to undeveloped irrigation network.

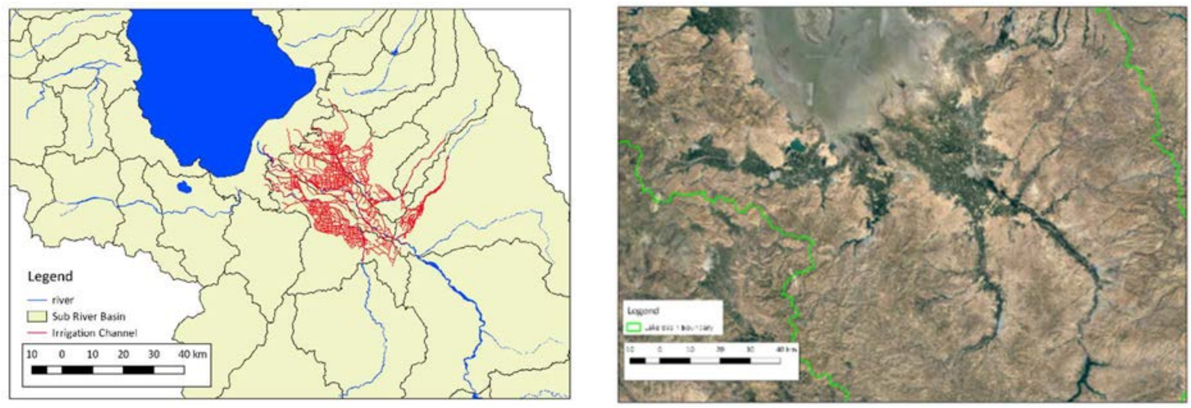


Figure 5.4.31 Irrigation Channel Network in Miandoab and Satellite Imagery of Southern Part

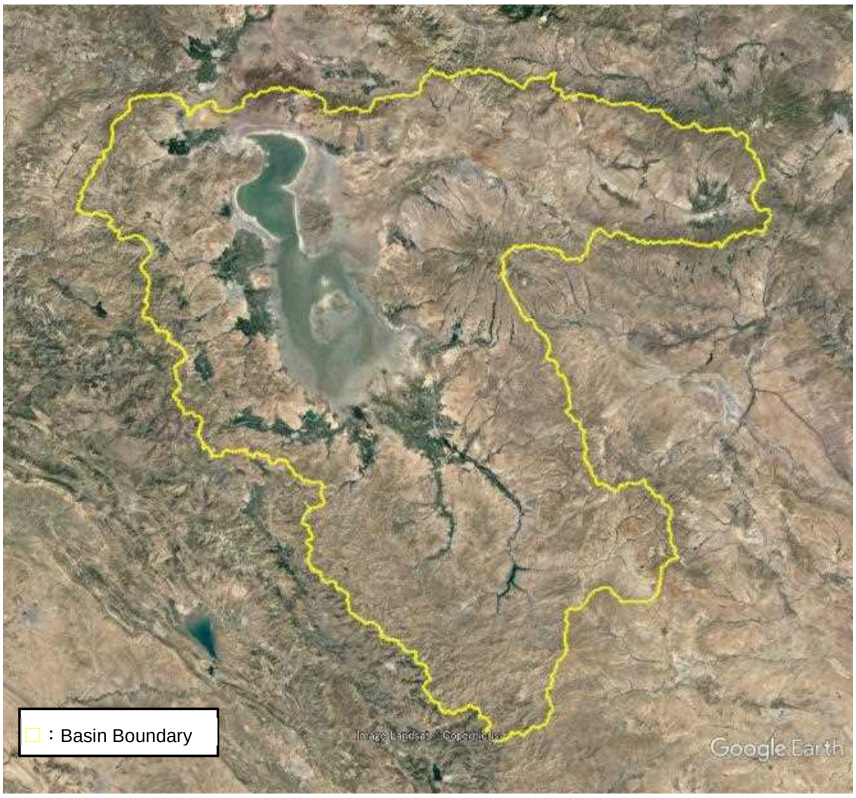
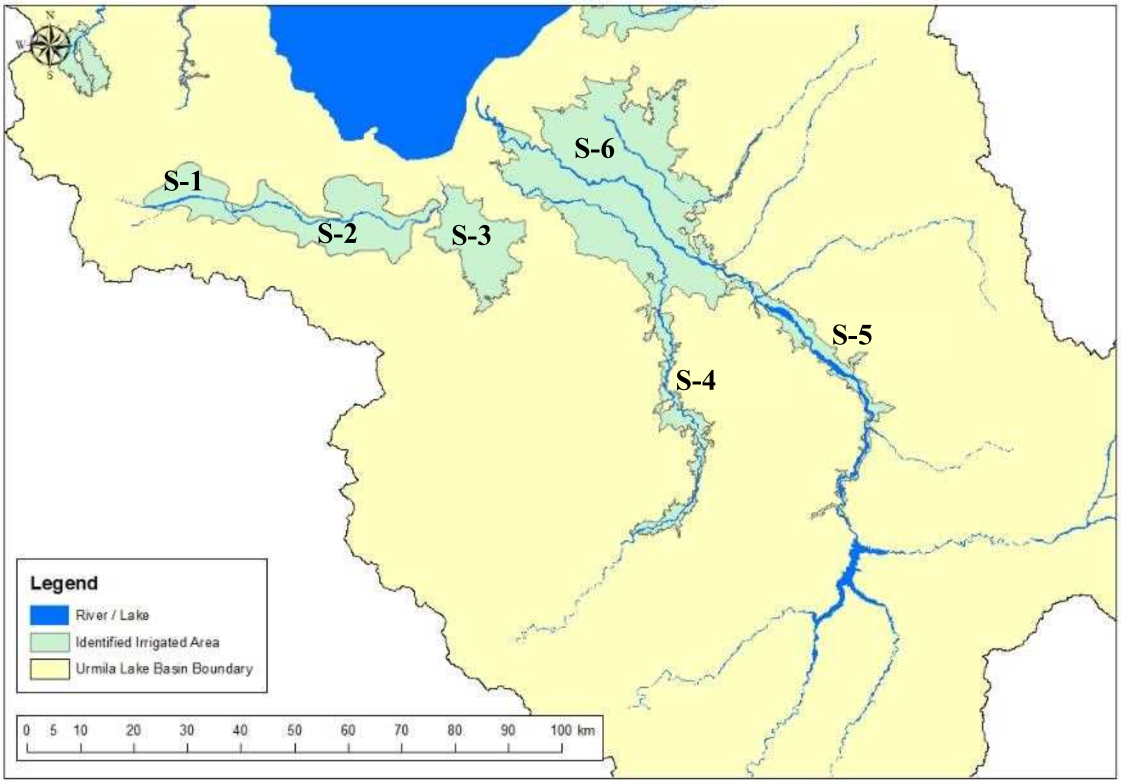
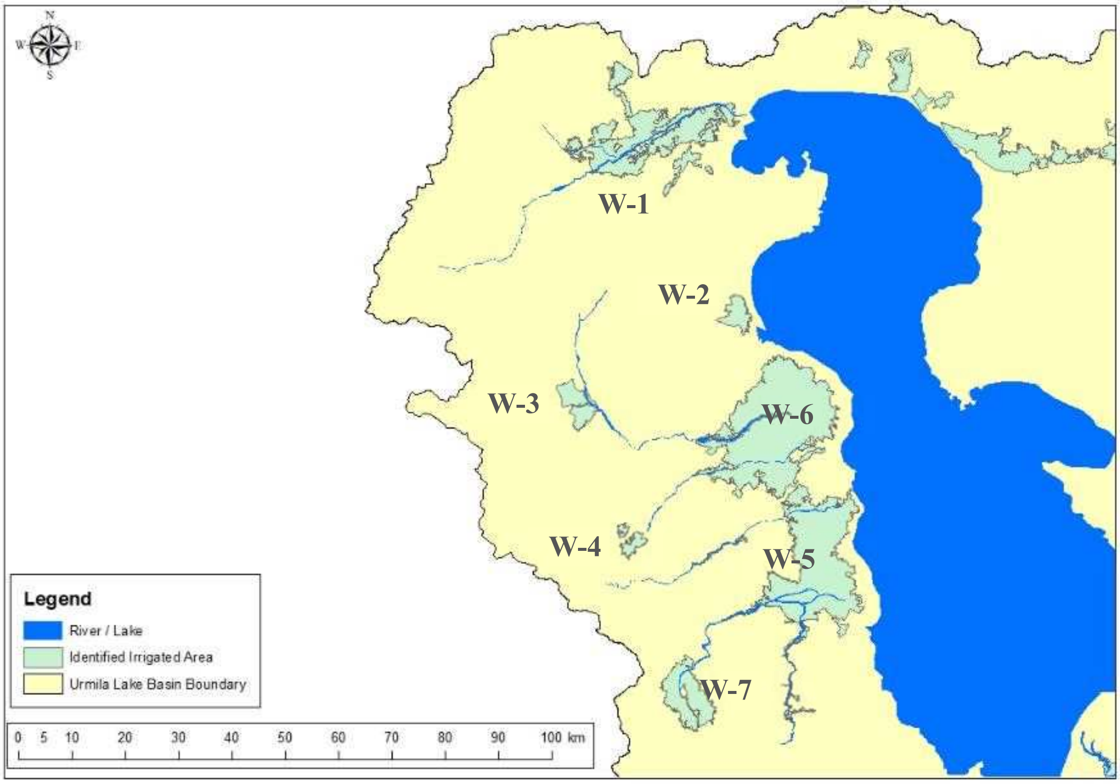


Figure 5.4.32 Distribution of Irrigated Area in Urmia Lake Basin



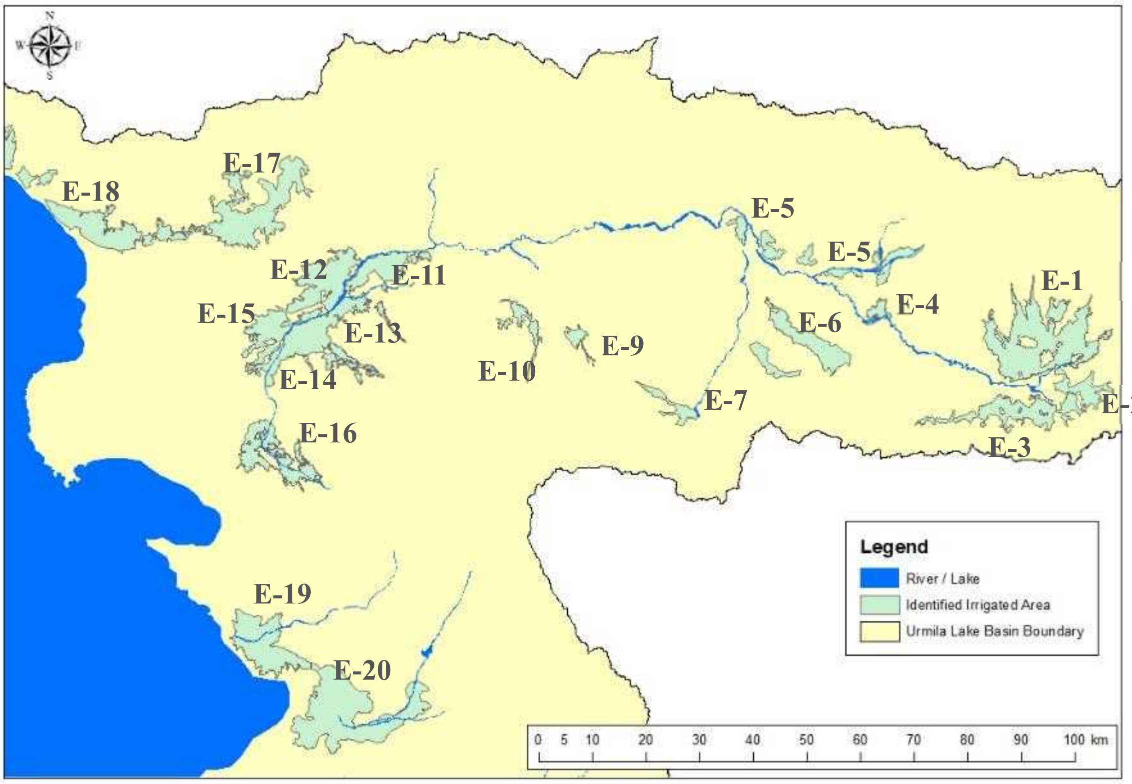
*Described numbers are referred to "No" in Table 5.4.9

Figure 5.4.33 Identified Irrigated Area in the Urmia Lake Basin (1) (Southern Part)



*Described numbers are referred to "No" in Table 5.4.9.

Figure 5.4.33 Identified Irrigated Area in the Urmia Lake Basin (2) (Western Part)



*Described numbers are referred to "No" in Table 5.4.9.

Figure 5.4.33 Identified Irrigated Area in the Urmia Lake Basin (3) (Eastern Part)

Table 5.4.9 Summary of Identified Irrigated Area and Applied Irrigation Efficiency

■Southern Part

No.	Name	Area (km²)	IE
S_1	Irr_Gedar_Up	110	0.30
S_2	Irr_Gedar_MidLow	288	0.30
S_3	Irr_Mahabad	202	0.28
S_4	Irr_Simineh_Mid	139	0.36
S_5	Irr_Zarineh_Mid	140	0.41
S_6	Irr_Zarineh_Simineh_Low	963	0.39
Sub Total (Average IE in Southern Part)		1,842	(0.36)

■Western Part

No.	Name	Area (km²)	IE
W_1	Irr_Zola_Chay	219	0.30
W_2	Irr_Salmas	23	0.30
W_3	Irr_Nazlo_Chay	34	0.30
W_4	Irr_Rose_Chay	14	0.30
W_5	Irr_Urmia1	295	0.30
W_6	Irr_Urmia2	366	0.30
W_7	Irr_Baranduz_Chay	73	0.30
Sub Total (Average IE in Western Part)		1,024	(0.30)

■Eastern Part

No.	Name	Area (km²)	IE
E_1	Irr_Sarab	184	0.30
E_2	Irr_Vanagh chay	42	0.30
E_3	Irr_Asbforushan	62	0.30
E_4	Irr_Arzanaq	11	0.30
E_5	Irr_Chekeh Chay, Mehraban	37	0.30
E_6	Irr_Duzduzan	53	0.30
E_7	Irr_Ojan_Chay	34	0.30
E_8	Irr_Kelvanaq, Bakhshayesh	21	0.30
E_9	Irr_Saiid Abad Chay	10	0.30
E_10	Irr_Lighavan Chay	20	0.30
E_11	Irr_Baghmaruf	46	0.30
E_12	Irr_Nojadeh	77	0.30
E_13	Irr_Tazeh Kand	90	0.30
E_14	Irr_Esfanjan	21	0.30
E_15	Irr_Satellu	53	0.30
E_16	Irr_Azar Shahr Chay	72	0.30
E_17	Irr_Sarbangholi	135	0.30
E_18	Irr_Kooshk, Qareh Tapeh	134	0.30
E_19	Irr_Ajabsir	89	0.30
E_20	Irr_Bonab_Maragheh	188	0.30
Sub Total (Average IE in Eastern Part)		1,379	(0.30)

Total	**4,245 km²**

*IE: Irrigation Efficiency

(c) Domestic Water Withdrawal from the River

Water pipes have been installed for domestic water supply for primary cities, such as Urmia and Tabriz. Based on the interview with ULRP, the constructed model also considers this water use by retrieving the amount from modelled river channel as shown in Table 5.4.10.

Table 5.4.10 Modelled Domestic Water Supply

Puporse	Retrieved from	Amount
Domestic Water Supply to Urmia	Shahr Chay (downstream Shahr Chay Dam)	85 – 120 MCM/year (existing data is inputted)
Domestic Water Supply to Tabriz	Zarineh Rud (downstream Noluzlu Diversion Dam)	5 m^3/s, constantly

*Source: ULRP

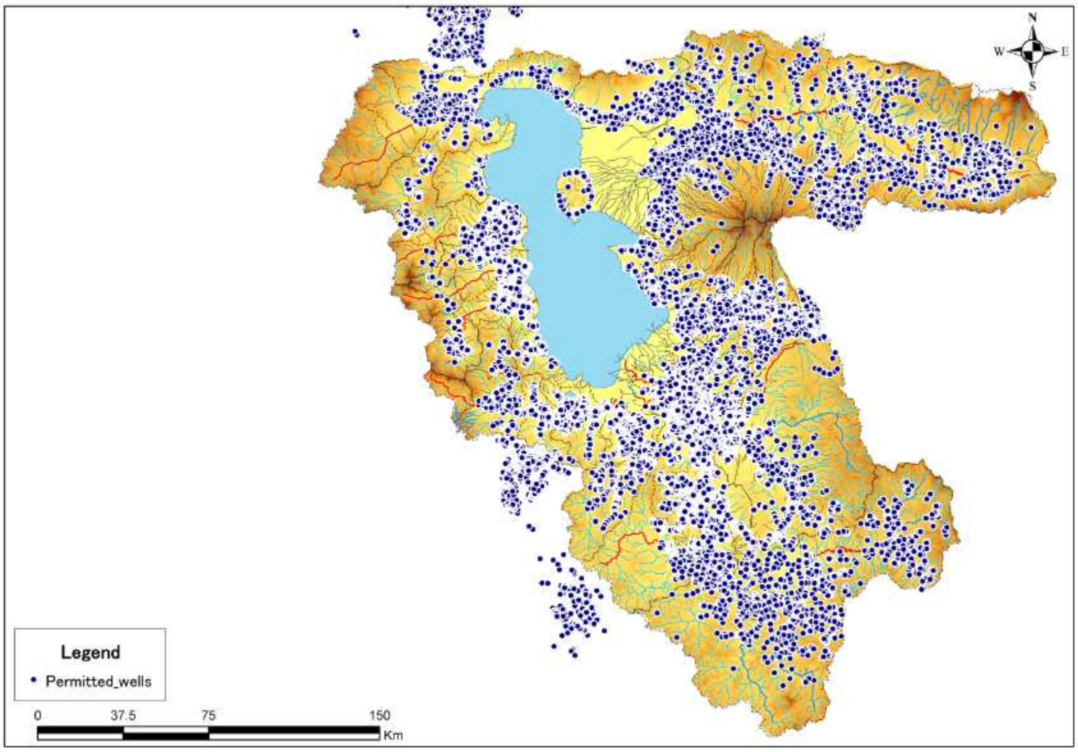
(d) Water Uptake from Groundwater

Locations of the 89,000 wells permitted by IWRM.Co are shown in Figure 5.4.34. The amount of water uptake from wells were referred from the data provided by IWRM.Co while the approach of water intake from the river, with reference to the M/P of the Ministry of Energy, at an increasing rate of 1.1 was obtained by dividing water uptake volume of the M/P with the total water uptake volume permitted by WRMC (see Appendix 5-6 for reference). The calculated water uptake volume was extracted from the layer of groundwater for each mesh. The schedule of water uptake for agriculture was determined based on calculated agricultural water use in the M/P as shown in Table 5.4.11. For other sectors, monthly water uptake data was estimated by dividing the annual water extraction data by 12.

Table 5.4.11 Seasonal Ratio of Monthly Agricultural Water Intake

Month	Water Requirement (10^3 m^3)	Seasonal Ratio
Jan	7,073	0.11%
Feb	24,987	0.38%
Mar	80,994	1.22%
Apr	405,070	6.11%
May	747,626	11.27%
Jun	1,439,579	21.70%
Jul	1,319,512	19.89%
Aug	1,135,134	17.11%
Sep	830,176	12.52%
Oct	330,185	4.98%
Nov	308,433	4.65%
Dec	3,718	0.06%
Total	6,632,487	100.00%

Note: Prepared by JICA Survey Team based on the data provided by WRMC



Source: IWRM Co.

Figure 5.4.34 Location of Registered Wells

(e) Groundwater Irrigation

Groundwater irrigation was considered by conversion of the groundwater extraction for agriculture which was summarized for sub-river basins and irrigated area, from the registered well database provided by WRMC in the previous survey. The areal annual extraction amount was obtained based on the accumulated volume. The annual volume was divided into monthly extraction with the dividing ratio based on operation hours of wells.

The supplementary well irrigation was considered in MIKE-SHE, which withdraws groundwater when soil water content decreases due to dry condition (e.g. in summer season) and more irrigation water is required. Figure 5.4.35 shows simulation result with consideration of supplementary well irrigation at irrigated area in Miandoab. Monthly ET trend shows better agreement with RSRC-ET, which mean error for fourteen years (2000-2013) is 6%. Figure 5.4.36 shows correlation charts of monthly/annual ET between RSRC-ET and ET calculated by MIKE-SHE. High correlations can be seen, namely, 0.985 in monthly basis and 0.839 in annual basis, respectively. This result indicates the consideration of supplementary well irrigation is effective for securing simulation accuracy of actual ET. This idea is also applied in the modeling of the western part of Urmia Lake Basin.

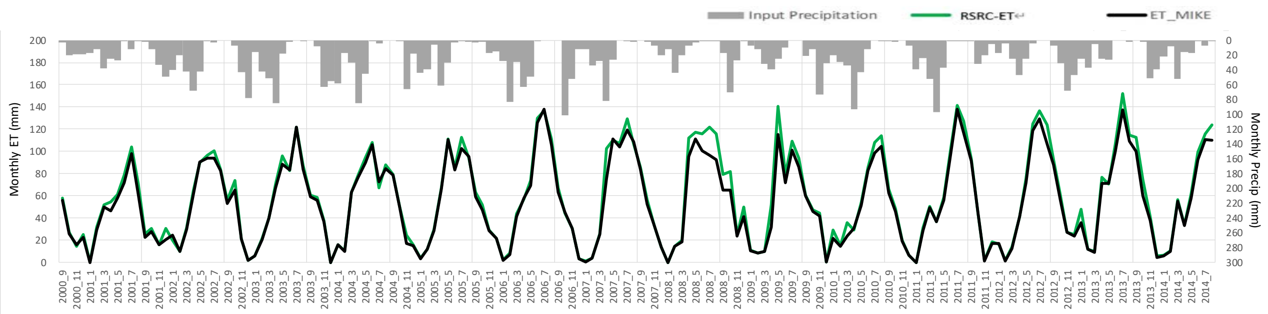


Figure 5.4.35 Temporal Change in Monthly Evapotranspiration in Miandoab Plain

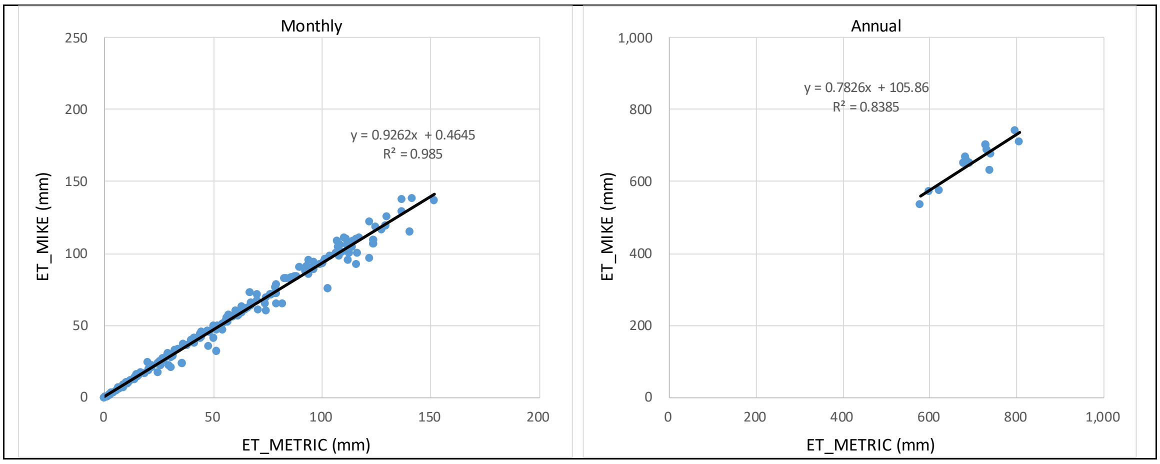


Figure 5.4.36 Comparison of Simulation Result between December 2018 (Top) and March 2019 (Bottom) with Correlation of Monthly/Annual Evapotranspiration in Miandoab Plain

5.5 Sensitivity Analysis

5.5.1 Outline

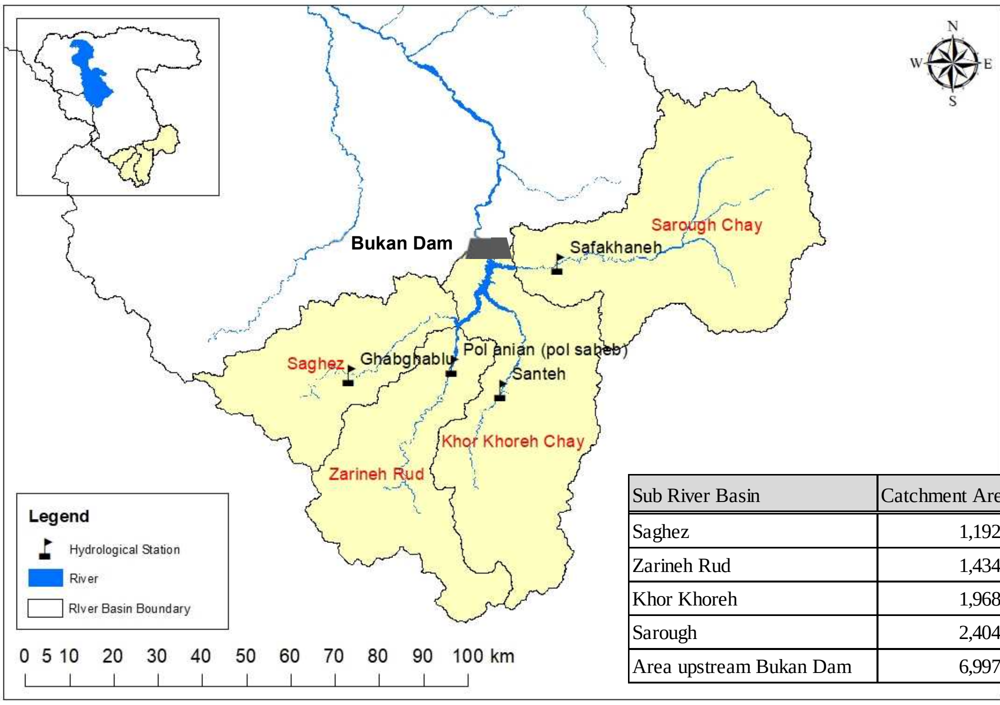
Sensitivity analysis is one of steps in the process of modeling to understand how target variables (simulated outputs) affected on changes in other input parameters. In the Survey, the representative parameters selected by ULRP was changed within the allowable maximum range based on the basin's natural condition in order to understand how the runoff discharge affected by the change. In other words, the sensitivity analysis should be carried out for more appropriately recognizing the output of the hydrological cycle model and guiding appropriate evaluation and parameter setting in order to contribute further calibrations using different-temporal data or new-finding information in the future.

Sensitivities of the constructed model have been evaluated with six parameters listed in Table 5.5.1. There were changes in runoff response with different values. From the aspect of water resource management, (1) annual runoff volume, (2) runoff volume during snow melt season (March - June), and (3) monthly runoff pattern was selected for evaluation indices. Besides, effect of these parameters on runoff was qualitatively evaluated.

As representative catchment area for identifying the runoff trend of Urmia Lake Basin, inflow of Bukan Dam (6,997 km^2 of catchment area) was selected to evaluate the constructed model's sensitivity (see Figure 5.5.1). This catchment area also has less hydraulic structures which affect the hydrological condition.

Table 5.5.1 Parameters for Sensitivity Analysis

No	Classification	Parameter	Applied Value
1	Land use	Roughness coefficient	Range land (n=0.05) Dry farming (n=0.06) Orchard (n=0.035) Bare soil (n=0.025)
2	Snow melt	Threshold snow melt temperature	-3℃, -2℃, -1℃, 0℃, 1℃, 2℃, 3℃
3	Infiltration	Depth of unsaturated zone layer (hereinafter referred to as "UZ")	15m, 25m, 35m, 45m
4	Infiltration	Soil Type	Fine sand / Coarse sand
5	Baseflow runoff	Horizontal hydraulic conductivity	K_h 10^{-7} m/s, 10^{-5} m/s, 10^{-3} m/s
6	Baseflow runoff	Vertical hydraulic conductivity	K_v: 10^{-7} m/s, 10^{-5} m/s, 10^{-3} m/s



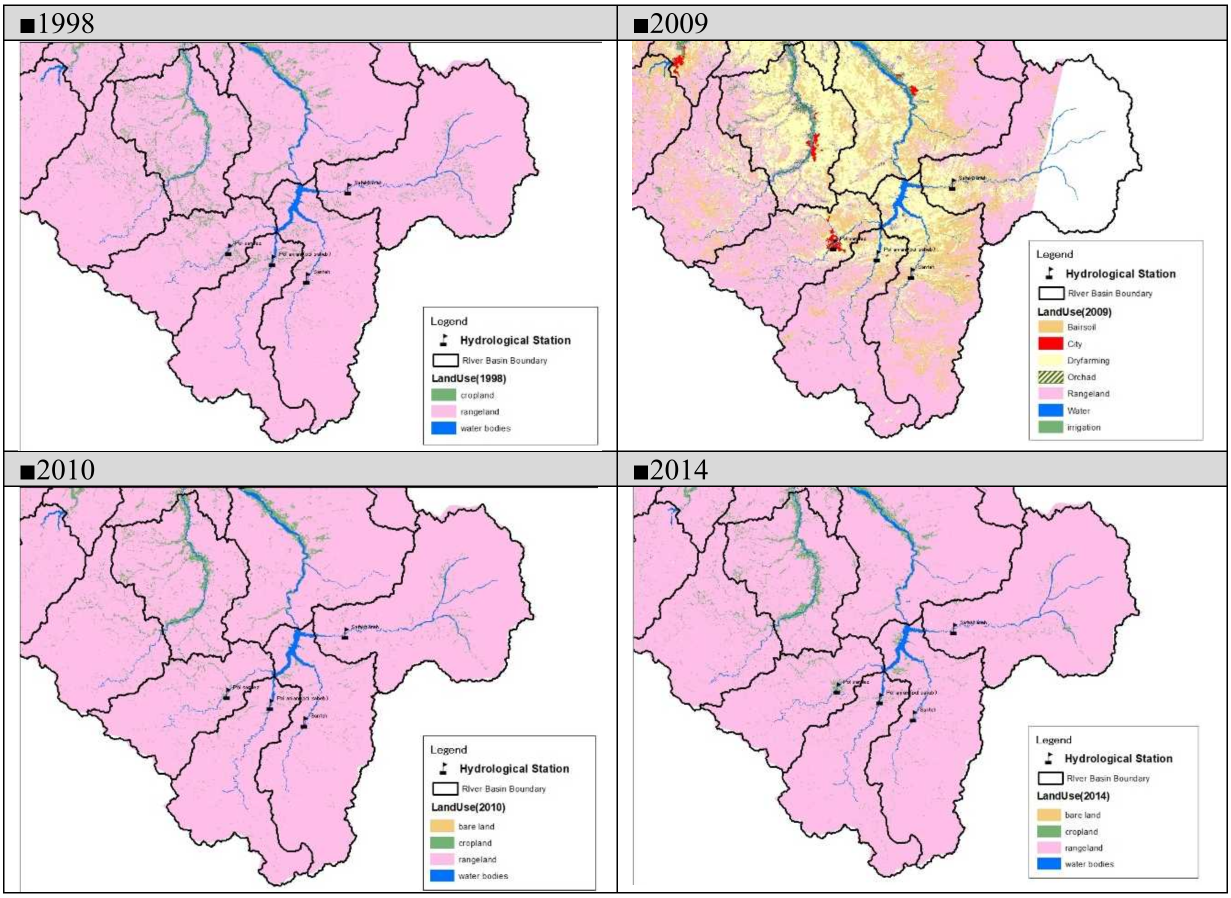
Sub River Basin	Catchment Area (km^2)
Saghez	1,192
Zarineh Rud	1,434
Khor Khoreh	1,968
Sarough	2,404
Area upstream Bukan Dam	6,997

Figure 5.5.1 Catchment Area Selected for Sensitivity Analysis

5.5.2 Land Use Change (Runoff Coefficient)

ULRP and other authorities (participants in TCM) commented that drastic land use change occurred in the Urmia Lake Basin in the middle of the 2010's, which caused change in hydrological cycle and flow regime. As described in Section 4.5, every land use map has different legends due to different analysis approach, therefore, it is difficult to mention justification of these land use change year by year (see Figure 5.5.2).

In the context that mountainous area has simple land use distribution, impact of land use change on river discharge was confirmed by changing a land use type in a whole area of selected catchment area. In hydrological modeling, roughness coefficient (Manning's n) is one of representative parameters compatible with land use. In the Survey, four types of different values were applied in accordance with land use types listed in Table 5.5.2.



Source: Land use map provided by ULRP

Figure 5.5.2 Change in Land Use Pattern Upstream Bukan Dam (1998-2014)

Table 5.5.2 Parameters Applied with Land Use for Sensitivity Analysis

Land use	Manning's Runoff Coefficient (n)
Range land	0.05
Dry Farmland	0.06
Orchard	0.035
Bare Soil	0.025

Reference:
https://www.wcc.nrcs.usda.gov/ftpref/wntsc/H&H/HecRAS/NEDC/lectures/docs/Manning%92s%20n-values%20for%20Kansas%20Dam%20Breach%20Analyses%20-%20Adopted%20071216.pdf

Daily and monthly discharge hyeto-hydrographs of inflow into Bukan Dam are shown in Figure 5.5.3 and Figure 5.5.4, respectively. Change has been confirmed at around peak discharge at every flood event, which shows difference with approximately 50 m^3/s of peak discharge between dry farming (n=0.06) and bare soil (n=0.025). Almost no difference in monthly discharge was confirmed. It tends that runoff coefficient does not significantly affect water resource supplement from mountainous area.

Despite no drastic change in runoff volume for daily basis, change was confirmed at around peak discharge at every flood event, which shows difference with 50 m3/s of peak discharge between dry farming (n=0.06) and bare soil (n=0.025) as shown in Figure 5.5.3. Few different discharge volumes were also confirmed on monthly basis as shown in Figure 5.5.4. As shown in Table 5.5.3,

Percentage of variance range (difference between maximum and minimum) to average runoff volumes for the years and snowmelt seasons were calculated as Table 5.5.3. It was shown that there is no significant difference in the annual runoff by land use and that the roughness coefficient does not have such a large effect on the hydrological cycle model.

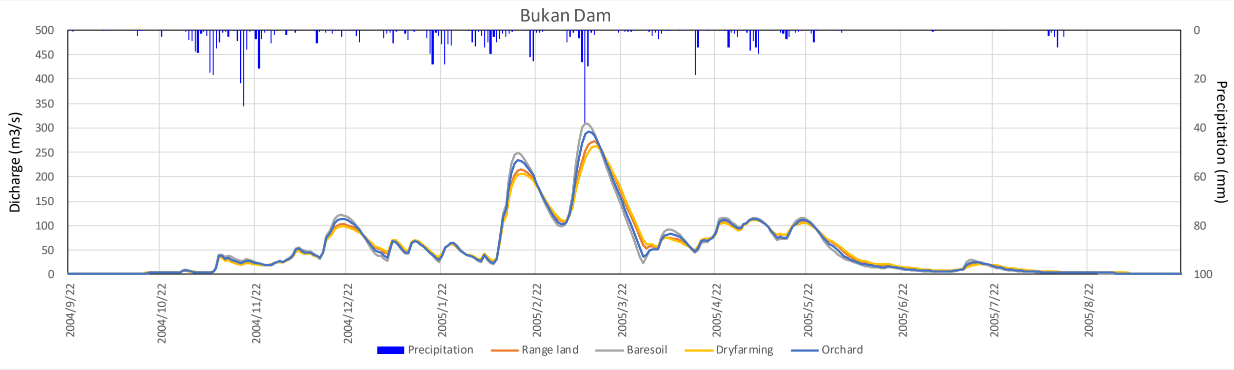


Figure 5.5.3 Daily Discharge Trend with Different Land Use Types

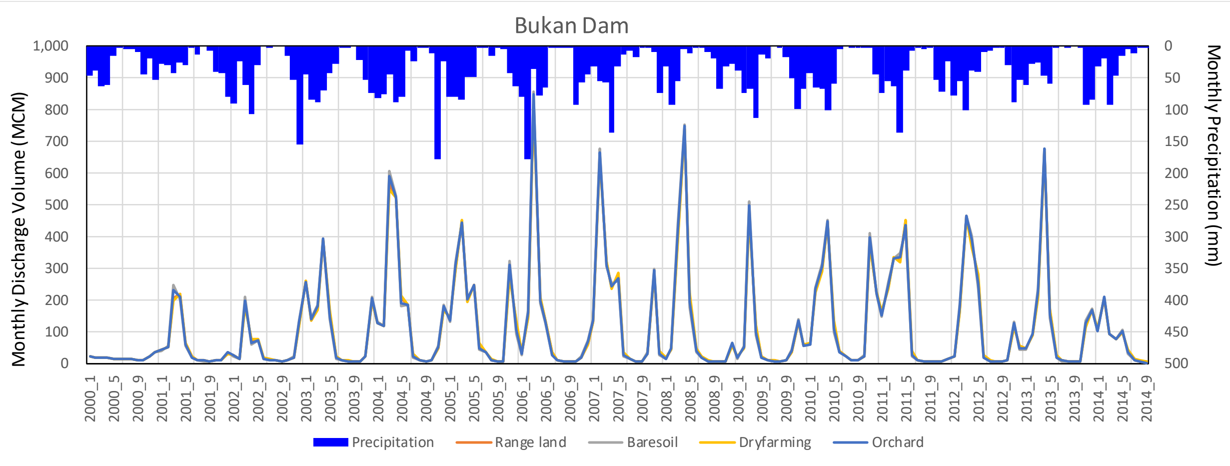


Figure 5.5.4 Monthly Discharge Trend with Different Land Use Types

Table 5.5.3 Calculation Result with Parameters for Sensitivity Analysis (Land use)

■Land use (Runoff coefficient)

Annual runoff volume(MCM)

	Range land	Baresoil	Dryfarming	Orchard	Max	Min	Average	(Max-Min) / Ave. (%)
2000	706	720	702	713	720	702	710	2.6
2001	485	485	485	485	485	485	485	0.1
2002	1,316	1,322	1,314	1,320	1,322	1,314	1,318	0.6
2003	1,998	2,021	1,994	2,011	2,021	1,994	2,006	1.3
2004	1,681	1,689	1,679	1,684	1,689	1,679	1,683	0.6
2005	1,824	1,844	1,819	1,839	1,844	1,819	1,832	1.4
2006	1,774	1,785	1,775	1,776	1,785	1,774	1,777	0.6
2007	1,849	1,857	1,847	1,855	1,857	1,847	1,852	0.5
2008	794	801	790	795	801	790	795	1.3
2009	1,468	1,475	1,466	1,472	1,475	1,466	1,470	0.6
2010	2,205	2,215	2,203	2,210	2,215	2,203	2,208	0.5
2011	1,364	1,376	1,361	1,370	1,376	1,361	1,368	1.1
2012	1,418	1,425	1,414	1,425	1,425	1,414	1,421	0.8
2013	950	963	950	951	963	950	953	1.4
Ave.	1,417	1,427	1,414	1,422	1,427	1,414	1,420	**0.9**

Runoff Volume during snow melt season (March - June)

	Range land	Baresoil	Dryfarming	Orchard	Max	Min	Average	(Max-Min) / Ave. (%)
2000	511	521	507	518	521	507	514	2.8
2001	356	358	355	357	358	355	357	0.8
2002	744	733	748	738	748	733	741	2.0
2003	1,479	1,498	1,473	1,491	1,498	1,473	1,485	1.7
2004	954	938	959	944	959	938	949	2.2
2005	1,198	1,201	1,196	1,204	1,204	1,196	1,200	0.6
2006	869	842	878	854	878	842	861	4.2
2007	1,396	1,404	1,393	1,403	1,404	1,393	1,399	0.8
2008	627	629	625	627	629	625	627	0.6
2009	906	898	909	901	909	898	903	1.3
2010	1,144	1,126	1,149	1,134	1,149	1,126	1,138	2.0
2011	1,131	1,123	1,133	1,127	1,133	1,123	1,129	0.9
2012	1,074	1,078	1,071	1,080	1,080	1,071	1,076	0.9
2013	312	309	313	310	313	309	311	1.4
Ave.	907	904	908	906	913	899	906	**1.5**

5.5.3 Snowmelt (Threshold Snowmelt Temperature)

In the MIKE-SHE's snow melt module with Day-Degree method, threshold snowmelt temperature is one of important parameters to determine runoff pattern especially in the mountainous area, which is recognized as dominant water recharge area in Urmia Lake Basin. Due to limited information on snowmelt around Urmia Lake Basin, it was necessary to change this parameter to improve reproducibility of runoff duration and runoff volume.

Daily and monthly discharge hydrographs, and discharge volume during snowmelt season with different threshold snowmelt temperatures at inflow into Bukan Dam are shown in Figure 5.5.5, Figure 5.5.6 and Figure 5.5.7, respectively. From the chart for daily basis, remarkable trends can be seen at the periods of transition of water; (a) from rainfall to snowfall (around December), and (b) from snow storage to snowmelt (March-May), respectively. As for the period (a), with lower temperatures for melting point (less than 0℃), more flood tends to occur with rainfall timing. Low snow melting temperatures seems to cause early snow melting. At the period (b), it can be clearly confirmed that both timing and amount of runoff are different with snowmelt temperatures. Approximately one month of timing difference of peak discharge occurrence has been confirmed between lowest (-3℃) and highest temperatures (3℃). It also tends that larger flood event occur around April than that in March because of increment of snow storage, which was induced by high snow melt temperatures.

According to monthly trends, variance trends are different from year to year. Some years show same trend with Figure 5.5.5, other years show same monthly trends with snow melt temperatures because of input temperature data. Discharge volume during snowmelt season (see Figure 5.5.7 and Table 5.5.4) shows that large variance of discharge volume for the period for the years with large discharge volume because of amount of snow storage. It tends that high discharge volume occurs with high snow melt temperature.

The difference in the annual runoff volume and runoff volume during snowmelt season by snowmelt temperature is extremely large, and setting the snowmelt temperature is recognized as one of the keys to model calibration in the Survey (See Table 5.5.4).

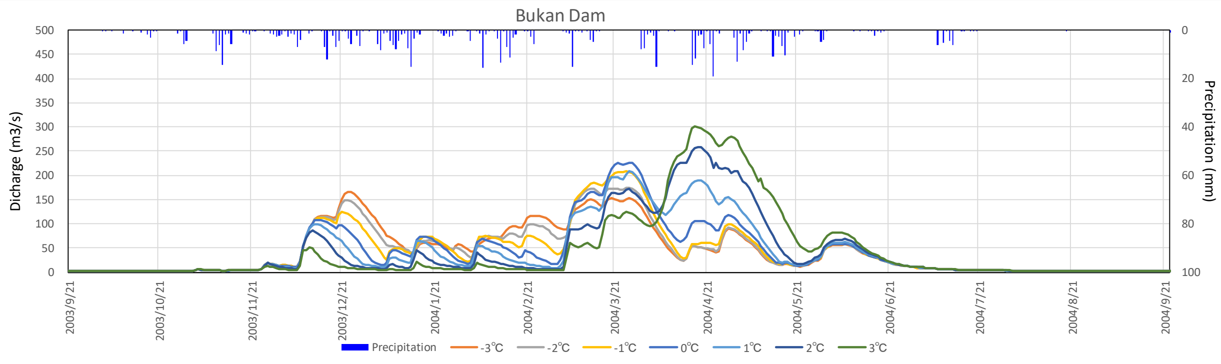


Figure 5.5.5 Daily Discharge Trend with Threshold Snow Melt Temperature

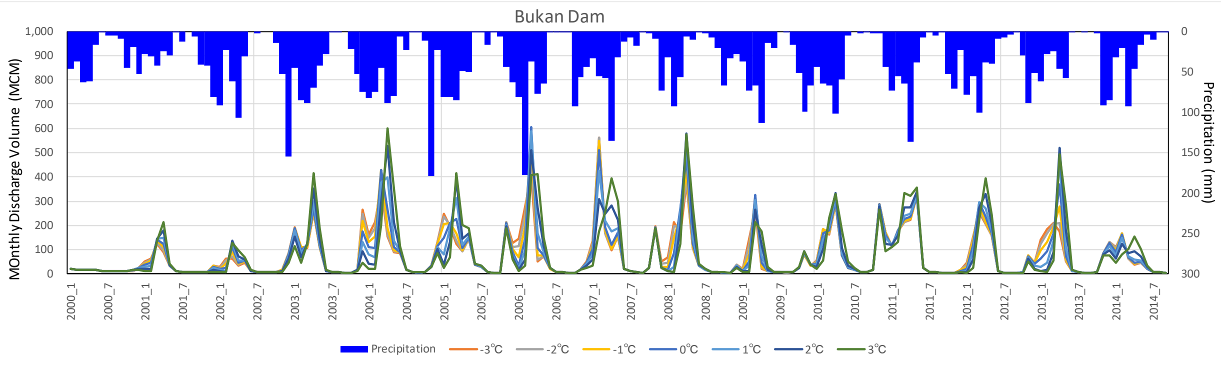
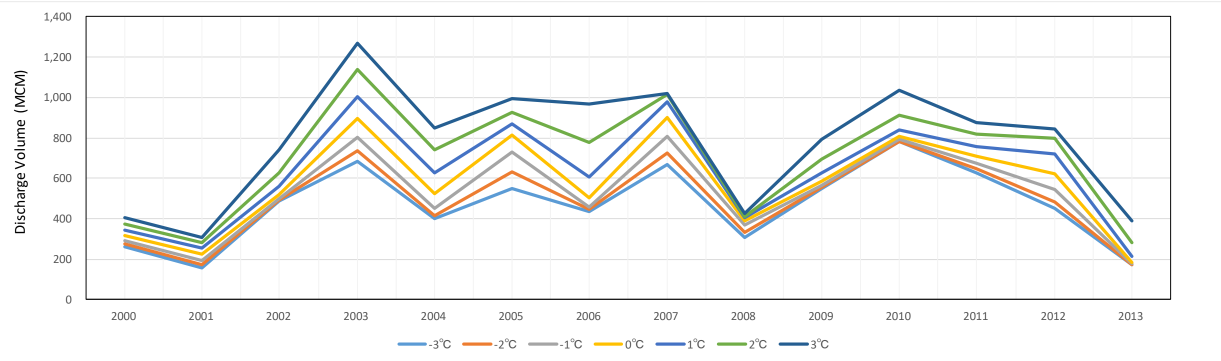


Figure 5.5.6 Monthly Discharge Volume Trend with Threshold Snow Melt Temperature



*Year refers hydrological year with aggregation period from September to next year's August.

Figure 5.5.7 Discharge Volume Trend with Threshold Snowmelt Temperature during Snowmelt Season (March-June)

Table 5.5.4 Calculation Result with Parameters for Sensitivity Analysis (Snow Melt)

■Snow melt (Threshold snow melt temperature)

Annual runoff volume(MCM)

	-3°C	-2°C	-1°C	0°C	1°C	2°C	3°C	Max	Min	Average	(Max-Min) / Ave. (%)
2000	454	460	469	478	487	497	509	509	454	479	11.5
2001	327	329	333	340	350	361	377	377	327	345	14.6
2002	912	916	921	928	937	953	990	990	912	937	8.3
2003	1,380	1,375	1,361	1,340	1,338	1,366	1,401	1,401	1,338	1,366	4.7
2004	1,067	1,069	1,074	1,084	1,092	1,099	1,111	1,111	1,067	1,085	4.0
2005	1,341	1,340	1,333	1,319	1,295	1,294	1,319	1,341	1,294	1,320	3.6
2006	1,229	1,229	1,219	1,207	1,198	1,222	1,253	1,253	1,198	1,222	4.4
2007	1,254	1,259	1,266	1,276	1,287	1,303	1,309	1,309	1,254	1,279	4.3
2008	539	536	530	521	510	499	504	539	499	520	7.7
2009	963	965	968	975	989	1,021	1,073	1,073	963	994	11.0
2010	1,575	1,577	1,582	1,591	1,604	1,638	1,684	1,684	1,575	1,607	6.8
2011	877	880	884	889	898	917	937	937	877	897	6.7
2012	924	923	921	920	925	936	952	952	920	929	3.5
2013	686	686	684	675	666	670	697	697	666	681	4.5
Ave.	966	967	967	967	970	984	1,008	1,012	953	976	**6.1**

Runoff Volume during snow melt season (March - June)

	-3°C	-2°C	-1°C	0°C	1°C	2°C	3°C	Max	Min	Average	(Max-Min) / Ave. (%)
2000	262	275	293	315	344	376	407	407	262	325	44.6
2001	160	172	192	223	255	282	308	308	160	227	65.0
2002	486	491	500	519	558	628	743	743	486	561	45.9
2003	685	736	805	894	1,007	1,140	1,266	1,266	685	933	62.3
2004	402	417	453	524	628	744	847	847	402	574	77.6
2005	551	632	730	815	869	925	996	996	551	788	56.4
2006	436	445	459	502	607	775	968	968	436	599	88.8
2007	671	727	808	902	977	1,014	1,022	1,022	671	874	40.1
2008	306	334	368	392	403	413	428	428	306	378	32.3
2009	550	553	564	587	627	695	793	793	550	624	38.8
2010	780	784	792	808	840	913	1,036	1,036	780	851	30.1
2011	629	647	674	710	757	817	873	873	629	730	33.5
2012	450	484	543	623	721	798	847	847	450	638	62.1
2013	173	175	178	185	214	281	392	392	173	228	95.6
Ave.	467	491	526	571	629	700	780	780	467	595	**52.6**

5.5.4 Infiltration (Depth of UZ Layer)

Change of infiltration into saturated zone with depth of unsaturated layer has been confirmed. Daily and monthly discharge hydrographs at four hydrological stations were shown in Figure 5.5.8 and Figure 5.5.9, respectively. Only negligible change has been confirmed from these charts, in which this parameter slightly affects peak discharge. Similarly, it does not significantly affect annual runoff volume (See Table 5.5.5).

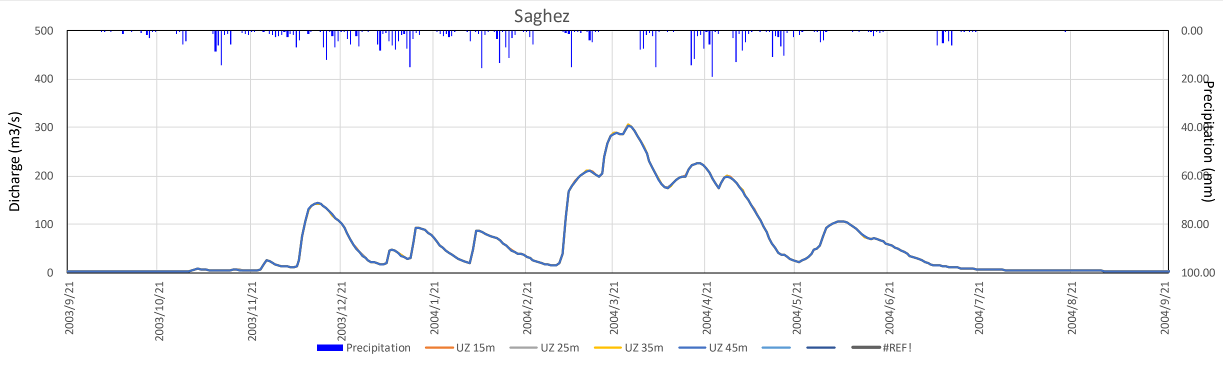


Figure 5.5.8 Daily Discharge Trend with UZ Depth

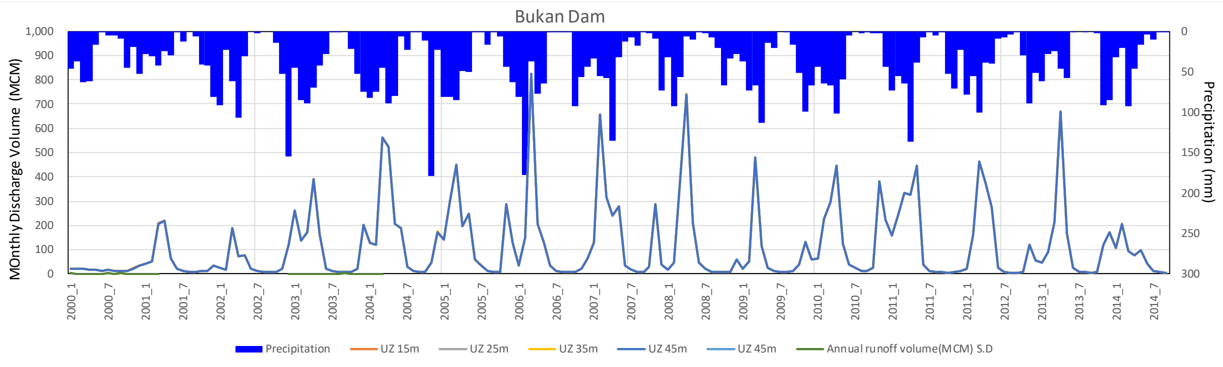


Figure 5.5.9 Monthly Discharge Trend with UZ Depth

Table 5.5.5 Calculation Result with Parameters for Sensitivity Analysis (Depth of Layer)

■Unsaturated zone (Depth of Layer)

Annual runoff volume(MCM)

	UZ 15m	UZ 25m	UZ 35m	UZ 45m	Max	Min	Average	(Max-Min) / Ave. (%)
2000	711	708	706	703	711	703	707	1.0
2001	485	485	485	484	485	484	485	0.2
2002	1,317	1,316	1,316	1,315	1,317	1,315	1,316	0.1
2003	2,001	2,000	1,998	1,998	2,001	1,998	1,999	0.1
2004	1,680	1,680	1,681	1,680	1,681	1,680	1,681	0.1
2005	1,825	1,824	1,824	1,824	1,825	1,824	1,824	0.0
2006	1,775	1,778	1,774	1,773	1,778	1,773	1,775	0.3
2007	1,848	1,849	1,849	1,848	1,849	1,848	1,848	0.1
2008	794	790	794	794	794	790	793	0.6
2009	1,468	1,468	1,468	1,468	1,468	1,468	1,468	0.0
2010	2,207	2,206	2,205	2,205	2,207	2,205	2,206	0.1
2011	1,364	1,364	1,364	1,364	1,364	1,364	1,364	0.0
2012	1,417	1,418	1,418	1,417	1,418	1,417	1,417	0.1
2013	951	950	950	950	951	950	950	0.1
Ave.	1,417	1,417	1,417	1,416	1,418	1,416	1,417	**0.2**

Runoff Volume during snow melt season (March - June)

	UZ 15m	UZ 25m	UZ 35m	UZ 45m	Max	Min	Average	(Max-Min) / Ave. (%)
2000	513	511	511	510	513	510	511	0.6
2001	356	356	356	355	356	355	356	0.2
2002	745	745	744	744	745	744	745	0.1
2003	1,481	1,480	1,479	1,478	1,481	1,478	1,480	0.1
2004	954	954	954	954	954	954	954	0.1
2005	1,198	1,197	1,198	1,198	1,198	1,197	1,198	0.1
2006	869	870	869	870	870	869	870	0.0
2007	1,394	1,397	1,396	1,395	1,397	1,394	1,395	0.2
2008	627	624	627	627	627	624	626	0.6
2009	906	906	906	906	906	906	906	0.1
2010	1,145	1,144	1,144	1,144	1,145	1,144	1,144	0.1
2011	1,132	1,132	1,131	1,132	1,132	1,131	1,132	0.0
2012	1,074	1,074	1,074	1,074	1,074	1,074	1,074	0.0
2013	312	312	312	312	312	312	312	0.0
Ave.	908	907	907	907	908	907	907	**0.1**

5.5.5 Infiltration (Soil Type)

In the Survey, two types of soil whose characteristics are shown in Figure 5.5.10 were applied for the hydrological modeling. Daily and monthly discharge hydrographs, and discharge volume during snowmelt season with different soil types at inflow into Bukan Dam are shown in Figure 5.5.11, Figure 5.5.12 and Figure 5.5.13, respectively. Change has been confirmed at around peak discharge of flood event, which shows difference with approximately 20 m^3/s of peak discharge between coarse sand and fine sand. Few different discharge volumes can be confirmed on monthly basis. It tends that soil type does minor affect water resource supplement from mountainous area, which is approximately 10-15% difference (see

Table 5.5.6).

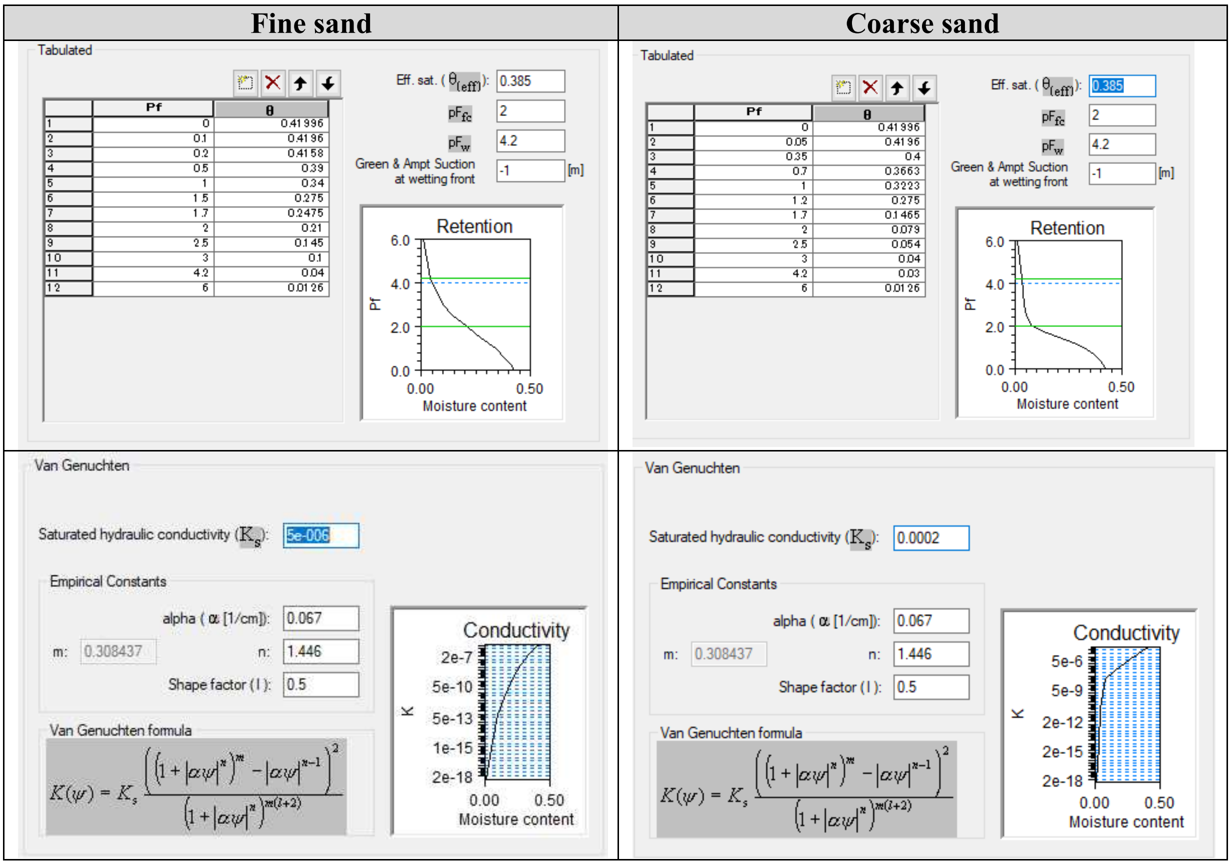


Figure 5.5.10 Applied Soil Types

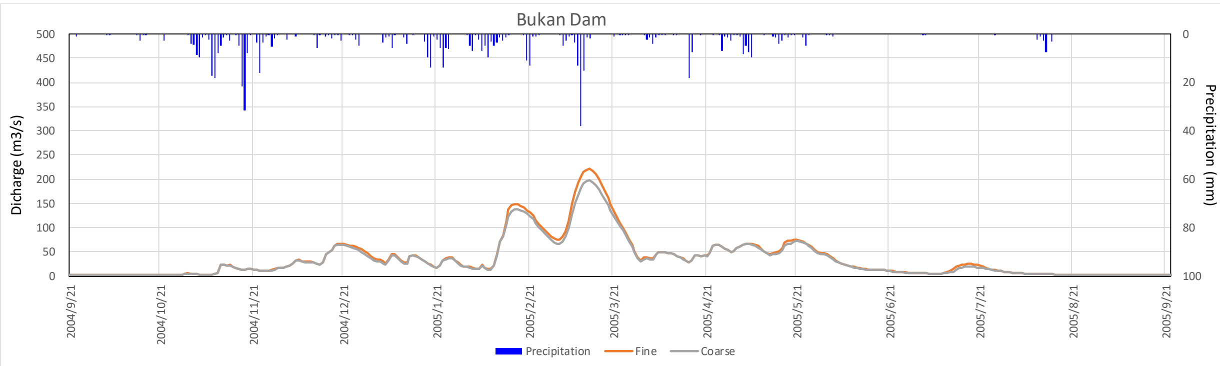


Figure 5.5.11 Daily Discharge Trend with UZ Soil Type

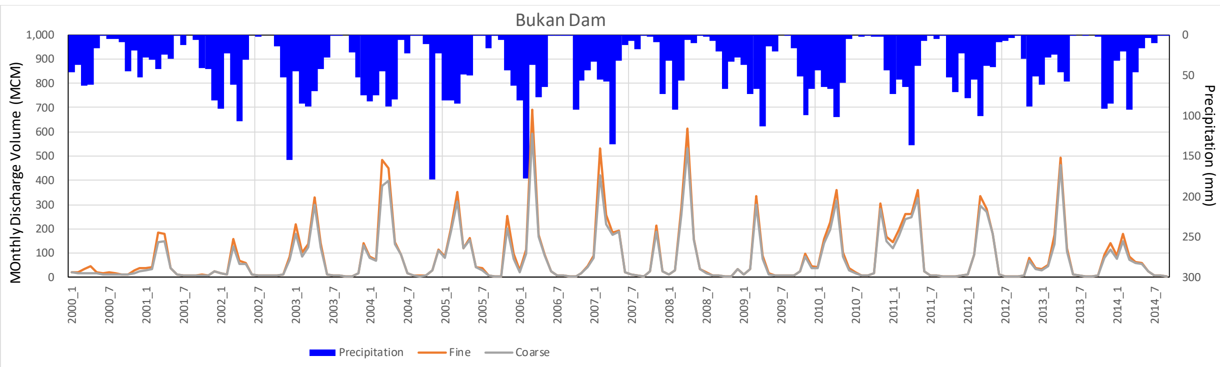
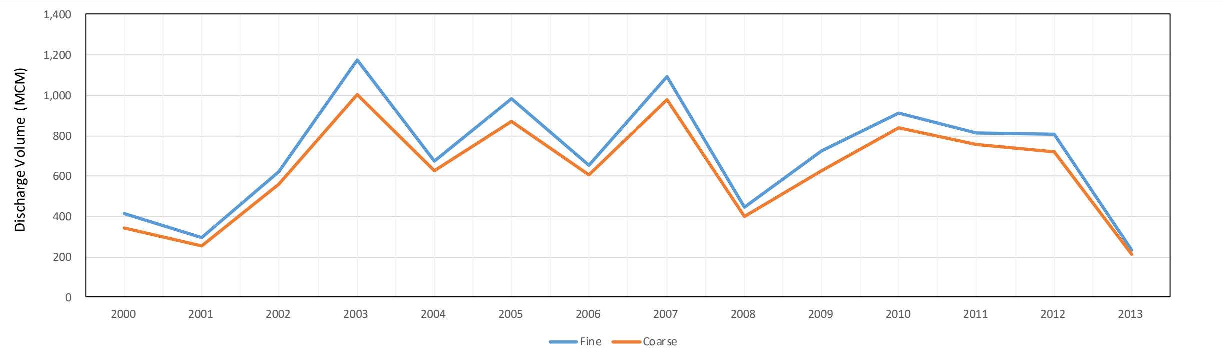


Figure 5.5.12 Monthly Discharge Trend with UZ Soil Type



*Year refers to hydrological year with aggregation period from September to next year's August.

Figure 5.5.13 Discharge Volume Trend with Threshold Snowmelt Temperature during Snowmelt Season (March-June)

Table 5.5.6 Calculation Result with Parameters for Sensitivity Analysis (Soil Type)

■Unsaturated zone (Soil Type)

Annual runoff volume(MCM)

	Fine	Coarse	Max	Min	Average	(Max-Min) / Ave. (%)
2000	602	487	602	487	457	25.3
2001	399	350	399	350	328	15.2
2002	1,068	937	1,068	937	914	14.4
2003	1,528	1,338	1,528	1,338	1,378	13.8
2004	1,165	1,091	1,165	1,091	1,068	6.9
2005	1,505	1,298	1,505	1,298	1,341	15.4
2006	1,369	1,196	1,369	1,196	1,229	14.1
2007	1,434	1,291	1,434	1,291	1,256	11.4
2008	557	505	557	505	537	9.7
2009	1,135	989	1,135	989	964	15.1
2010	1,774	1,604	1,774	1,604	1,576	10.8
2011	959	899	959	899	878	6.9
2012	1,033	924	1,033	924	924	11.8
2013	762	666	762	666	686	14.0
Ave.	1,092	970	1,092	970	967	**12.7**

Runoff Volume during snow melt season (March - June)

	Fine	Coarse	Max	Min	Average	(Max-Min) / Ave. (%)
2000	414	344	414	344	269	26.0
2001	297	255	297	255	166	25.5
2002	620	558	620	558	488	12.7
2003	1,174	1,007	1,174	1,007	711	23.6
2004	673	628	673	628	410	11.1
2005	982	872	982	872	592	18.7
2006	651	607	651	607	441	10.0
2007	1,095	981	1,095	981	699	16.3
2008	445	399	445	399	320	14.3
2009	726	627	726	627	552	18.0
2010	912	840	912	840	782	9.2
2011	814	757	814	757	638	8.8
2012	806	721	806	721	467	18.2
2013	234	214	234	214	174	11.7
Ave.	703	629	703	629	479	**15.4**

5.5.6 Base Flow Runoff (Hydraulic Conductivity)

The hydraulic conductivity as main parameter of saturated zone tends to affect base flow. Change of infiltration into saturated zone with depth of unsaturated layer has been confirmed. Daily and monthly discharge hydrographs at four hydrological stations are shown in Figure 5.5.14 and Figure 5.5.15, respectively. With low horizontal hydraulic conductivity (Kh=10^{-7} m/s), discharge decreases for a whole season due to low movement of groundwater. High value (Kh=10^{-3} m/s) shows baseflow increment due to high movement of groundwater while flood discharge decrements due to low groundwater storage. As for intermediate one (Kh=10^{5}m/s), baseflow increases due to high movement of groundwater, in which high runoff respond to rainfall due to groundwater storage. Monthly discharge with low and intermediate values for the period between 2000 and 2005 show tremendous discharge was calculated excessively due to drainage from saturated zone until groundwater balance is in equilibrium (see Figure 5.5.15). Therefore, the initial calculation results (2000-2005) were excluded from the sensitivity analysis evaluation (see Table 5.5.3).

As for vertical hydraulic conductivity, only negligible change has been confirmed from charts, which indicates that this parameter slightly affects peak discharge (see Figure 5.5.16 and Figure 5.5.17).

The difference in horizontal hydraulic conductivity greatly affects the annual runoff volume as shown in Table 5.5.7. Because the horizontal hydraulic conductivity can be the most effective one for baseflow, it is one of the important factors for the setting parameter in the hydrological model.

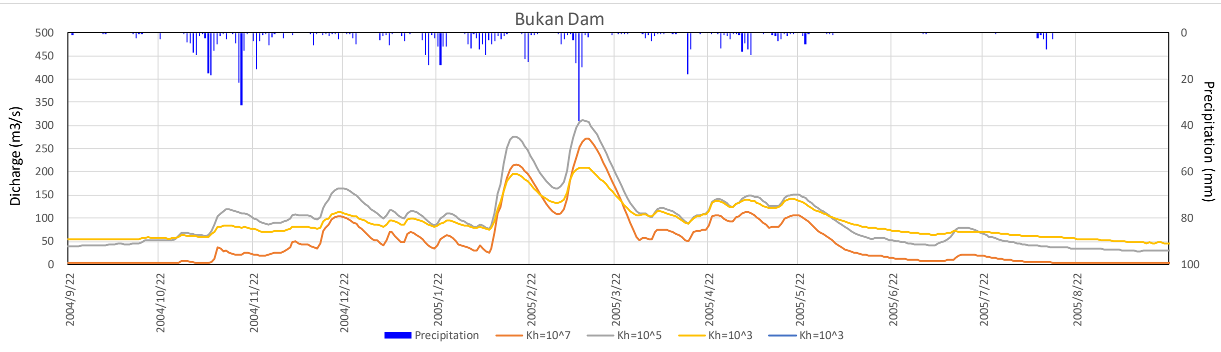


Figure 5.5.14 Daily Discharge Trend with Horizontal Hydraulic Conductivity

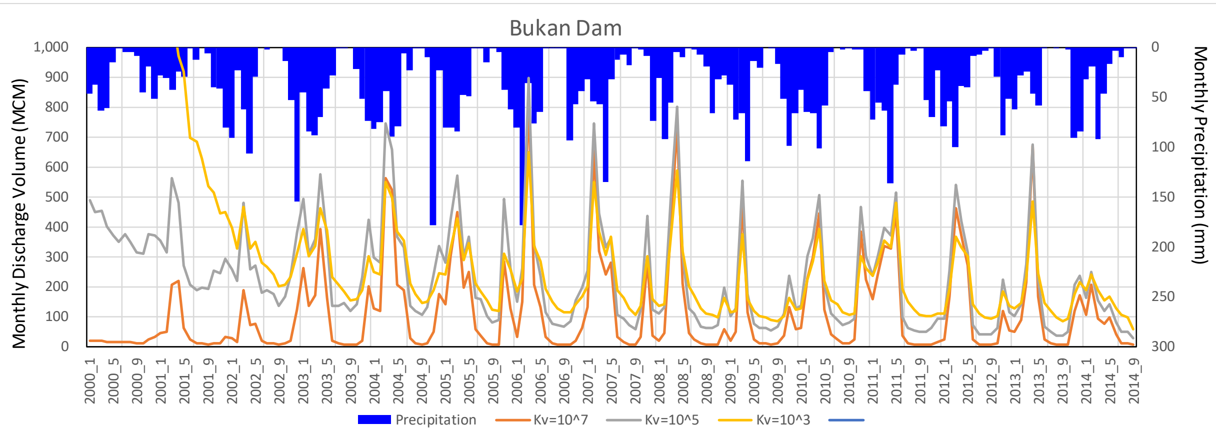


Figure 5.5.15 Monthly Discharge Trend with Horizontal Hydraulic Conductivity

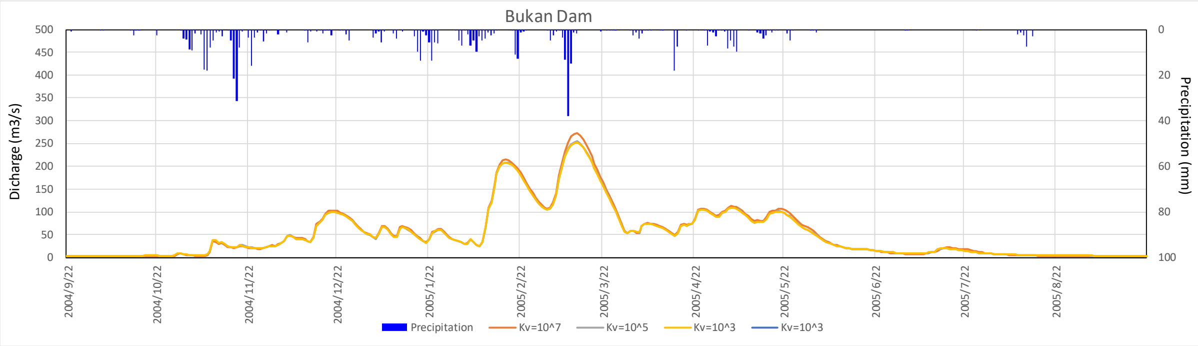


Figure 5.5.16 Daily Discharge Trend with Vertical Hydraulic Conductivity

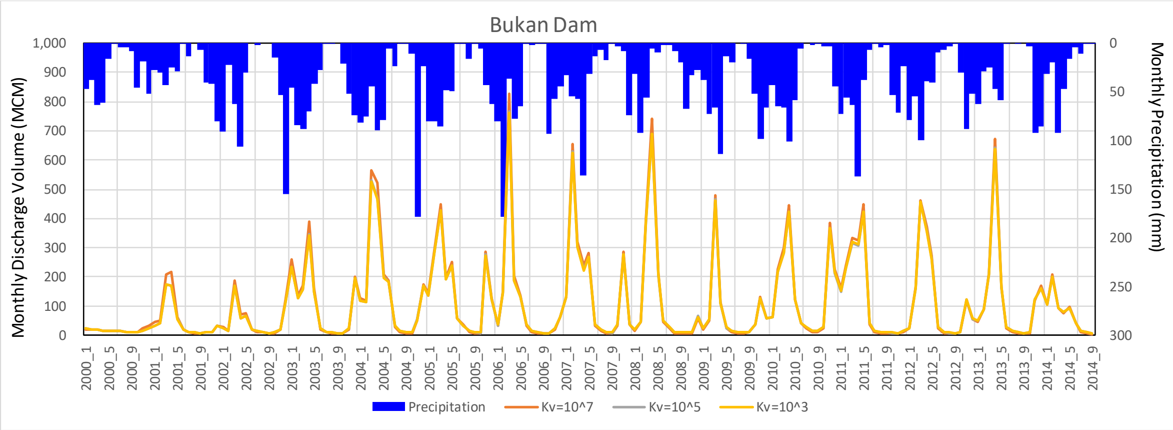


Figure 5.5.17 Monthly Discharge Trend with Vertical Hydraulic Conductivity

Table 5.5.7(1) Calculation Result with Parameters for Sensitivity Analysis (Horizontal hydraulic conductivity)

■Saturated zone (Horizontal hydraulic conductivity)

Annual runoff volume(MCM)

	Kh=10^7	Kh=10^5	Kh=10^3	Max	Min	Average	(Max-Min) / Ave. (%)
2000	706	3,942	14,279	-	-	-	-
2001	485	3,013	4,598	-	-	-	-
2002	1,316	3,435	3,452	-	-	-	-
2003	1,998	3,848	3,461	-	-	-	-
2004	1,681	3,173	2,907	-	-	-	-
2005	1,824	3,069	2,961	-	-	-	-
2006	1,774	2,903	2,819	2,903	1,774	2,499	45.1
2007	1,849	2,891	2,741	2,891	1,849	2,494	41.8
2008	794	1,604	1,653	1,653	794	1,350	63.6
2009	1,468	2,322	2,128	2,322	1,468	1,973	43.3
2010	2,205	2,972	2,922	2,972	2,205	2,700	28.4
2011	1,364	2,022	2,069	2,069	1,364	1,818	38.8
2012	1,418	2,005	2,118	2,118	1,418	1,847	37.9
2013	950	1,528	1,838	1,838	950	1,438	61.7
Ave.	1,417	2,766	3,568	2,346	1,478	2,583	**33.6**

Runoff Volume during snow melt season (March - June)

	Kh=10^7	Kh=10^5	Kh=10^3	Max	Min	Average	(Max-Min) / Ave. (%)
2000	511	1,516	3,704	-	-	-	-
2001	356	1,188	1,422	-	-	-	-
2002	744	1,430	1,421	-	-	-	-
2003	1,479	2,104	1,782	-	-	-	-
2004	954	1,398	1,271	-	-	-	-
2005	1,198	1,586	1,458	-	-	-	-
2006	869	1,242	1,247	1,247	869	1,119	33.7
2007	1,396	1,728	1,469	1,728	1,396	1,531	21.7
2008	627	866	754	866	627	749	31.8
2009	906	1,181	1,048	1,181	906	1,045	26.3
2010	1,144	1,379	1,359	1,379	1,144	1,294	18.1
2011	1,131	1,343	1,140	1,343	1,131	1,205	17.6
2012	1,074	1,236	1,111	1,236	1,074	1,140	14.2
2013	312	493	634	634	312	480	67.2
Ave.	907	1,335	1,416	1,202	932	1,219	**22.1**

Table 5.5.7(2) Calculation Result with Parameters for Sensitivity Analysis (Vertical hydraulic conductivity)

■Saturated zone (Vertical hydraulic conductivity)

Annual runoff volume(MCM)

	$Kv=10^7$	$Kv=10^5$	$Kv=10^3$	Max	Min	Average	(Max-Min) / Ave. (%)
2000	706	585	580	706	580	624	-
2001	485	447	448	485	447	460	-
2002	1,316	1,205	1,201	1,316	1,201	1,241	-
2003	1,998	1,895	1,883	1,998	1,883	1,926	-
2004	1,681	1,633	1,632	1,681	1,632	1,649	-
2005	1,824	1,744	1,734	1,824	1,734	1,767	-
2006	1,774	1,730	1,726	1,774	1,726	1,743	2.8
2007	1,849	1,795	1,798	1,849	1,795	1,814	2.9
2008	794	806	804	806	794	801	1.6
2009	1,468	1,428	1,433	1,468	1,428	1,443	2.7
2010	2,205	2,124	2,132	2,205	2,124	2,154	3.8
2011	1,364	1,355	1,354	1,364	1,354	1,358	0.7
2012	1,418	1,400	1,401	1,418	1,400	1,406	1.3
2013	950	945	948	950	945	948	0.6
Ave.	1,417	1,364	1,362	1,417	1,360	1,381	**4.1**

Runoff Volume during snow melt season (March - June)

	$Kv=10^7$	$Kv=10^5$	$Kv=10^3$	Max	Min	Average	(Max-Min) / Ave. (%)
2000	511	423	419	511	419	451	-
2001	356	318	319	356	318	331	-
2002	744	672	668	744	668	695	-
2003	1,479	1,381	1,370	1,479	1,370	1,410	-
2004	954	915	913	954	913	928	-
2005	1,198	1,121	1,114	1,198	1,114	1,144	-
2006	869	834	831	869	831	845	4.6
2007	1,396	1,329	1,331	1,396	1,329	1,352	5.0
2008	627	614	610	627	610	617	2.7
2009	906	869	870	906	869	882	4.2
2010	1,144	1,091	1,091	1,144	1,091	1,109	4.8
2011	1,131	1,104	1,102	1,131	1,102	1,112	2.7
2012	1,074	1,040	1,039	1,074	1,039	1,051	3.3
2013	312	308	310	312	308	310	1.2
Ave.	907	858	856	907	856	874	**5.9**

5.5.7 Evaluation with Indices and Summary

Extent of impact of parameters on runoff phenomenon was quantitatively and qualitatively evaluated with the indices, (1) annual runoff volume, (2) runoff volume during snowmelt season (from March to June), described in Subsection 5.5.1. Percentage of variance range (difference between maximum and minimum) to average runoff volumes for the years and snowmelt seasons were calculated for each parameter listed as Table 5.5.8. Table 5.5.3 shows the calculation results (annual runoff discharge) for each classification used to calculate "Percentage of variance range". In the Survey it can be said that threshold snowmelt temperature is the most prioritized parameter affecting amount and occurrence timing of flood. It was confirmed that soil type and horizontal hydraulic conductivity also can affect runoff including baseflow for a whole year. Among these two parameters, horizontal hydraulic conductivity can be the most effective one for baseflow. Table 5.5.9 summarizes characteristics of sensitivity to the selected parameters. In this analysis, it was found that important parameters are threshold snowmelt temperature, horizontal hydraulic conductivity and soil type. Therefore, these parameters were particularly carefully adjusted in the calibration of the hydrological cycle model constructed in the study.

Table 5.5.8 Percentage of Variance Range to Average Runoff Volume with Parameters

Classification	Parameter	Applied Value	Annual runoff volume (%)	Runoff Volume during snow melt season (March - June) (%)
Land use change	**Roughness coefficient**	Range land (n=0.05) Dry farming (n=0.06) Orchard (n=0.035) Bare soil (n=0.025)	0.9	1.5
Snow melt	**Threshold snow melt temperature**	-3℃, -2℃, -1℃, 0℃, 1℃, 2℃, 3℃	6.1	52.6
Infiltration	**Depth of unsaturated zone**	15m, 25m, 35m, 45m	0.2	0.1
Infiltration	**Soil Type**	Fine sand / Coarse sand	12.7	15.4
Baseflow runoff	**Horizontal hydraulic conductivity**	K_h 10^{-7} m/s, 10^{-5} m/s, 10^{-3} m/s	33.6	22.1
Baseflow runoff	**Vertical hydraulic conductivity**	K_v: 10^{-7} m/s, 10^{-5} m/s, 10^{-3} m/s	4.1	5.9

*Variance range is the difference between maximum and minimum discharge volumes for the aggregation period (2000-2013)

Table 5.5.9 Summary of Model's Sensitivity to Parameters

Classification	Parameter	Impact to runoff volume	Summary
Land use change	**Roughness coefficient**	Small	Depite no drastic change in runoff volume for daily basis, change was confirmed at around peak discharge at every flood event, which shows difference with 50 m^3/s of peak discharge between dry farming (n=0.06) and bare soil (n=0.025). Few different discharge volumes were also confirmed on monthly-basis.
Snow melt	**Threshold snow melt temperature**	Effective during snow melt season	Remarkable trends can be seen at the timing of transition; a) from rainfall to snowfall (around December), and b) from snow storage to snowmelt (March-May), respectively. The difference of temperature cause differences in both timing of flood peak occurrence and amount of flood volume, which depends on timing of melting and amount of snow storage. As for discharge volume during snowmelt season, it tends that high discharge volume occurs with high snow melt temperature.
Infiltration	**Depth of unsaturated zone**	Very small	Negligble change has been confirmed. This parameter slightly affects peak discharge.
Infiltration	**Soil Type**	Effective for a whole season /snow melt season	Comparing two types of soil, approximately 15% different discharge volume was confirmed for snowmelt season. It was confirmed that soil type can affect water resource supplement from mountainous area due to change in infiltration and moisture storage, which is not as significant as snowmelt temperature.
Percolation	**Horizontal hydraulic conductivity**	Effective for a whole season	With low horizontal hydraulic conductivity (Kh=10^7 m/s), discharge decreases for a whole season due to low movement of groundwater. High value (Kh=10^3 m/s) shows baseflow increment due to high movement of groundwater while flood discharge decrement due to low groundwater storage. As for intermediate one (Kh=10^5m/s), baseflow increases due to high movement of groundwater, whigh high runoff response to rainfall due to groundwater storage.
Percolation	**Vertical hydraulic conductivity**	Very small	Negligble change has been confirmed from these charts, which this parameter slightly affects peak discharge.

5.6 Preparation of Calibration

5.6.1 Selection of Calibration Points

In the calibration of the established model, climatological and hydraulic parameters were adjusted so that the calculated river discharge matches that of observed at the calibration points shown in Figure 5.6.1 with river network, Figure 5.6.2 with schematic diagram and summarized in Table 5.6.1. Hydrological stations were selected as calibration points based on their location (e.g. located downstream and upstream that can express hydrological characteristics) and inventory condition of observed daily discharge data.

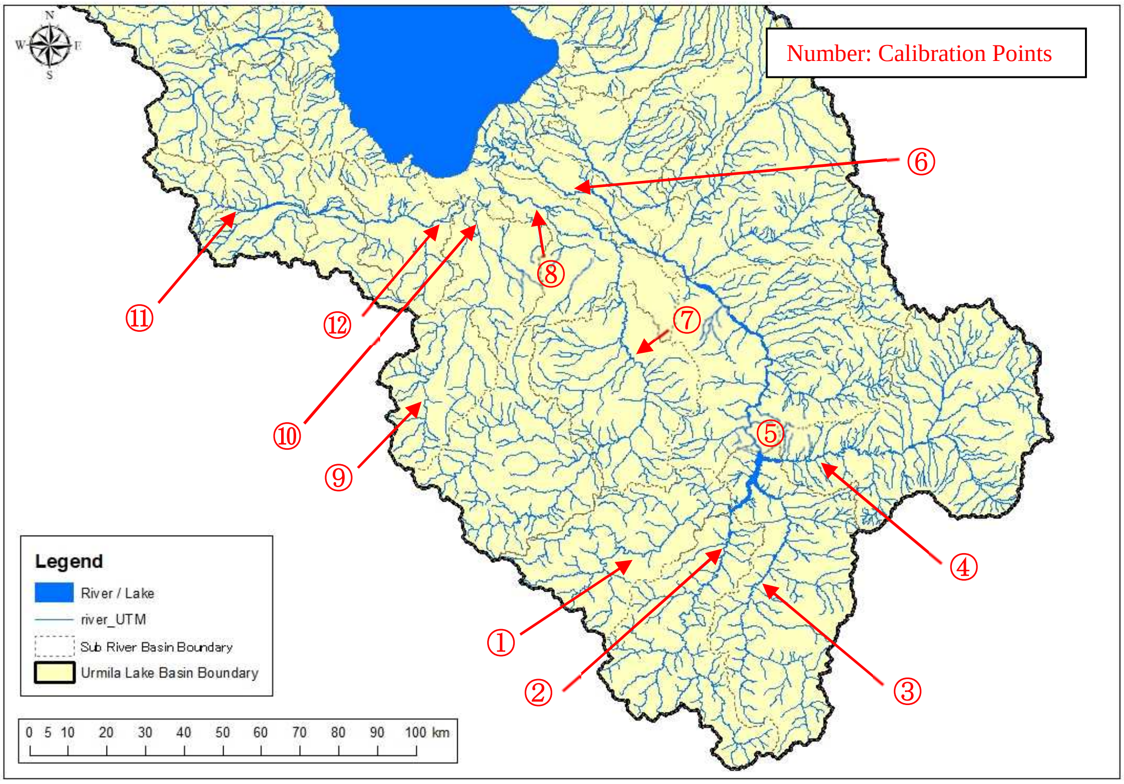


Figure 5.6.1 Calibration Points for River Discharge (Southern Part) (1/3)

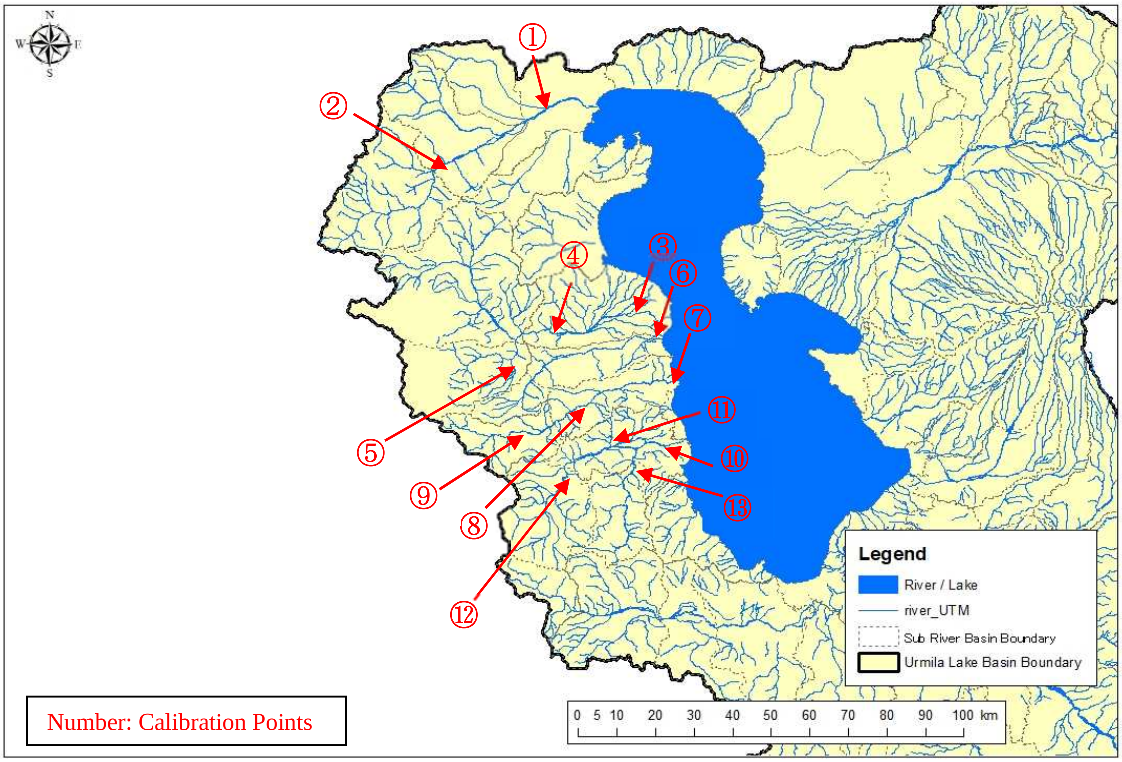


Figure 5.6.1 Calibration Points for River Discharge (Western Part) (2/3)

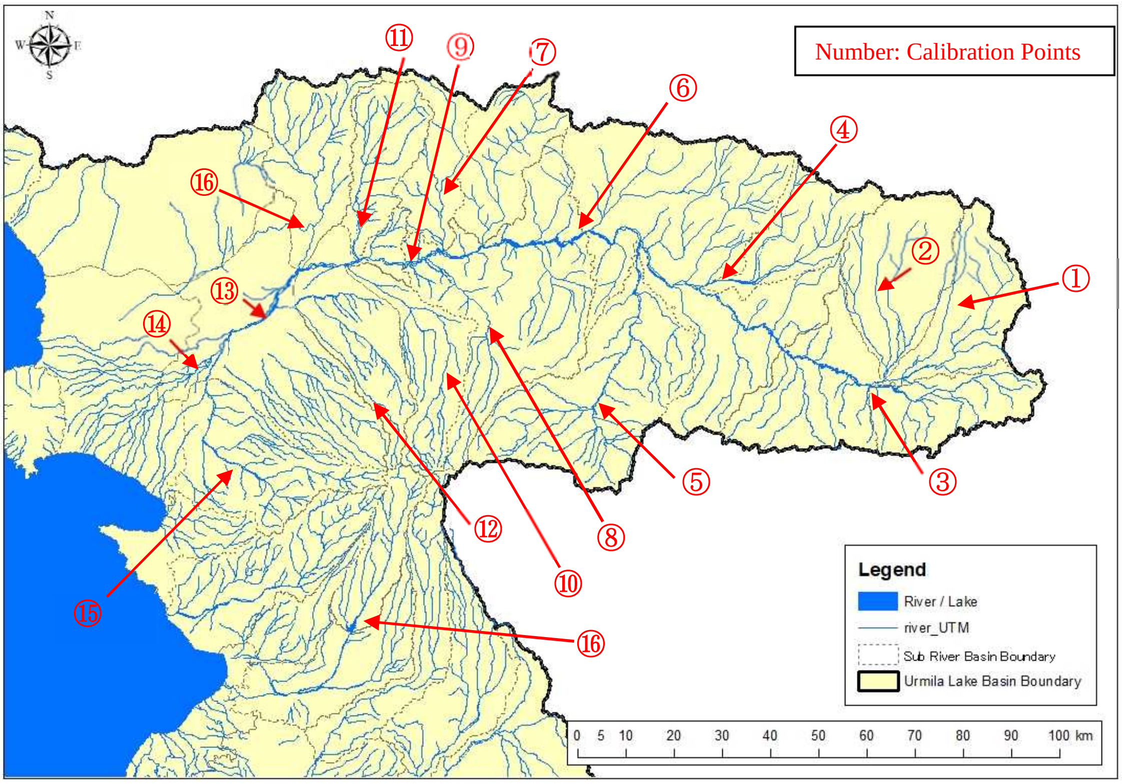
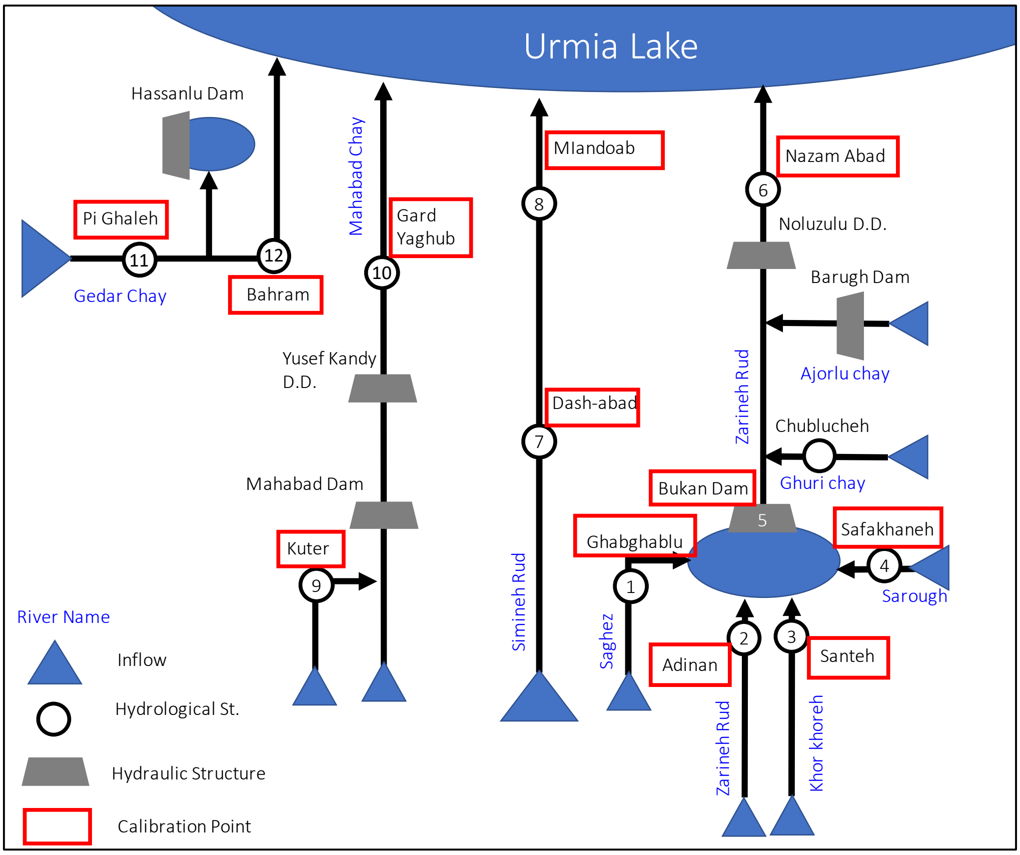
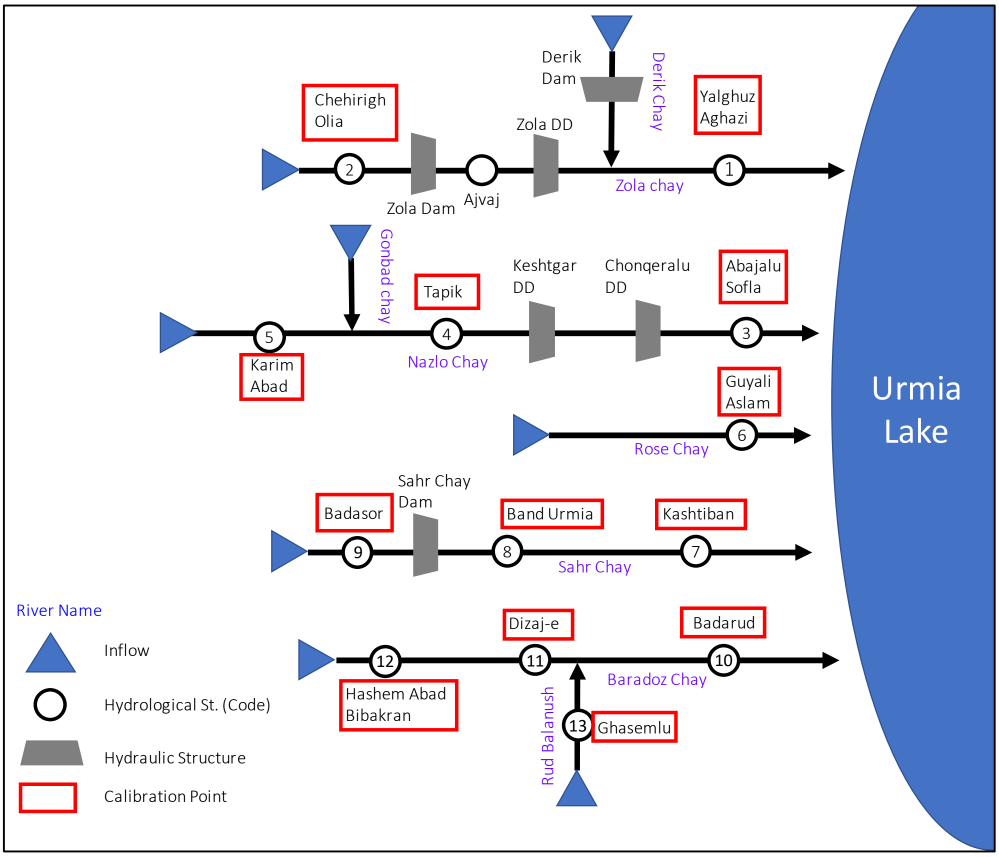


Figure 5.6.1 Calibration Points for River Discharge (Eastern Part) (3/3)



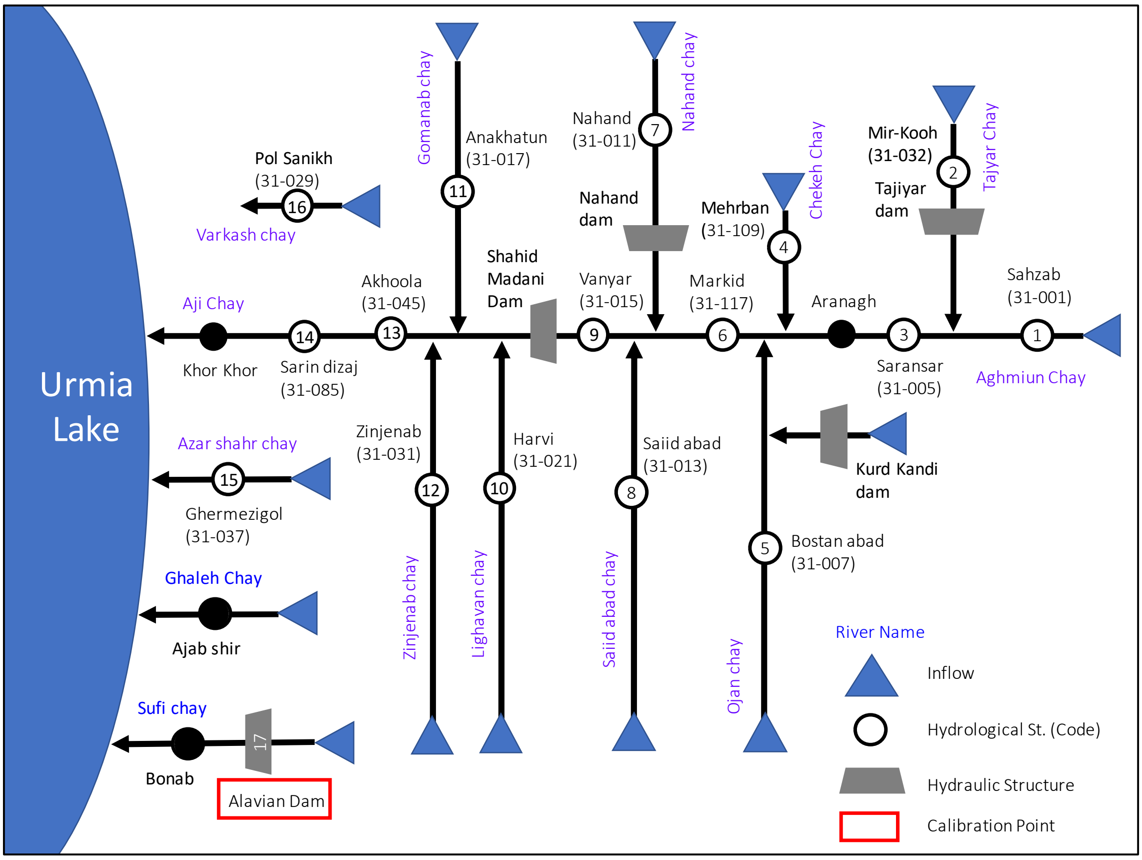
*Described numbers are referred to Figure 5.6.1(1) and Table 5.6.1.

Figure 5.6.2 Schematic Diagram of Calibration Points for River Discharge (Southern Part) (1/3)



*Described numbers are referred to Figure 5.6.1 (2) and Table 5.6.1.

Figure 5.6.2 Schematic Diagram of Calibration Points for River Discharge (Western Part) (2/3)



*Described numbers are referred to Figure 5.6.1 (3) and Table 5.6.1.

Figure 5.6.2 Schematic Diagram of Calibration Points for River Discharge (Eastern Part) (3/3)

Table 5.6.1 Summary of Candidates for Calibration Points

■Southern Part

No.	River	Hydrological Station	Station Code	Catchment Area (km^2)
1	Saghez chay	Ghabghablu	33-007	660
2	Jighato chay	Pol anian (pol saheb)	33-015	1,221
3	Kherkhereh chay	Santeh	33-919	766
4	Sarugh chay	Safakhaneh	33-021	2,219
5	Zarineh rud	Bukan Dam (Inflow)	-	6,994
6	Zarineh rud	Nezam abad	33-917	11,578
7	Simineh rud	Dashband bukan	33-035	2,431
8	Simineh rud	Miandoab (Simine rud)	33-037	3,783
9	Mahad chay	Kuter	34-003	415
10	Mahabad chay	Gard yaghub	34-009	1,635
11	Gadar chay	Pi ghaleh	34-011	225
12	Gadar chay	Pol bahramlu santu	34-021	2,090

■Western Part

No.	River	Hydrological Station	Station Code	Catchment Area (km^2)
1	Zola chay	Yalghuz aghaj	36-011	2,204
2	Zola chay	Chehrigh olia	36-001	819
3	Nazlu chay	Abajalu sofla	35-033	1,965
4	Nazlu chay	Tapik	35-031	1,715
5	Arzin chay	Karim abad (arzin)	35-045	506
6	Rozeh chay	Guyjali aslan	35-037	331
7	Shahr chay	Kashtiban	35-013	670
8	Shahr chay	Band urmia	35-011	418
9	Shahr chay	Badasor	-	-
10	Baranduz chay	Babarud	35-007	1,160
11	Baranduz chay	Dizaj (orumieh)	35-005	618
12	Baranduz chay	Hashem abad bibakran	35-003	382
13	Balanj chay	Ghasemlu	35-001	287

■Eastern Part

No.	River	Hydrological Station	Station Code	Catchment Area (km^2)
1	Aghmiun chay	Sahzab	31-001	73
2	Tajyar sarab	Mirkuh haji	31-032	128
3	Ajichay	Saransar	31-005	1,700
4	Mehrban (Chekeh chay)	Mehrban	31-109	391
5	Ojan chay	Bostan abad	31-007	575
6	Ajichay	Markid	31-117	5,619
7	Nahand chay	Nahand	31-011	216
8	Saiid abad	Saiid abad	31-013	224
9	Ajichay	Vanyar	31-015	7,432
10	Lighavan	Harvi	31-021	186
11	Gomnab chay	Anakhatun	31-017	396
12	Sardorud	Zinjenab	31-031	43
13	Ajichay	Akhola	31-045	9,752
14	Ajichay	Sarin dizaj	31-085	10,622
15	Azar Shahr	Ghermezigol	31-037	103
16	Sanikh chay	Pol sanikh	31-029	498
17	Sufi chay	Alavian Dam (Inflow)	-	314

Source: IWRM Co.

5.6.2 Evaluation of Calibration Result by Daily Runoff Trend

This subsection describes the accuracy of the model from the viewpoint of surface water. Two locations on representative rivers, upstream (mountainous area) and downstream (lowland) of the primary rivers modelled in three parts, were selected as shown in Figure 5.6.3 to Figure 5.6.5, in order to confirm the accuracy of daily trend of river discharge. Appendix 5-7 shows all the hydrographs at calibration points.

As for hydrological characteristics of mountainous area in Urmia Lake Basin, delayed runoff phenomenon due to the snowmelt during spring (from March to May) is the most primary in runoff factors, which is precious and limited water source in the basin under arid region. Simulated runoff responds to precipitation at three locations, “Upstream of Bukan Dam” on Zarineh Rud River, “Badasor” on Shahr Chay River, and “Markid” on Aji Chay River, appear appropriate flood patterns with agreements with observed one. Although peak discharge tends to be underestimated, it can be said that simulation results secure flood volume as much as actual situation. Since the model applies simple snowmelt estimation using Degree-Day method under limited climatological data, e.g., air temperature, for further improvement of runoff accuracy, it would be necessary to enhance observation network of climatological information in mountainous area, such as precipitation, air temperature snow cover area and depth, radiation and so on.

In lowland area with few runoff occurrences due to plain topological condition and less precipitation than that in mountainous area, water withdrawal mainly by irrigation and loss by evapotranspiration affect flow regime. Since it has been confirmed that accuracy of simulation of runoff from mountainous area is secured, it can be said that agricultural water use would be correctly simulated if simulated river discharge agrees with observed one at the calibration points in downstream that are located closest to Urmia Lake. As with the simulation result upstream, simulated daily discharge at three locations, namely, “Neam Abad” on Zarineh Rud River, “Abajalu Sofla” on Nazlo Chay River and “Akhola” on Aji Chay River, appropriate flood patterns in agreement with the observed ones also appear. As described in Subsection 5.6.5, in the context that evapotranspiration from irrigated area is correctly simulated, it can be said that the model has sufficient accuracy on runoff part, which is river inflow into Urmia Lake, so as to evaluate impact of the scenarios proposed by ULRP on flow regime.

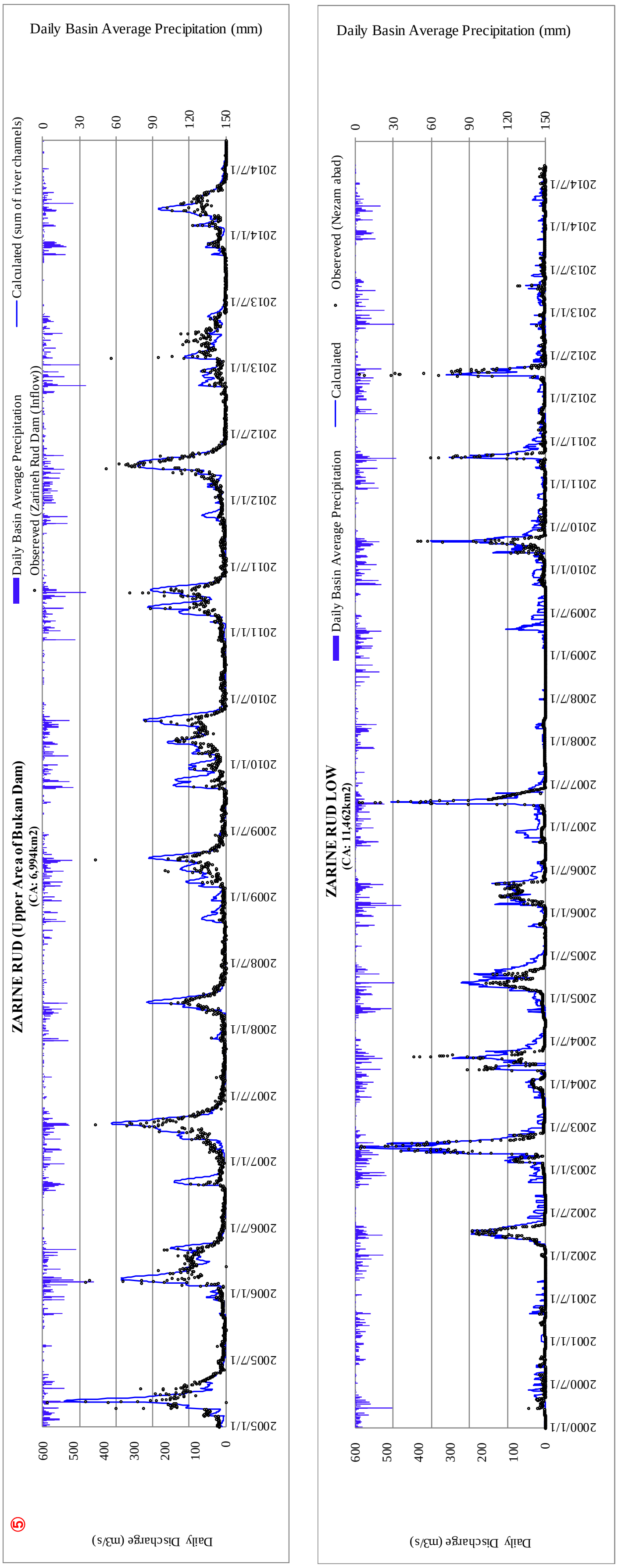


Figure 5.6.3 Calibration Result of River Discharge for Southern Part (Top: Dam inflow of Bukan Dam, Bottom: Nezam Abad)

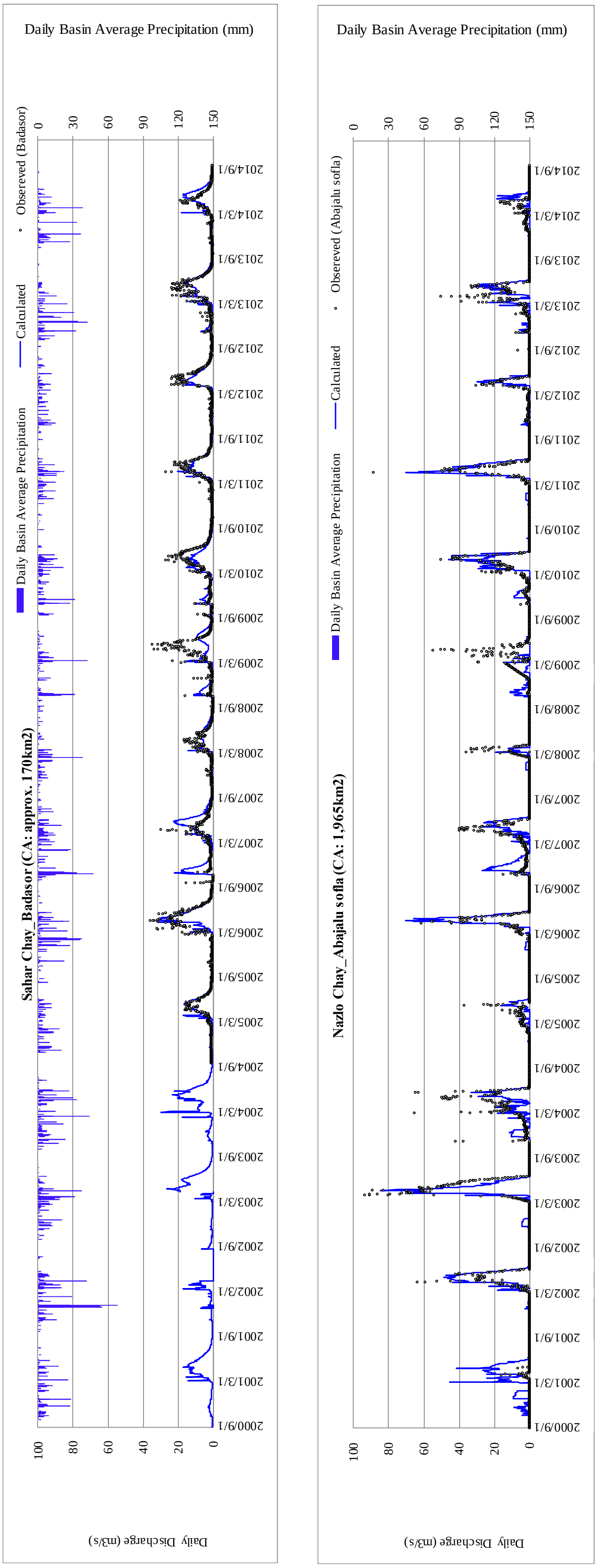


Figure 5.6.4 Calibration Result of River Discharge for Western Part (Top: Badasor, Bottom: Abajalu Sofla)

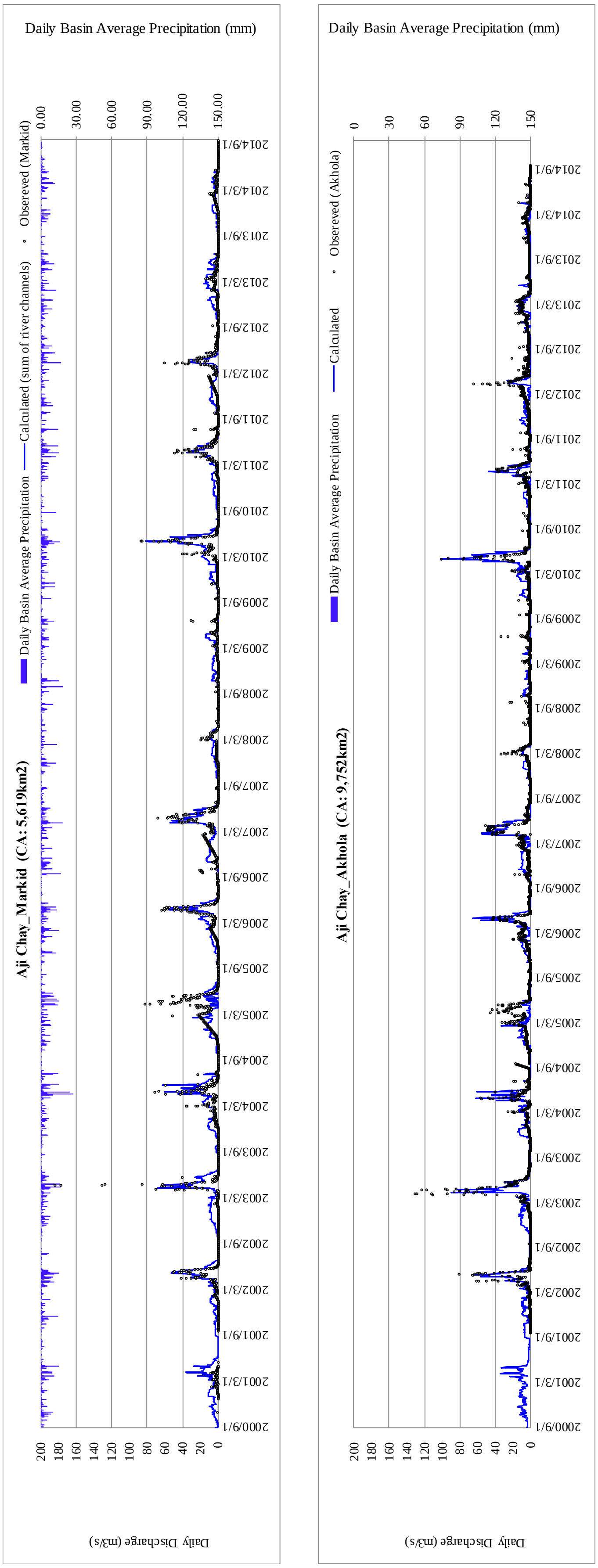
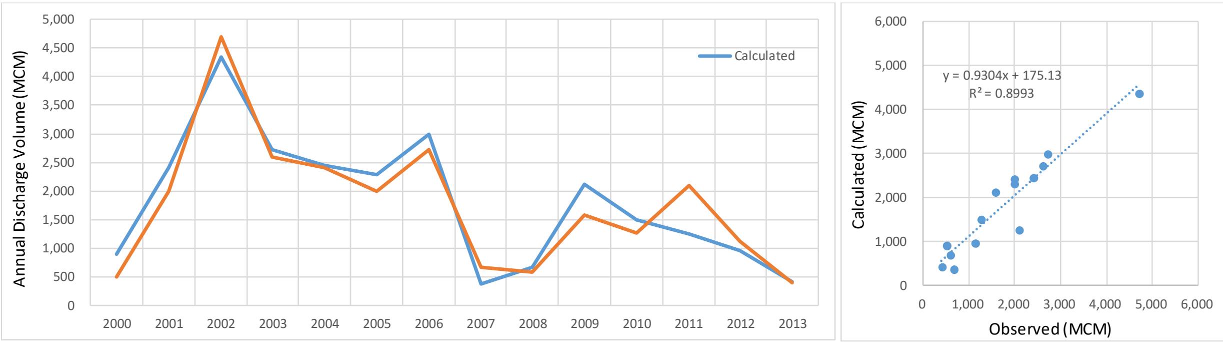


Figure 5.6.5 Calibration Result of River Discharge for Eastern Part (Top: Markid, Bottom: Akhola)

5.6.3 Total Discharge Volume among Lowest Hydrological Stations

From the viewpoint of water resource management on Urmia Lake Basin, heightening of the accuracy of simulated inflow volume into the lake is necessary. Since it is difficult to confirm accuracy of inflow volume itself, agreement of total volume of discharge at the most downstream hydrological station of sub-river basins was confirmed. Charts in Figure 5.6.6 show temporal agreement and correlation of total discharge volume between simulated and observed. Although simulated discharge volume tends to be overestimated, it can be said that simulated discharge volume has high agreement with the observed one in terms of massive scale.



* Data for the hydrological stations that were omitted to evaluate with NSE were omitted.

Figure 5.6.6 Comparison and Correlation of Total Annual Discharge Volume among Hydrological Stations between Simulated and Observed

5.6.4 Evaluation of Calibration Result by Nash-Sutcliff Efficiency

To evaluate the model calibration, Nash-Sutlcliff Efficiency (hereinafter referred to as "N-S Efficiency" or "NSE") for monthly discharge volume, which is commonly used as an index to assess the predictive power of the hydrological model, was applied.

The efficiency E is defined as one minus the sum of the absolute squared differences between the predicted and observed values normalized by the variance of the observed values during the period under investigation. It is calculated as:

$$E = 1 - \Sigma(Q_{ob}-Q_{cal})^2/\Sigma(Q_{obav}- Q_{ob})^2$$

where;

E	: Nash-Sutcliffe efficiency
Q_{ob}	: Observed Monthly River Discharge Volume (MCM)
Q_{cal}	: Calculated Monthly River Discharge Volume (MCM)
Q_{obav}	: Average of Observed Discharge (MCM)

D. N. Moriasi et al (2007) reported that long-term simulation with monthly time step can be judged as "satisfactory" if E > 0.5.[4]

With application of the modification ratio for RSRC-ET as shown in Appendix 5-8, it can be seen that N-S efficiencies at most of the calibration points are improved near "satisfactory" level during calibration period and verification period (see Figure 5.6.7 to Figure 5.6.9). However, some hydrological stations show low values. Table 5.6.2 and Table 5.6.3 show the lists of hydrological stations omitted from evaluation and that with slightly-lower accuracies than 0.5 of N-S values in spite of the fact that a certain amount of agreement with observed discharge can be confirmed. As described in Subsection 5.7, inflows from rivers with low accuracies; e.g. Zola Chay River and Shahr Chay River tend to less contribute than that with high contribution; e.g. Zarineh Rud River. Adverse effects of these simulated results would be small.

[4] "MODEL EVALUATION GUIDELINES FOR SYSTEMATIC QUANTIFICATION OF ACCURACY IN WATERSHED SIMULATIONS" D.N. Moriasi et al (2007), American Society of Agricultural and Biological Engineers ISSN 0001−2351 Vol. 50(3): 885−900

Table 5.6.2 Omitted Hydrological Stations for Evaluation of Model Calibration

Part	River	Hydrological Station	Station Code	Description
West	Zola chay	Yalghuz aghaj	36-011	There is possibilty of underestimation of observed discharge due to severe scouring, which simulation result cannot agree with observed one.
West	Shahr chay	Kashtiban	35-013	High accuracy cannot be obtained when using the outflow of Shahr Chay Dam as upstream inflow, which show different discharge pattern with observed discharge at Kashtiban.
West	Shahr chay	Band urmia	35-011	As with Kashtiban, simulated river discharge do not agree with observed one when using the outflow of Shahr Chay dam.
East	Gomnab chay	Anakhatun	31-017	Most of observed flood events are linearly interpolated.
East	Sanikh chay	Pol sanikh	31-029	Small amount of discharg less than 10 m^3/s in spite of approx. 500 km^2 of catchmetnt area upstream and none of large irrigated area. Flood does not respond with precipitation.

Table 5.6.3 Evaluation of Hydrological Stations with Low N-S Efficiencies

Part	River	Hydrological Station	Station Code	Description
West	Zola chay	Chehrigh olia	36-001	Small amount of discharg less than 20 m^3/s during flood events is observed despite approx. 800 km^2 of catchmetnt area in mountainous area. Besides 90 m^3/s of maximum peak discharge take place at Karim Abad located upstream Nazlo Chay with 500 km^2 of catchement area. MIKE-SHE cannot express this difference of runoff characteristics between neighboring catchment areas.
West	Baranduz chay	Babarud	35-007	During calculation period, despite of precipitation occurrence, only one small flood event takes place. Although some weirs exist upstream, it is skeptical that flood event is hardly observed even duing winter season, while hydrological stations upstream (e.g. Dizaj-e and Ghasemlu) show flood events occurrence. MIKE-SHE cannot express this drastic difference (cutting off the water flow) in limited condition.
East	Lighavan	Harvi	31-021	Small amount of discharg less than 15 m^3/s during flood events is observed despite approx. 190 km^2 of catchmetnt area in mountainous area. Due to steep slope of Mt. Kuh-e Sahand, simulated discharge might be overestimated with sharp flood patterns.

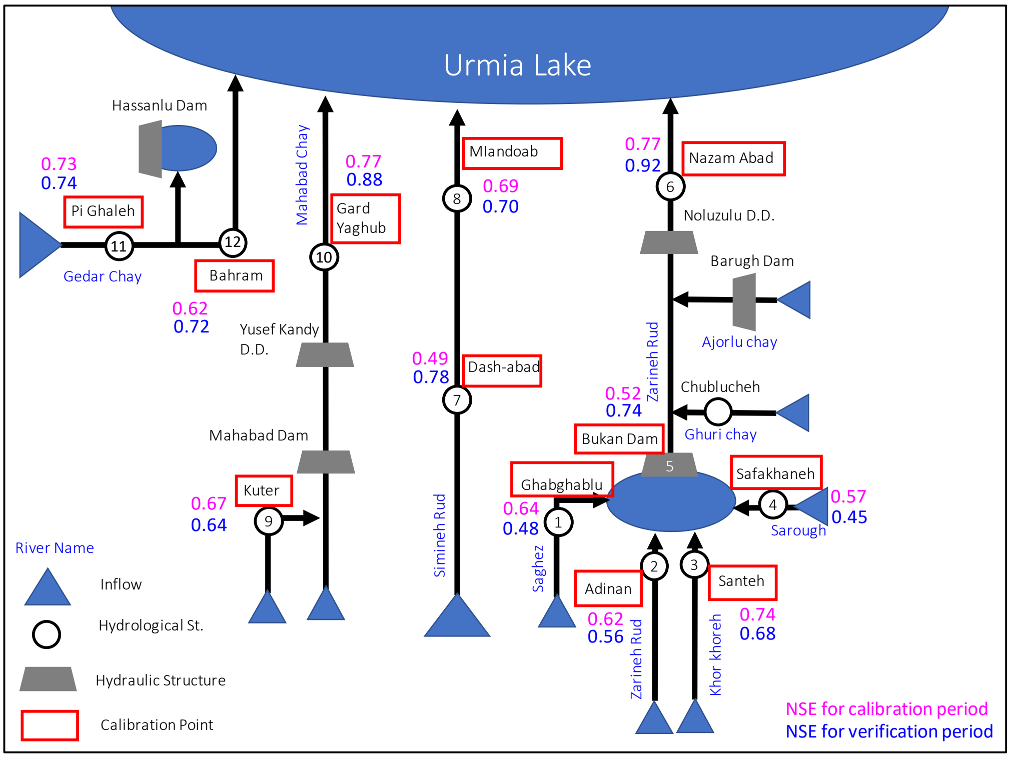


Figure 5.6.7 Nash-Sutcliff Efficiencies for Monthly Discharge Volume at the Calibration Point (1) (Southern Part)

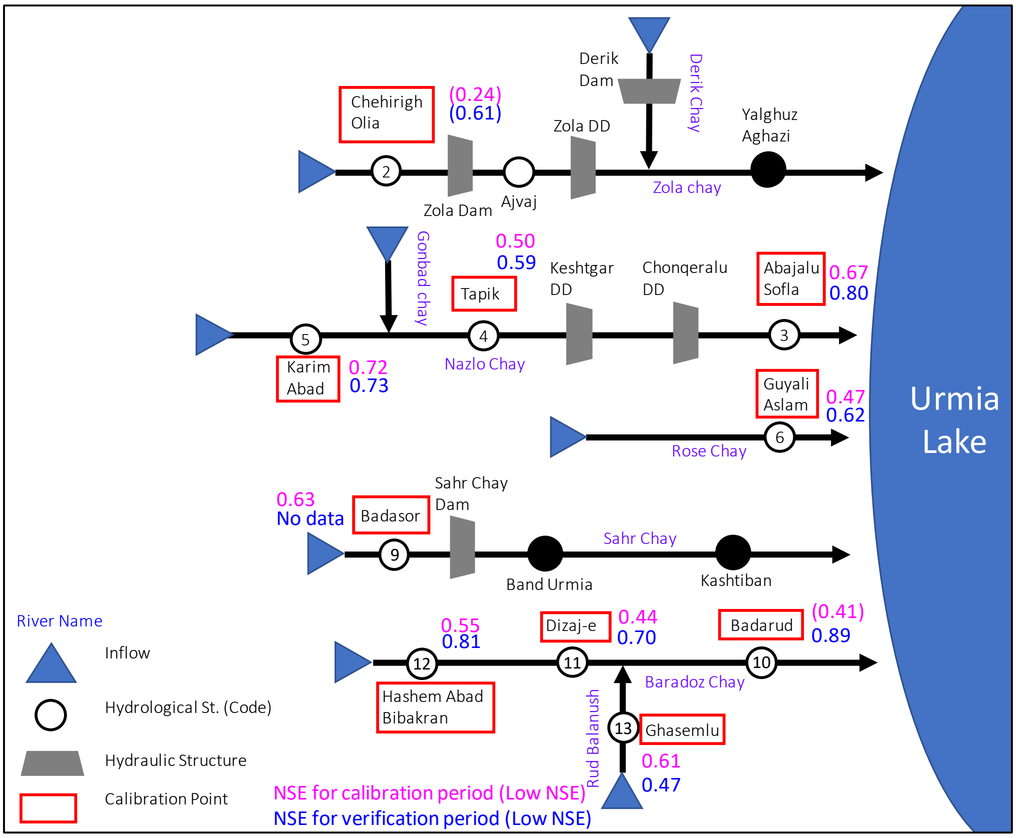


Figure 5.6.8 Nash-Sutcliff Efficiencies for Monthly Discharge Volume at the Calibration Point (2) (Western Part)

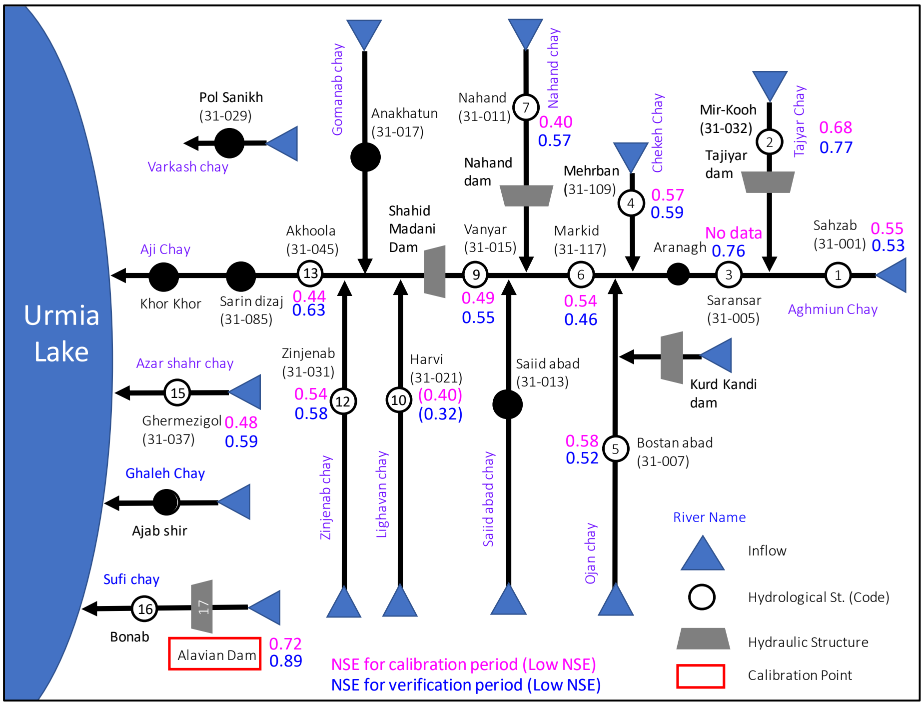


Figure 5.6.9 Nash-Sutcliff Efficiencies for Monthly Discharge Volume at the Calibration Point (3) (Eastern Part)

5.6.5 Calculation of Evapotranspiration at Irrigated Area

MIKE-SHE tends to underestimate actual ET when inputting RSRC-ET because MIKE-SHE considers decrement of actual ET with soil moisture. One of the actions for accuracy improvement of the model is calculation of evapotranspiration at irrigated field by MIKE-SHE so as to agree with RCRC-ET as model input data. Supplementary well irrigation was considered in MIKE-SHE's irrigation module for gap-filling. The difference between simulated actual ET and RSRC-ET at primary irrigated field were confirmed.

Charts in Figure 5.6.10 show comparison of monthly actual ET between simulated by MIKE-SHE and RSRC-ET at Miandoab (southern part), Urmia (western part) and Tazeh Kand (eastern part), respectively. Although simulated actual ET shows slightly less than RSRC-ET, every chart shows sufficient agreement with MIKE-SHE's ET and RSRC-ET in monthly basis. Charts in Figure 5.6.11 also show these correlations with monthly and annual basis. Errors in annual basis for the periods (2000-2013) between simulated actual ET and RCRS-ET are 3% for Miandoab, 4% at Urmia and 4% at Tazeh Kand, These results show that the constructed model secures sufficient accuracy on actual ET at irrigated area.

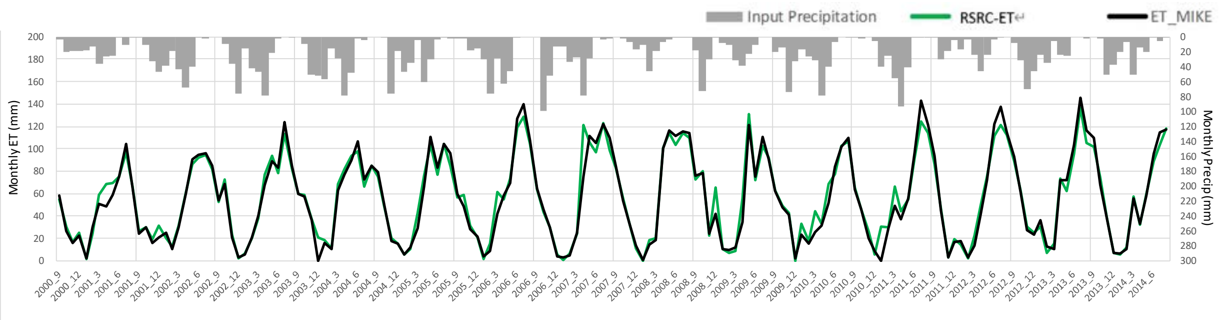


Figure 5.6.10 Temporal Change in Monthly Evapotranspiration in Irrigated Area (1) (Miandoab Plain)

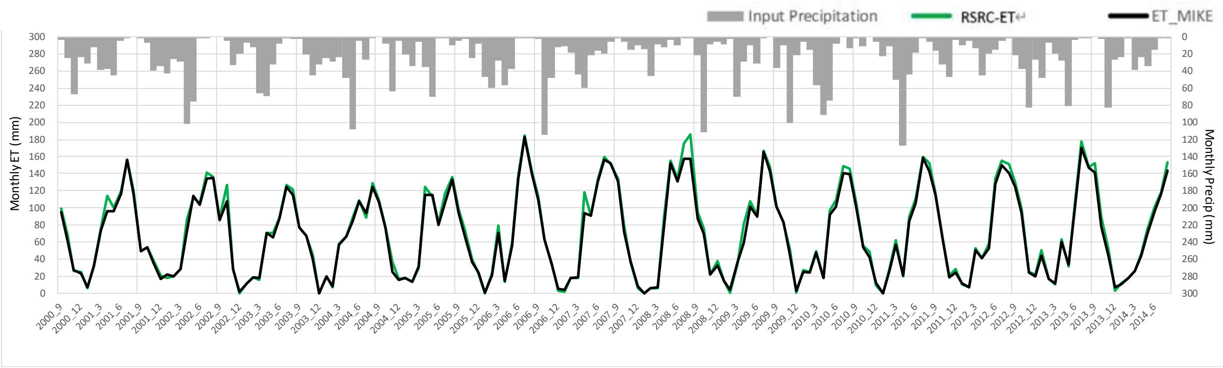


Figure 5.6.10 Temporal Change in Monthly Evapotranspiration in Irrigated Area (2) (Urmia Plain)

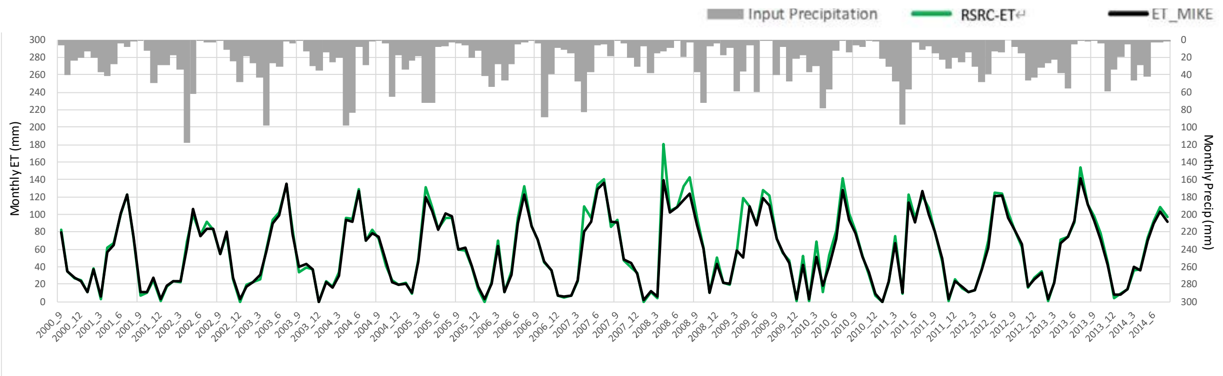


Figure 5.6.10 Temporal Change in Monthly Evapotranspiration in Irrigated Aera (3) (Tazeh Kand)

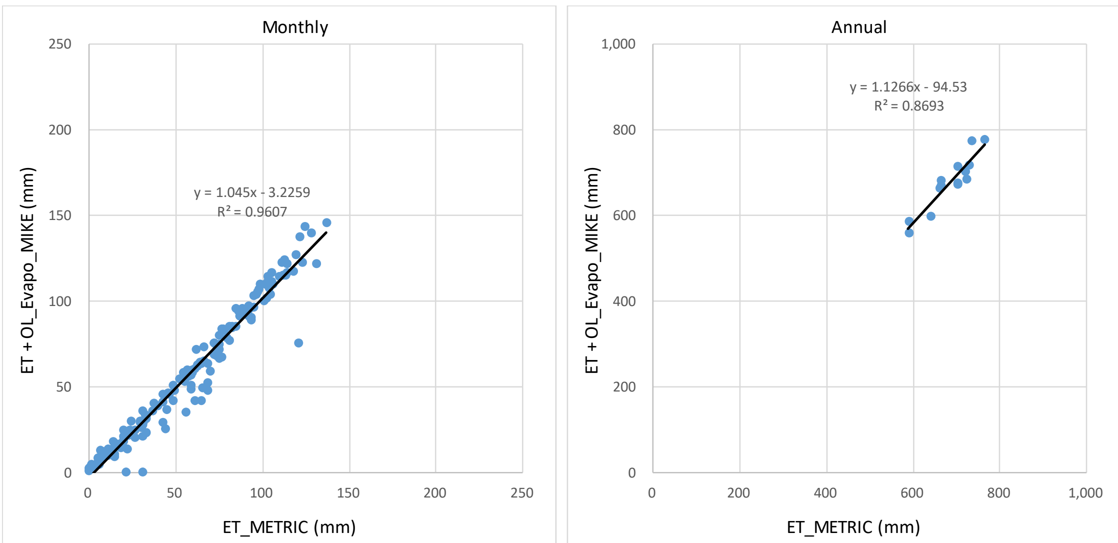


Figure 5.6.11 Correlation of Monthly/Annual Evapotranspiration in Miandoab Plain

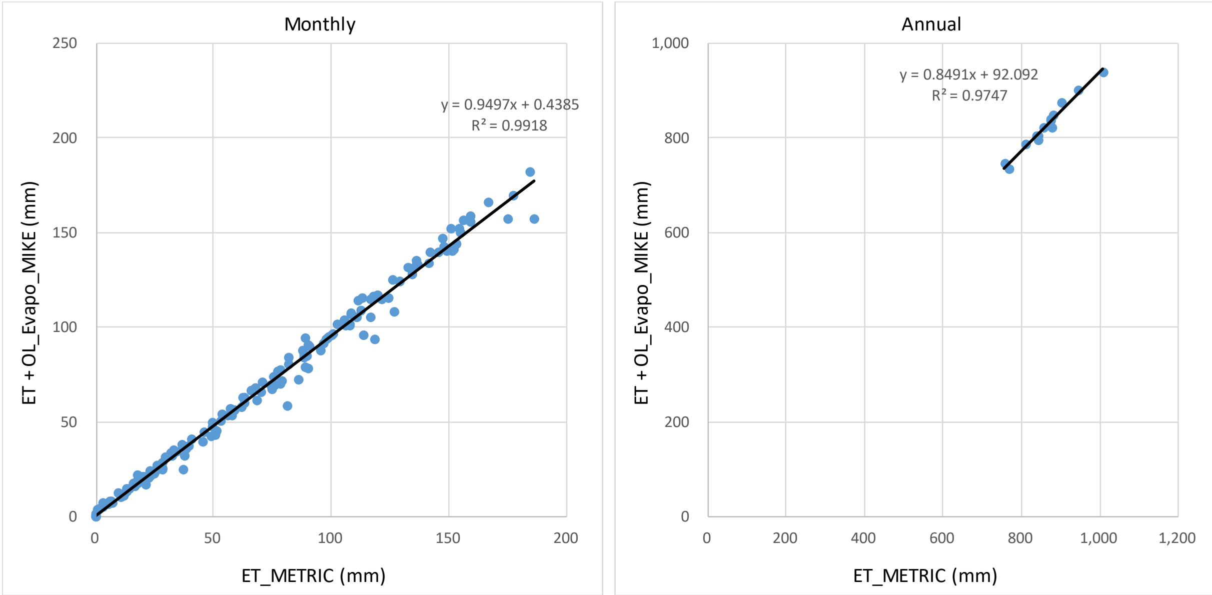


Figure 5.6.11 Correlation of Monthly/Annual Evapotranspiration in Urmia Plain

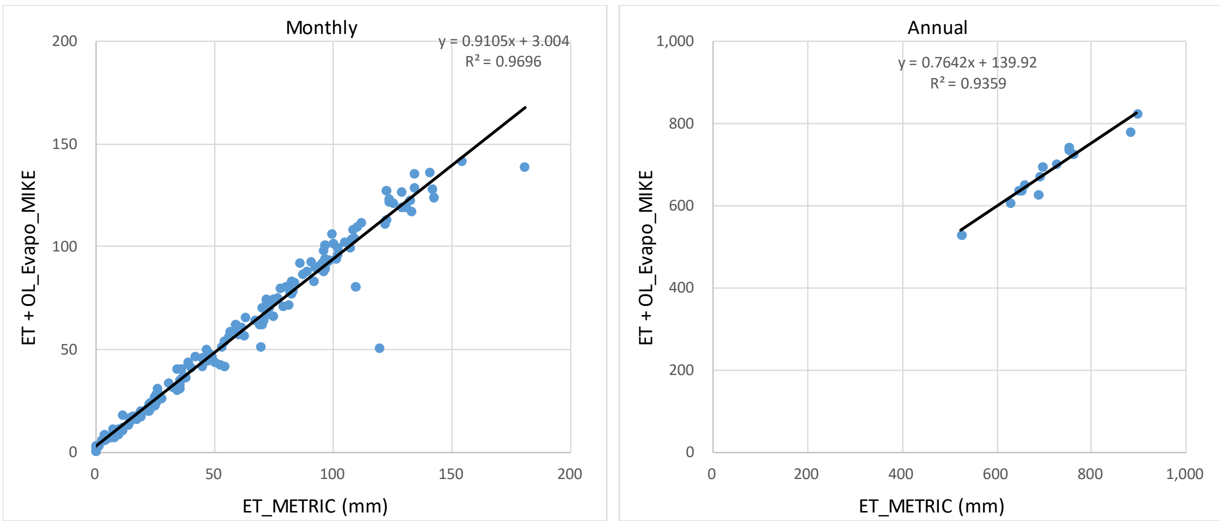


Figure 5.6.11 Correlation of Monthly/Annual Evapotranspiration in Irrigated Aera in Tazeh Kand

5.6.6 Calibration Result of Groundwater Level

Groundwater model was also calibrated so that simulated piezometric head (equivalent to groundwater level) in saturated zone agrees to observed one at several points around Urmia Lake. At least one extraction point was selected in irrigated area of lowland area. Since data of the piezometric head provided by ULRP does not have information of strainer depth (equivalent to observation depth of piezometric head), screen depth of each point was assumed based on the depth of the closest boring logs. Location of extraction points are drawn in Figure 5.6.12 and their coordinates and depth are listed in Table 5.6.4.

Charts in Figure 5.6.13 show comparison between calculated piezometric head and observed one at the extraction points in each part, with applied hydraulic parameters tabulated in Table 5.6.5. Table 5.6.6 summarizes annual mean groundwater level between simulated and observed. The model expresses acceptable agreement between calculated and observed groundwater level (such as on overall trend and seasonal fluctuation) with applied hydraulic parameters.

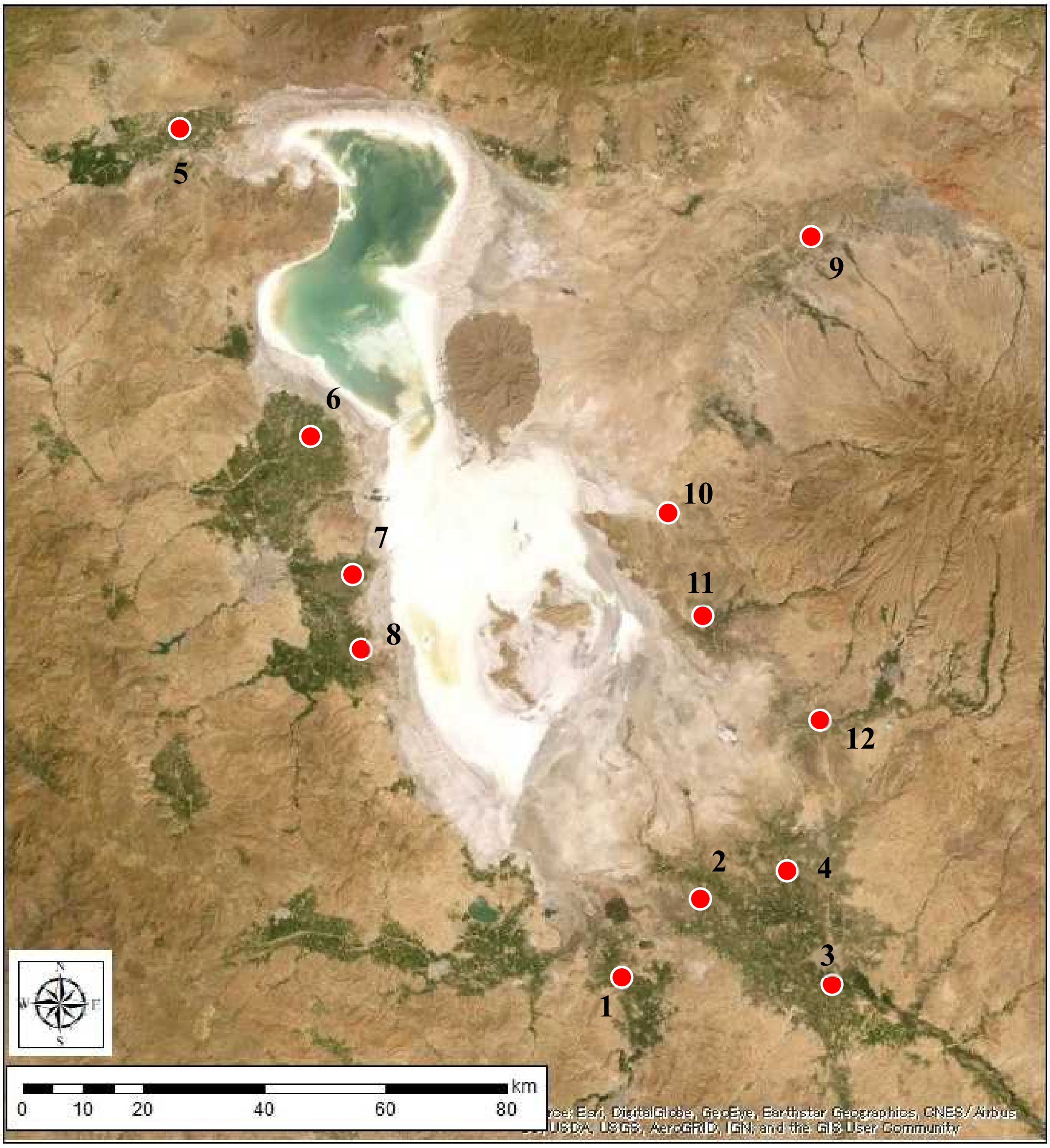


Figure 5.6.12 Extraction Points for Piezometric Head around Urmia Lake

Table 5.6.4 Summary of Extraction Points of Piezometric Head around Urmia Lake

No.	Location	Part	X	Y	Depth (m)*
1	Qezel gapi-Qara qeshlaq	South	564259	4088748	15.8
2	Choqanlou	South	576550	4099245	17
3	Hasel qouei	South	588634	4096980	14.42
4	Tazeh qaleh	South	595000	4110650	24
5	Ghezeljah	West	491013	4228068	100
6	Hesar separqan	West	517458	4177213	27.1
7	Balderlou	West	521344	4155516	24.83
8	Och olar	West	517117	4148320	41.3
9	Satlou bridge	East	586950	4205750	100
10	Qaryaqdi road	East	572940	4166226	25
11	Shishvan baq azimi	East	579200	4147250	34
12	Qarachopoq behdasht	East	589800	4130500	24

*Strainer depths of piezometers were assumed based on the depth of bottom depth of the closest boring log provided by URLP

Table 5.6.5 Applied Geological Hydraulic Parameters (1) (Southern Part)

Items	Applied Values
Horizontal Hydraulic Conductivity	10^{-4} m/s
Vertical Hydraulic Conductivity	10^{-7} m/s
Specific yield	0.15
Specific storage	1.0 – 2.0 x 10^{-3} 1/m

Applied Geological Hydraulic Parameters (2) (Western Part)

Items	Applied Values
Horizontal Hydraulic Conductivity	10^{-4} m/s
Vertical Hydraulic Conductivity	10^{-7} m/s
Specific yield	0.15
Specific storage	1.0 – 2.0 x 10^{-3} 1/m

Applied Geological Hydraulic Parameters (3) (Western Part)

Items	Applied Values
Horizontal Hydraulic Conductivity	10^{-4} m/s
Vertical Hydraulic Conductivity	10^{-7} m/s
Specific yield	0.15
Specific storage	1.0 – 2.0 x 10^{-3} 1/m

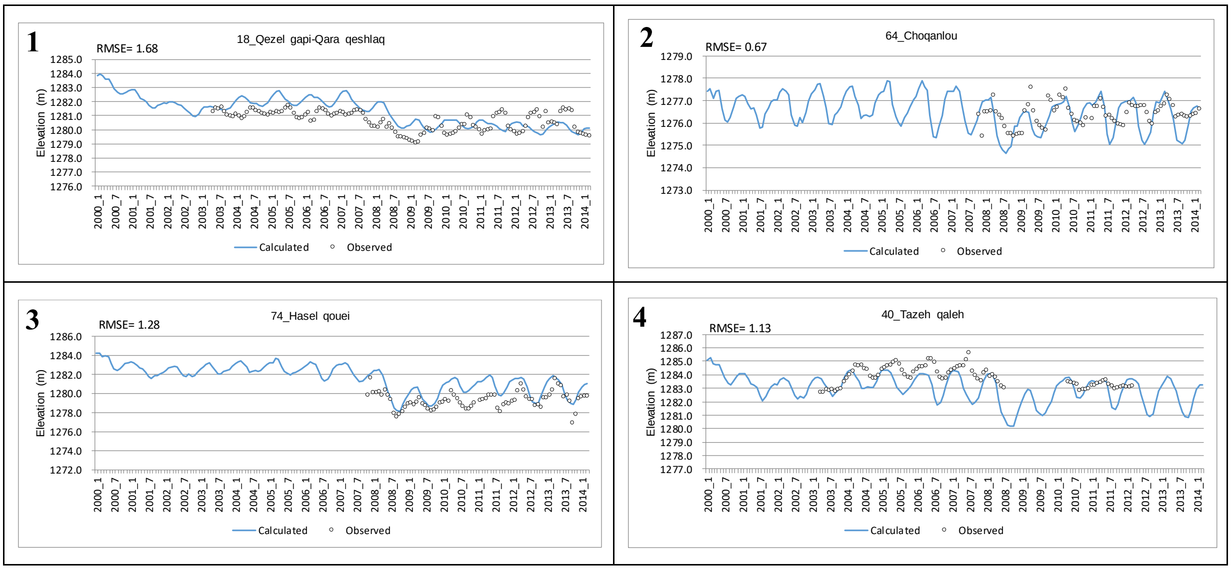


Figure 5.6.13 Calibration Results for Groundwater Level around Urmia Lake (1) (Southern Part)

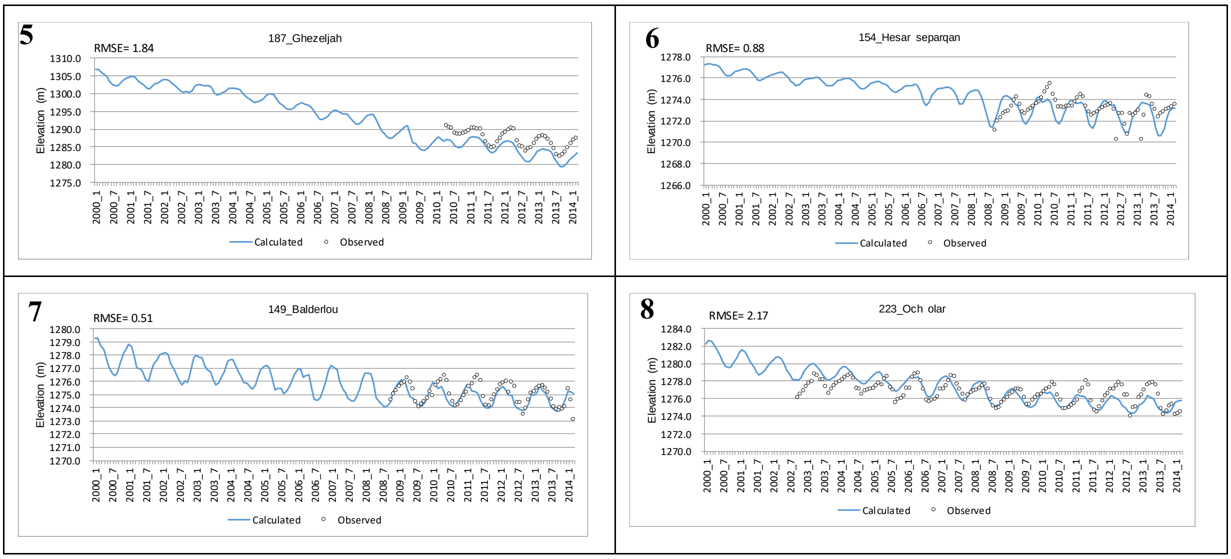


Figure 5.6.13 Calibration Results for Groundwater Level around Urmia Lake (2) (Western Part)

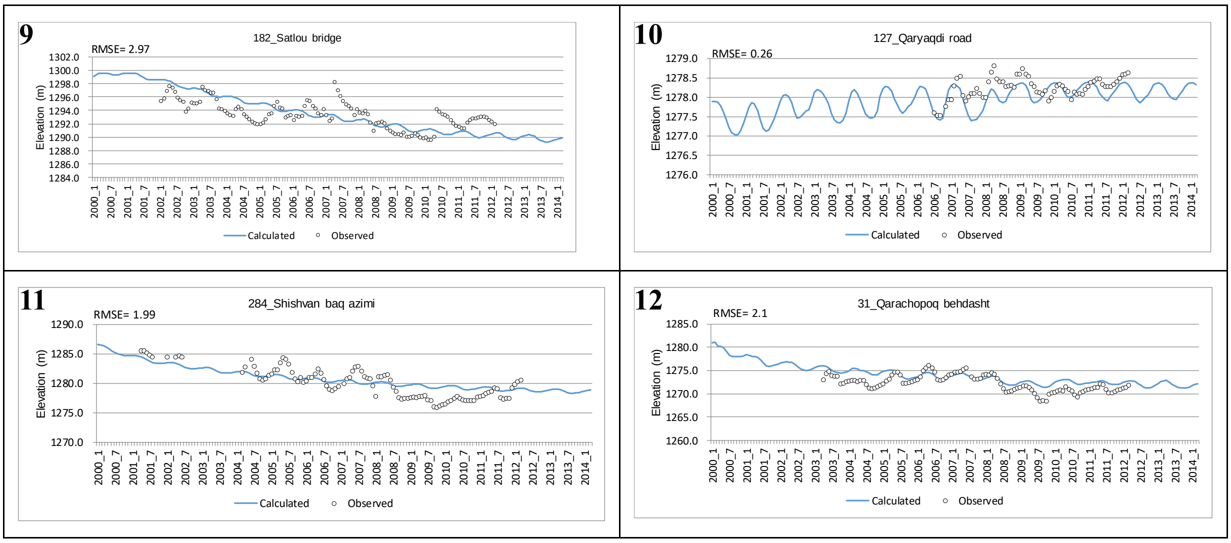


Figure 5.6.13 Calibration Results for Groundwater Level around Urmia Lake (3) (Eastern Part)

Table 5.6.6 Annual Mean Groundwater Level between Observed and Simulated

■ Southern Part

Year	1		2		3		4	
	Qezel gapi-Qara qeshlaq		Choqanlou		Hasel qouei		Tazeh qaleh	
	Calculated	Observed	Calculated	Observed	Calculated	Observed	Calculated	Observed
2000	1282.36	-	1276.63	-	1282.62	-	1283.35	-
2001	1281.77	-	1276.81	-	1282.23	-	1283.07	-
2002	1281.39	-	1276.80	-	1282.38	-	1283.06	-
2003	1281.92	1281.13	1276.84	-	1282.70	-	1283.49	1283.92
2004	1282.17	1281.28	1276.85	-	1282.75	-	1283.58	1284.36
2005	1282.10	1281.06	1276.75	-	1282.46	-	1283.31	1284.44
2006	1282.10	1281.18	1276.69	-	1282.35	-	1283.12	1284.40
2007	1281.43	1280.38	1276.06	-	1281.26	-	1282.56	-
2008	1280.28	1279.49	1275.73	1276.04	1279.36	1278.59	1281.53	-
2009	1280.43	1280.12	1276.45	1276.66	1280.50	1279.04	1282.86	-
2010	1280.38	1280.43	1276.50	-	1280.97	-	1283.02	1283.19
2011	1280.23	1280.44	1276.33	1276.42	1280.74	1279.41	1282.71	-
2012	1280.17	1280.94	1276.32	1276.56	1280.54	1279.83	1282.57	-
2013	1279.91	1279.97	1276.09	1276.39	1280.00	1278.89	1282.11	-

■ Western Part

Year	5		6		7		8	
	Ghezeljah		Hesar separqan		Balderlou		Och olar	
	Calculated	Observed	Calculated	Observed	Calculated	Observed	Calculated	Observed
2000	1303.35	-	1276.50	-	1277.38	-	1280.18	-
2001	1302.54	-	1276.18	-	1277.21	-	1279.68	-
2002	1301.41	-	1275.75	-	1276.88	-	1279.05	-
2003	1300.33	-	1275.66	-	1276.63	-	1278.76	1277.79
2004	1298.27	-	1275.34	-	1276.11	-	1278.13	1277.35
2005	1295.90	-	1274.96	-	1275.95	-	1277.69	1277.09
2006	1293.97	-	1274.65	-	1275.81	-	1277.38	1277.09
2007	1291.68	-	1273.89	-	1275.35	-	1276.68	1276.65
2008	1287.85	-	1273.23	-	1275.07	-	1276.12	1276.10
2009	1286.19	-	1273.18	1273.95	1274.98	1275.30	1275.91	1276.59
2010	1286.28	1288.65	1273.05	1273.57	1274.87	1275.20	1275.66	1275.93
2011	1284.71	1287.26	1272.81	1272.80	1274.71	1275.20	1275.43	1276.53
2012	1282.74	1285.76	1272.57	1272.61	1274.64	1274.89	1275.29	1276.31
2013	1281.20	1284.70	1271.98	1272.98	1274.51	1274.16	1275.06	1274.62

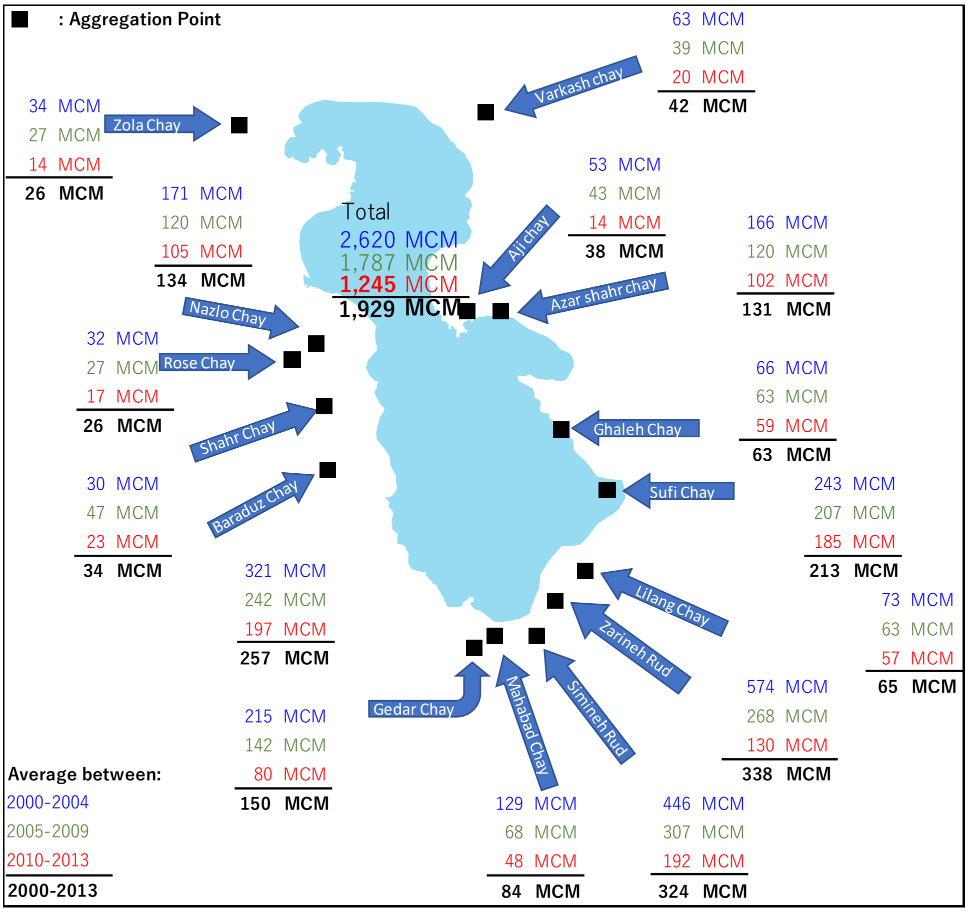
■ Eastern Part

Year	9		10		11		12	
	Satlou bridge		Qaryaqdi road		Shishvan baq azimi		Qarachopoq behdasht	
	Calculated	Observed	Calculated	Observed	Calculated	Observed	Calculated	Observed
2000	1299.34	-	1277.40	-	1284.43	-	1277.71	-
2001	1298.35	-	1277.66	-	1283.27	-	1276.32	-
2002	1297.06	1295.49	1277.84	-	1282.39	-	1275.42	-
2003	1295.87	1294.15	1277.73	-	1281.73	-	1274.88	1272.59
2004	1294.81	1292.88	1277.87	-	1281.20	1282.26	1274.45	1272.82
2005	1293.80	1293.70	1277.92	-	1280.73	1280.93	1273.81	1273.93
2006	1293.06	1294.51	1277.89	-	1280.32	-	1273.76	-
2007	1292.36	1293.29	1277.83	1278.32	1279.97	1280.35	1273.10	1273.19
2008	1291.59	1290.87	1278.13	1278.40	1279.60	1277.59	1272.19	1270.72
2009	1290.93	1290.85	1278.18	1278.14	1279.34	1276.85	1272.40	1270.21
2010	1290.57	1292.16	1278.20	1278.29	1279.10	1278.05	1272.39	1270.95
2011	1290.27	-	1278.16	-	1278.89	-	1272.25	-
2012	1289.94	-	1278.15	-	1278.72	-	1272.00	-
2013	1289.55	-	1278.27	-	1278.61	-	1271.60	-

Unit: Elevation (m)

5.7 Preliminary Evaluation of Inflow into Urmia Lake

With the calibrated model, calculated annual discharge volume at downstream of main rivers were aggregated to understand regional origins and medium-term changes of inflow volume to Urmia Lake. Figure 5.7.1 and Figure 5.7.2 show potential contribution and temporal change of inflow into lake during the three periods, 2000-2004, 2005-2009, 2010-2014 and whole calculation period, respectively. Table 5.7.1 shows calculated annual discharge at each river. With period proceeds, gradual decrement of river discharge volume into Urmia Lake can be confirmed. Calculation result also shows that rivers in southern part have more than 50% of portion of total inflow, and same contribution of inflow to Urmia Lake has been confirmed between western and eastern parts.



*Aggregation period is between September to August

Figure 5.7.1 Calculated Annual Inflow into Urmia Lake

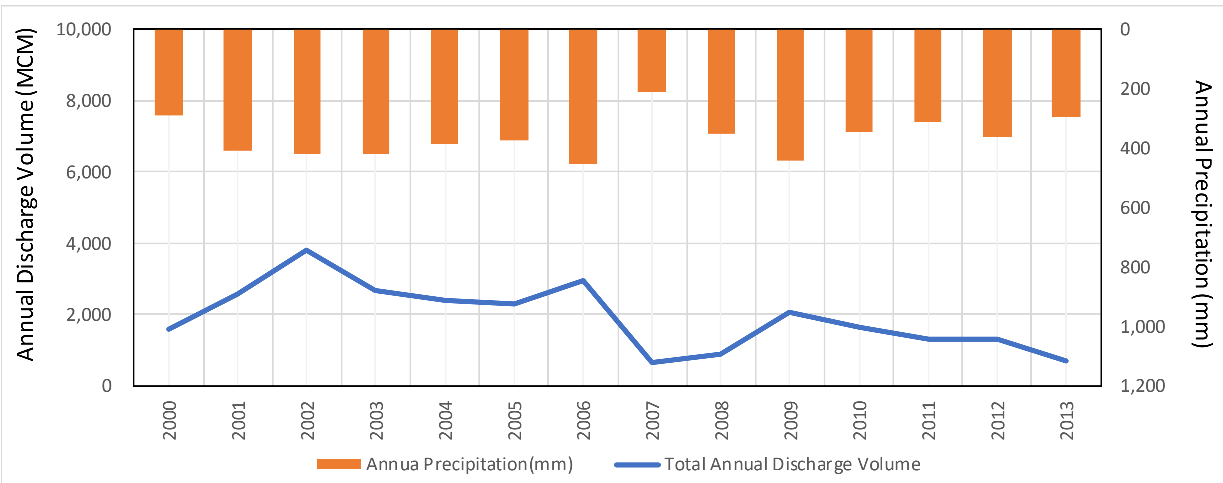


Figure 5.7.2 Temporal Change of Calculated Annual Inflow into Urmia Lake

Table 5.7.1 Annual Discharge Volume at Aggregation Points

Unit: MCM

Year	Mardugh chay	Zarrineh rud	Mahabad chay	Gedar chay	Simineh rud	-	Southern Part	Percentage	
2000	68	5	26	212	238	-	548	34%	
2001	70	409	60	251	429	-	1,219	47%	
2002	74	1,247	216	242	567	-	2,346	62%	
2003	77	500	204	218	501	-	1,500	56%	
2004	75	708	138	154	492	-	1,568	66%	
2005	74	366	77	196	492	-	1,205	52%	
2006	76	503	177	237	566	-	1,559	52%	
2007	52	5	17	64	86	-	224	35%	
2008	45	45	24	70	129	-	313	34%	
2009	66	423	45	141	262	-	936	45%	
2010	65	237	43	118	286	-	748	45%	
2011	56	272	59	81	153	-	622	47%	
2012	58	9	55	77	271	-	470	36%	
2013	49	3	36	45	58	-	191	27%	
Ave. 2000-2004	73	574	129	215	446	-	1,436	55%	
Ave. 2005-2009	63	268	68	142	307	-	848	47%	
Ave. 2010-2013	57	130	48	80	192	-	508	41%	
Ave. 2000-2013	65	338	84	150	324	-	961	50%	
Year	**Zola chay**	**Nazlu chay**	**Rose chay**	**Shahr chay**	**Ghaleh chay**	**Baranduz chay**	**Western Part**	**Percentage**	
2000	36	193	29	24	37	259	579	36%	
2001	27	208	44	28	91	409	806	31%	
2002	52	255	38	24	68	408	845	22%	
2003	53	158	32	18	76	327	664	25%	
2004	3	41	15	55	58	202	374	16%	
2005	18	182	26	94	64	265	651	28%	
2006	46	177	45	86	90	442	886	30%	
2007	2	35	9	13	30	82	170	26%	
2008	12	42	24	14	44	178	314	35%	
2009	55	165	30	30	89	244	614	29%	
2010	17	204	21	30	82	170	523	31%	
2011	0	63	15	22	58	221	379	29%	
2012	37	122	19	28	56	230	492	38%	
2013	0	31	12	13	41	166	263	37%	
Ave. 2000-2004	34	171	32	30	66	321	654	25%	
Ave. 2005-2009	27	120	27	47	63	242	527	29%	
Ave. 2010-2013	14	105	17	23	59	197	414	33%	
Ave. 2000-2013	26	134	26	34	63	257	540	28%	
Year	**Aji chay**	**Azar Shahr chay**	**Varkash chay**	**Sufi chay**	**Lilang Chay**	**-**	**Eastern Part**	**Percentage**	**Total**
2000	62	179	77	8	148	-	473	30%	**1,601**
2001	71	188	83	4	235	-	582	22%	**2,607**
2002	71	158	71	5	308	-	613	16%	**3,804**
2003	43	159	47	4	280	-	533	20%	**2,697**
2004	19	146	37	2	243	-	447	19%	**2,388**
2005	46	128	43	3	240	-	460	20%	**2,316**
2006	53	142	61	3	267	-	526	18%	**2,972**
2007	15	100	23	3	113	-	253	39%	**648**
2008	4	108	27	1	141	-	281	31%	**908**
2009	95	125	44	4	272	-	541	26%	**2,091**
2010	24	110	29	3	231	-	397	24%	**1,668**
2011	15	99	19	1	175	-	309	24%	**1,310**
2012	15	104	20	1	200	-	340	26%	**1,302**
2013	5	96	12	2	133	-	247	35%	**701**
Ave. 2000-2004	53	166	63	5	243	-	530	20%	**2,620**
Ave. 2005-2009	43	120	39	3	207	-	412	23%	**1,787**
Ave. 2010-2013	14	102	20	2	185	-	323	26%	**1,245**
Ave. 2000-2013	38	131	42	3	213	-	429	22%	**1,929**

*Aggregation period is between September and August

5.8 Evaluation of Groundwater Abstraction Status

In order to assume current status of groundwater use, simulated groundwater abstraction by MIKE-SHE and registered groundwater abstraction by IWRM Co. were compared at representative irrigated area of three parts as shown in Figure 5.8.1, Miandoab Plain for southern part (approximately 15,000 registered wells exist), Urmia plain for western part (approx. 22,400 registered wells) and eastern part (approx. 1,700 registered wells), respectively. According to staff of IWRM Co., groundwater abstraction registered by IWRM Co. includes both legal and illegal well extraction.

Charts in Figure 5.8.2 show comparison of annual groundwater abstraction between simulated and registered, and their ratios (simulated groundwater abstraction to registered one). The constructed model considers the supplement groundwater irrigation in irrigation module besides well module of SZ module, which water supply to irrigated field meets irrigation demand. For example, simulation results in 2013 show approximately 6 times of groundwater abstraction as registered one at southern and western parts, and approximately 2 times at eastern part. It tends that, with more wells exist, more illegal water abstraction was induced.

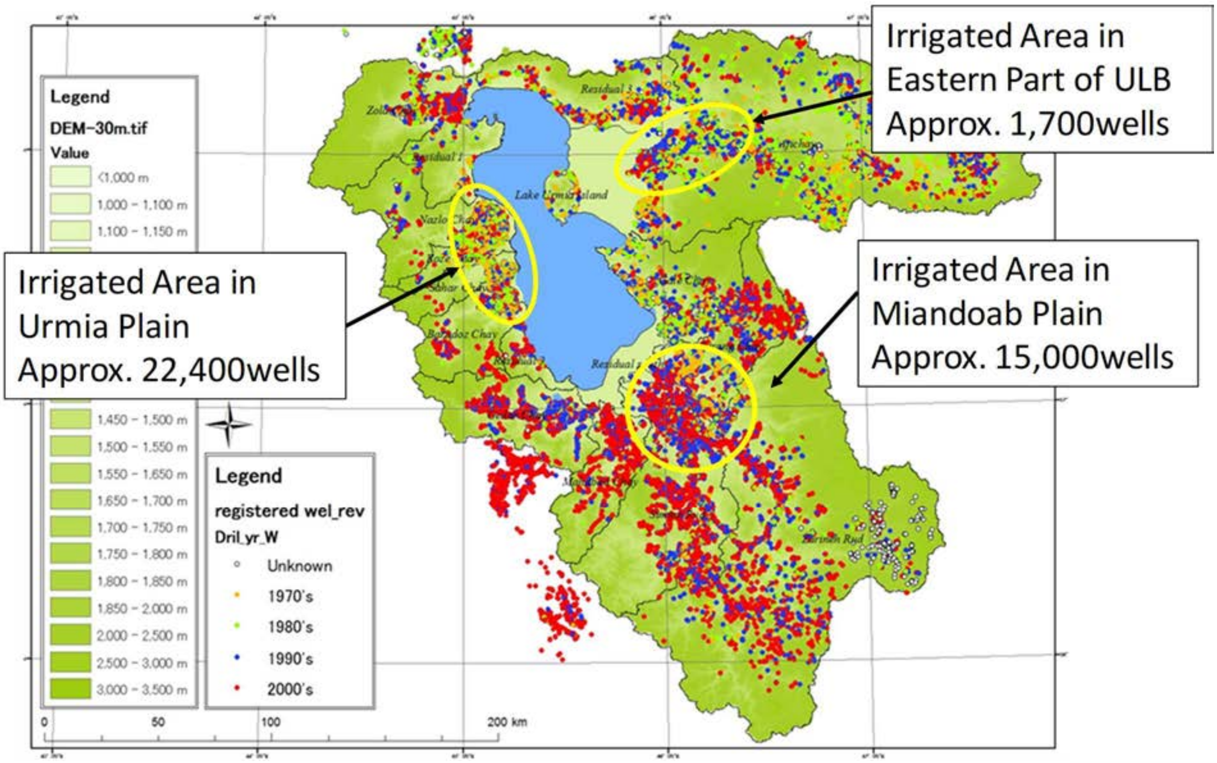
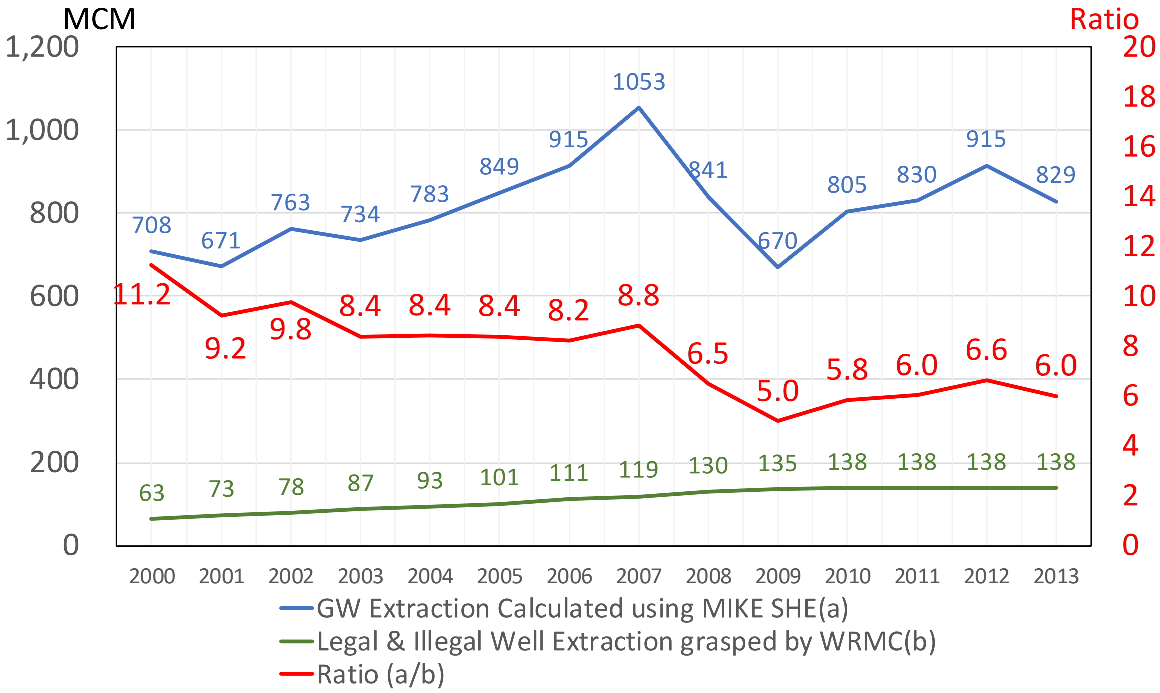
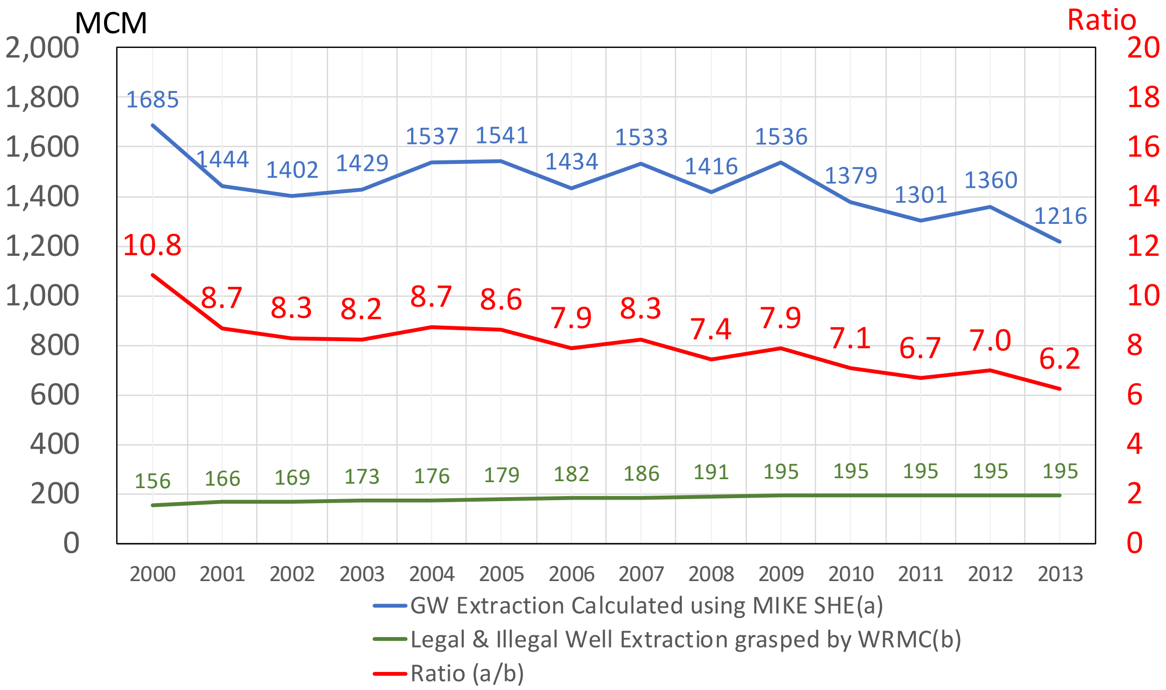


Figure 5.8.1 Selected Irrigated Area and Spatial Distribution of Registered Well



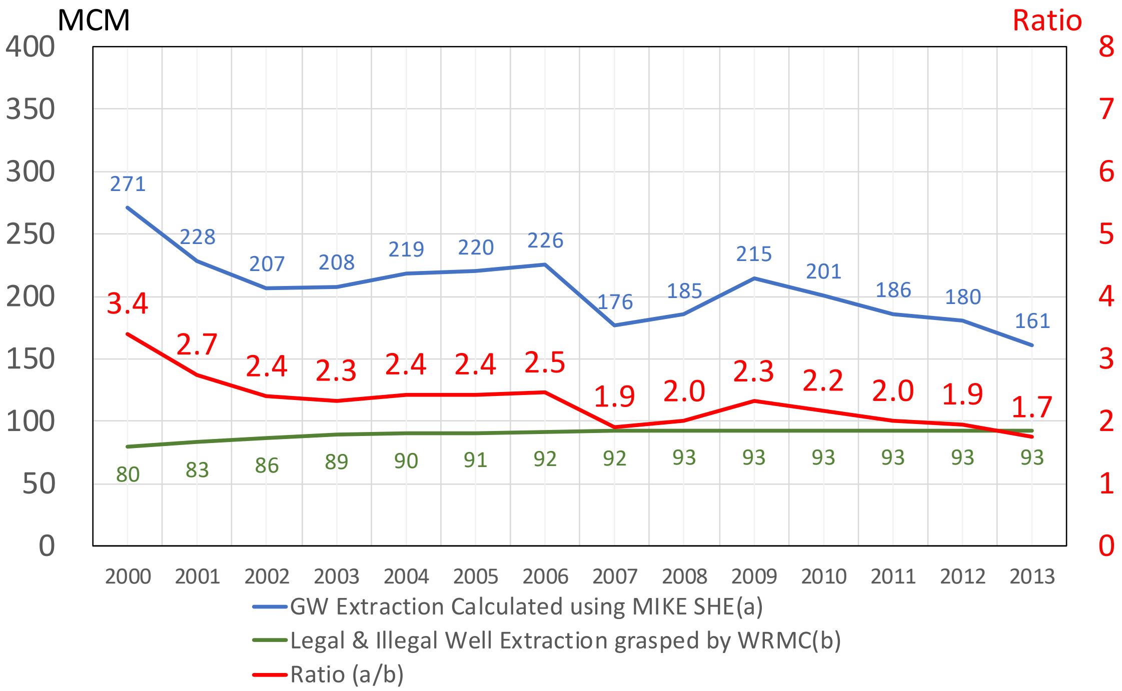
*Aggregation period is between September and August

Figure 5.8.2 Comparison of Groundwater Abstraction between Registered and Simulated in Miandoab Plain



*Aggregation period is between September and August

Figure 5.8.2 Comparison of Groundwater Abstraction between Registered and Simulated in Urmia Plain



*Aggregation period is between September to August

Figure 5.8.2 Comparison of Groundwater Abstraction between Registered and Simulated in Irrigated Area in Eastern Part of the Urmia Lake Basin

5.9 Calibration Result of Urmia Lake Water Level

With the river discharge calculated based on calibrated model, water level of Urmia Lake near observation point were compared between simulated and observed (see Figure 5.9.1). It was confirmed that water level of simulated result agrees with observed one, in which 0.96 of NSE (Nash-Sutcliff Efficiency) for daily basis was obtained. The hydrological cycle model in the Survey maintains the same high accuracy level as the model of the previous survey.

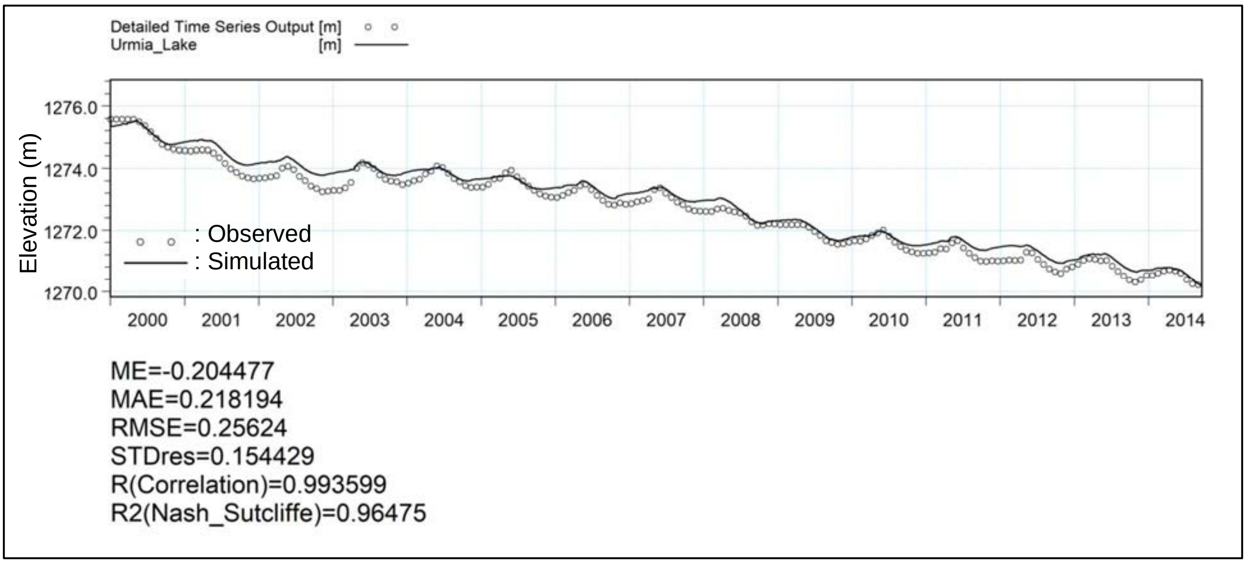


Figure 5.9.1 Comparison of Lake Water Level between Observed and Simulated

5.10 Summary of Calibration Result

Since the hydrological cycle model ensures the high accuracy as described below, it can be used for the analysis of the water balance and the examination of countermeasures planned by ULRP in the whole basin and each regional area as one of hydrological analysis engines of the Decision Support System (DSS).

(1) Daily Runoff Trend

As described in Subsection 5.6.5, the Nash-Sutcliffe efficiency (NSE) at the most downstream hydrological stations of major rivers during the calibration period are proving the high accuracy of the model in terms of simulated daily discharge hydrograph. The NSE of major rivers are is about 0.7 to 0.9 in the southern part, about 0.6 to 0.9 in the western part and about 0.6 in the eastern part. The NSE of verification period is relatively low in comparison with that of calibration period, which may be due to using the same land use data in the both periods. Compared with the hydrological cycle model established in the previous survey, the accuracy of the hydrological cycle model of the Survey was improved in the western and eastern area and maintain the same high level of accuracy in the southern area.

(2) Total Discharge Volume

As explained in Subsection 5.6.3, a high mutual similarity with the correlation coefficient 0.9 is obtained between observed and simulated yearly discharge. Therefore, it can be said that the model has a high applicability to be utilized for the evaluation of total inflow to the Urmia Lake. Additionally, in consideration of the high NSE in the major rivers, the simulated regional (i.e. southern, eastern and western parts) inflow proportion to the lake is coincident with that of observed discharge volume.

(3) Lake Water Level

Using the calculated river discharge by the calibrated model, the water level of Urmia Lake was simulated and the observed and simulated values were compared as shown in Section 5.9. The simulated daily water level showed an extremely high agreement with the observed water level as shown in Figure 5.9.1 which indicates the NSE of 0.96.

(4) Ground Water Level

The simulated groundwater level in the saturated aquifers at irrigation areas well-agreed to the observed one in terms of temporal behavior such as overall water level trends and seasonal fluctuations as shown in Subsection 5.6.6. If information of height of strainers of the monitoring wells are available, the simulation result of groundwater level will be improved in height.

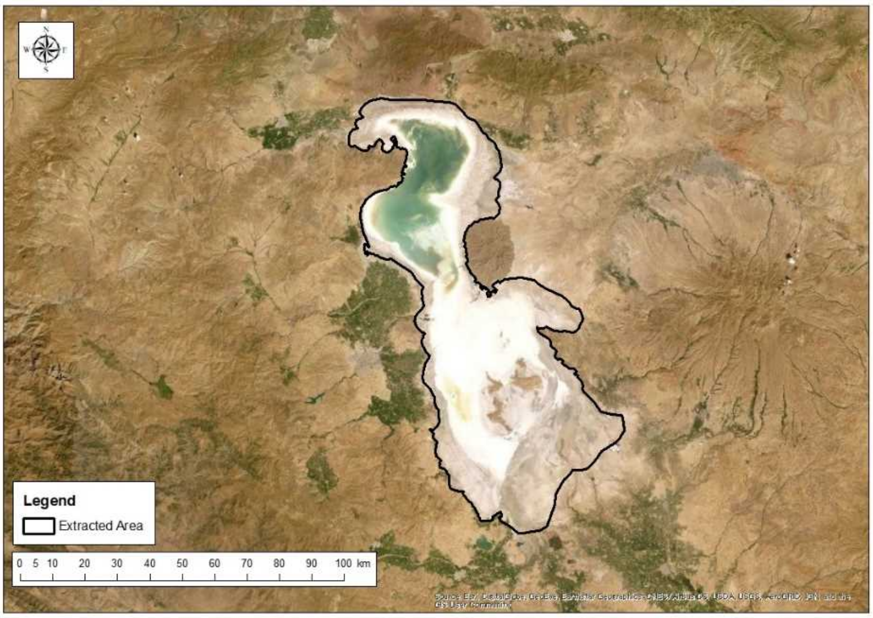
(5) Relationship of Among Three Elements of Water Balance

One of the formidable challenges in the calibration of the hydrological cycle model in the Survey is to grasp the irrigation water use amount (including unknown water intake). In the modeling, the time series of irrigation water use data was prepared based on the evapotranspiration through the METRIC method. Judging from the accuracy of daily river flow discharge, behavior of groundwater level and lake water level, the estimated evapotranspiration by the METRIC method and the setting of current irrigation efficiencies in the basin are also processed properly.

5.11 Water Balance of Urmia Lake

(1) The components of the water balance of Urmia Lake

The water balance of Urmia Lake was evaluated by extracting necessary elements for water balance. The target area for the water balance analysis of Urmia Lake is the administrative area of Urmia Lake as shown in Figure 5.11.1, where elements of water balance were extracted. The elements required to calculate the water balance are shown in Figure 5.11.2.



*Source: IWRM Co.

Figure 5.11.1 Lake Area where Water Balance Elements were Extracted

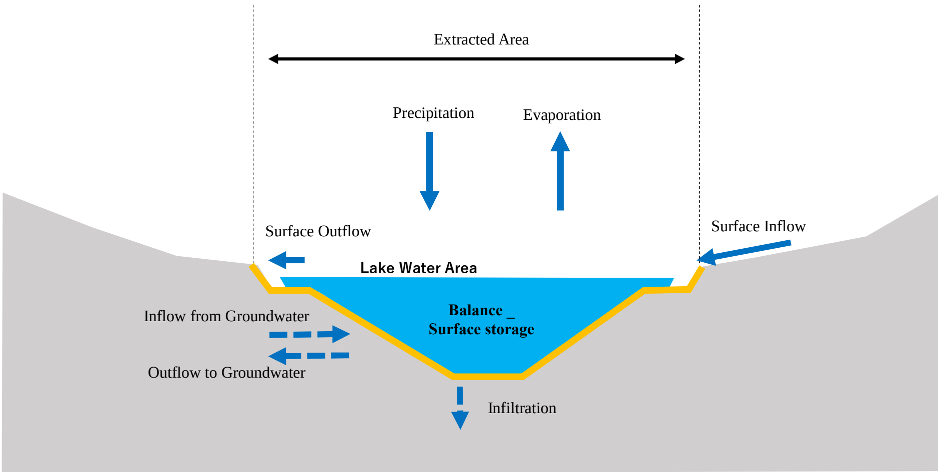


Figure 5.11.2 Scheme of Elements for Water Balance of Urmia Lake

(2) Annual total volume for each element

Although lake evaporation tends to decrease because of shrinking of water surface area year by year, lake evaporation largely contributes to loss of lake water. Besides, it was found that surface inflow to the lake has quite similar trend with seeing the scale of lake water balance (See Figure 5.11.3).

In hydrological years 2002, 2006 and 2009, the simulated lake water balance approaches zero (see Figure 5.11.3). In particular, in hydrological year 2002, the lake water is nearly balanced and the water level change from 2002 to 2003 was estimated to be just -0.05m (See Figure 5.11.4) which is suggesting the most stable condition of lake water level during the period. The water balance in 2002 is summarized in Table 5.11.2.

Referring to the simulated result in 2002, the right river inflow volume to sustain the Minimum Ecological Balance Level (1274.1m) is back calculated on the condition of two average rainfall (to the lake surface) in Table 5.11.2. To maintain the lake water level at the water level 1274.1m, the annual river inflow volume around 4,100 to 4,300 MCM is necessary in case of indicated annual rainfall to the lake surface, although annual average river inflow volume is simulated at about 1,900 MCM during the period from 2000 to 2013 (See surface inflow bars of Figure 5.11.3).

Table 5.11.1 Water Balance Calculation

Cases		Lake Water Level (m)	In-Volume (MCM) to the lake				Out-Volume from the lake*5 (MCM)
			Rainfall*2	River Flow*1	Groundwater*3	Total*4	
Simulation Result (Year 2002)		1273.9	1,583	4,055	14.1	5,652	5,674
Back-Calculated Water Balance	Rainfall=318mm (Year 2002 Level)	1274.1	1,611	4,132	14.1	5,757	5,757*6
	Rainfall=287mm (Average for 14 years)	1274.1	1,454	4,289	14.1	5,757	5,757*6

*1: Only river flow of in-volume is back-calculated to sustain the water level 1274.1m in case of out-volume 5,757 MCM.
*2: Rainfall of in-volume to the lake is estimated from rainfall depth on the lake surface.
*3: Ground water of in-volume is set as the same volume as 2002 simulation.
*4: Total in-volume of the back-calculated water balance is set as the same volume with the out-volume from the lake.
*5: Out-volume consists of 4 elements, namely, evaporation from the lake, infiltration, groundwater flow and overland flow.
*6: Multiplying the lake surface area by the unit evapotranspiration height gives the evapotranspiration volume in the case of back-calculated water balance (4,325km^2 × 1.1MCM/km^2=4,742MCM)). The unit evaporation height is estimated from 2002 simulation result (4,659MCM/4,249km^2=1.1MCM/km^2). The total volume of other elements is estimated at 1,015MCM which is the same volume with the 2002 simulation.

Additionally, the total volume of minus elements such as the evaporation and infiltration in Figure 5.11.4 shows a virtually constant volume 4,000MCM during recent 7 years, even though the total volume of plus elements keeps less than that of minus elements. This phenomenon proves that the annual inflow volume with more than about 4,000 MCM is essential in order to start to attain increment tendency of the lake water level.

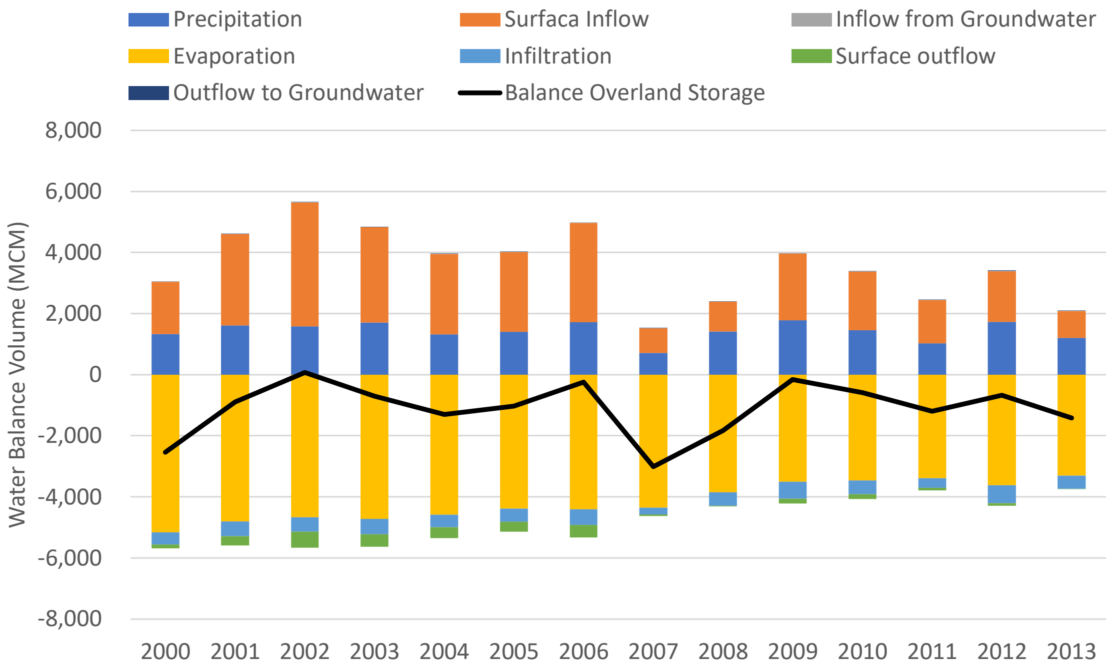
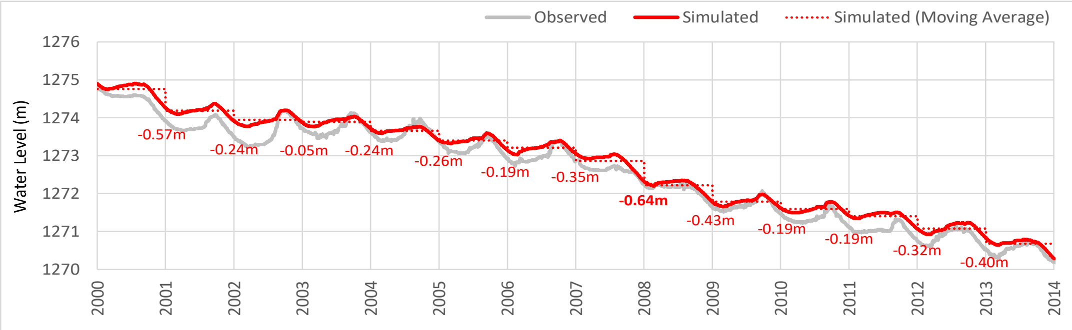


Figure 5.11.3 Water Balance for the Urmia Lake (unit: MCM)



*Aggregation period is between September and August

Figure 5.11.4 The Urmia Lake Water Level and Change of the Water Level(unit: MCM)

Table 5.11.2 Extracted Elements for Water Balance (unit: MCM)

Unit: MCM

	In_ Precipitation	In_ Surface Inflow	In_ Inflow from Groundwater	In_ Subtotal	Out_ Evaporation	Out_ Infiltration	Out_ Surface outflow	Out_ Outflow to Groundwater	Out_ Subtotal	Balance_ Overland Storage
2000	1,331	1,707	21	**3,058**	5,156	408	117	7	**5,688**	**-2,538**
2001	1,616	2,983	16	**4,614**	4,797	487	303	8	**5,595**	**-891**
2002	1,583	4,055	14	**5,652**	4,659	473	534	8	**5,674**	**75**
2003	1,702	3,124	13	**4,839**	4,719	510	410	8	**5,646**	**-703**
2004	1,325	2,626	12	**3,963**	4,590	398	362	8	**5,358**	**-1,306**
2005	1,404	2,610	11	**4,025**	4,387	422	328	9	**5,146**	**-1,025**
2006	1,720	3,249	12	**4,981**	4,397	521	408	9	**5,336**	**-243**
2007	712	810	11	**1,533**	4,349	223	46	9	**4,628**	**-3,007**
2008	1,411	973	11	**2,395**	3,845	442	24	10	**4,321**	**-1,823**
2009	1,781	2,184	11	**3,976**	3,505	553	165	10	**4,233**	**-163**
2010	1,462	1,912	11	**3,385**	3,463	448	152	10	**4,073**	**-587**
2011	1,024	1,416	11	**2,451**	3,386	322	77	10	**3,795**	**-1,194**
2012	1,731	1,659	11	**3,401**	3,625	582	83	10	**4,300**	**-670**
2013	1,199	883	11	**2,092**	3,303	438	9	10	**3,760**	**-1,416**
2000-2004	1,511	2,899	15	**4,425**	4,784	455	345	8	**5,592**	**-1,072**
2005-2009	1,405	1,965	11	**3,382**	4,097	432	194	9	**4,733**	**-1,252**
2010-2013	1,354	1,468	11	**2,832**	3,444	447	80	10	**3,982**	**-967**

*Aggregation period is between September and August

(3) Water balance of the entire basin

The elements of water balance for the entire basin is shown in Figure 5.11.5 and summarized in Table 5.11.3 in order to understand the behavior of water balance.

- The evapotranspiration from irrigated areas has not changed significantly over the years, and evapotranspiration from the basin except irrigated areas also have a similar behavior. (See top of Figure 5.11.5). The fact indicates that the irrigation water intake amount from rivers have not been reduced.
- As shown in the center figure in Figure 5.11.5, the river discharge into the lake in 2002 is the maximum amount among 14 years and at that time the decease of lake water level is negligibly small (see Figure 5.11.4). The irrigation water use much affects the total discharge volume into the lake and occupies 50 to 90% of river flow discharge during a decade.
- As shown in the bottom figure in Figure 5.11.5, in 2007 the irrigation water is much extracted from groundwater in comparison with other years due to the smallest precipitation volume

during the simulation period and shortage of river water. The fact may prove that farmers extract the groundwater more than permission amount in case of drying up the river water in the basin.

- Although the peroration amount overcomes the irrigation water on average for 14 years with varying the difference between them from year to year as shown in Table 5.11.3, the groundwater balance water has a tendency to decrease year by year. The tendency of decrees of groundwater level is also detected in the monitoring wells at the irrigation areas. Therefore, it can be said that more peroration water should be poured into the aquifers to prevent them from heading in the direction of unbalance in considering the various percolation water movement under the ground.

Figure 5.11.5 Each Element of Water Balance for the Urmia Lake Basin (unit: MCM)

Table 5.11.3 Extracted Elements for Water Balance (unit: MCM)

	(1) Preciptation	(2) ET from Whole Area	(3) ET from Irrigated Area	(4) ET (Excluding Irrigated Area)	(5) River Runoff	(6) River Discharge into Lake	(7) Irrigation Demand	(8) Irrigation from GW	(9) Irrigation from river	(10) Base Flow	(11) GW Percolation (Whole Area)	(12) GW Balance (Whole Area)
2000	14,262	12,274	2,613	9,661	2,842	1,601	8,280	5,697	2,583	2,904	4,447	-4,154
2001	20,202	12,908	2,498	10,411	5,368	2,607	7,812	5,112	2,700	2,486	6,214	-1,385
2002	20,869	12,771	2,632	10,139	7,136	3,804	8,287	5,360	2,927	2,262	5,865	-1,758
2003	20,870	13,592	2,578	11,013	5,926	2,697	8,065	5,230	2,834	2,223	6,449	-1,004
2004	19,190	14,495	2,857	11,639	5,665	2,388	9,023	5,707	3,316	2,107	4,898	-2,917
2005	18,578	12,684	2,740	9,944	5,584	2,316	8,560	5,724	2,836	1,963	5,748	-1,940
2006	22,534	13,423	2,791	10,631	7,047	2,972	8,756	5,643	3,113	1,923	7,631	64
2007	10,536	12,275	3,319	8,956	2,035	648	10,334	6,514	3,820	1,827	3,175	-5,165
2008	17,486	12,812	3,161	9,651	3,772	908	9,984	6,350	3,634	1,560	7,222	-688
2009	21,982	11,873	2,728	9,145	6,662	2,091	8,565	5,714	2,850	1,566	8,722	1,441
2010	17,039	12,366	2,606	9,760	4,603	1,668	8,133	5,434	2,699	1,575	5,372	-1,636
2011	15,551	12,311	2,658	9,653	3,681	1,310	8,271	5,391	2,880	1,572	5,239	-1,724
2012	17,720	13,300	2,958	10,342	3,733	1,302	9,214	5,816	3,398	1,546	6,496	-865
2013	14,614	12,374	2,869	9,504	2,910	701	8,942	5,550	3,392	1,472	5,246	-1,777
2000-2004	19,078	13,208	2,636	10,573	5,387	2,077	8,293	5,421	2,872	2,397	5,574	-2,244
2005-2009	18,223	12,613	2,948	9,665	5,020	1,354	9,240	5,989	3,251	1,768	6,500	-1,257
2010-2013	16,231	12,588	2,773	9,815	3,732	878	8,640	5,548	3,092	1,541	5,588	-1,501
2000-2013	17,960	12,818	2,786	10,032	4,783	1,476	8,730	5,660	3,070	1,928	5,909	-1,679

(4) Agricultural water use

Figure 5.11.7 shows comparison of annual evapotranspiration and precipitation at the irrigation areas such as Miandoab (southern part), Urmia (western part) and Tazeh Kand (eastern part), respectively. The evapotranspiration in the irrigation areas means that the irrigation water was consumed in the area.

- Overall, the variation in agricultural water use in each irrigation area is not so significant during the simulation period, and there is no so much regional difference. In the southern area, the amount of agricultural water is slightly increasing.
- In the driest year 2007 during the simulation period, the evapotranspiration was the highest in each region and agricultural water use was also high as shown in Figure 5.11.7. Based on the figures, it might result from that the farmers use reserved water in the previous year and conduct excess water extraction from the groundwater.

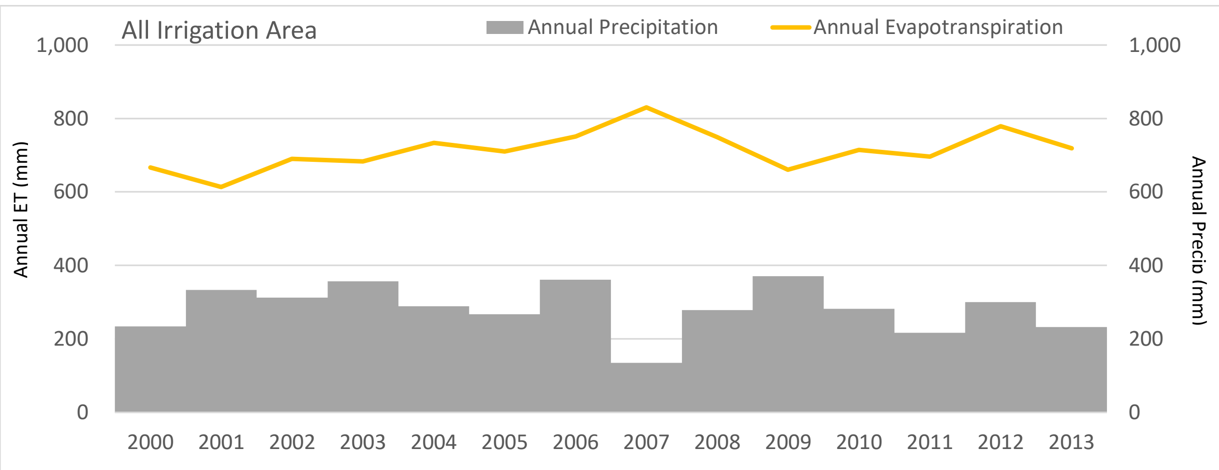


Figure 5.11.6 Annual precipitation and Evapotranspiration for all irrigation area

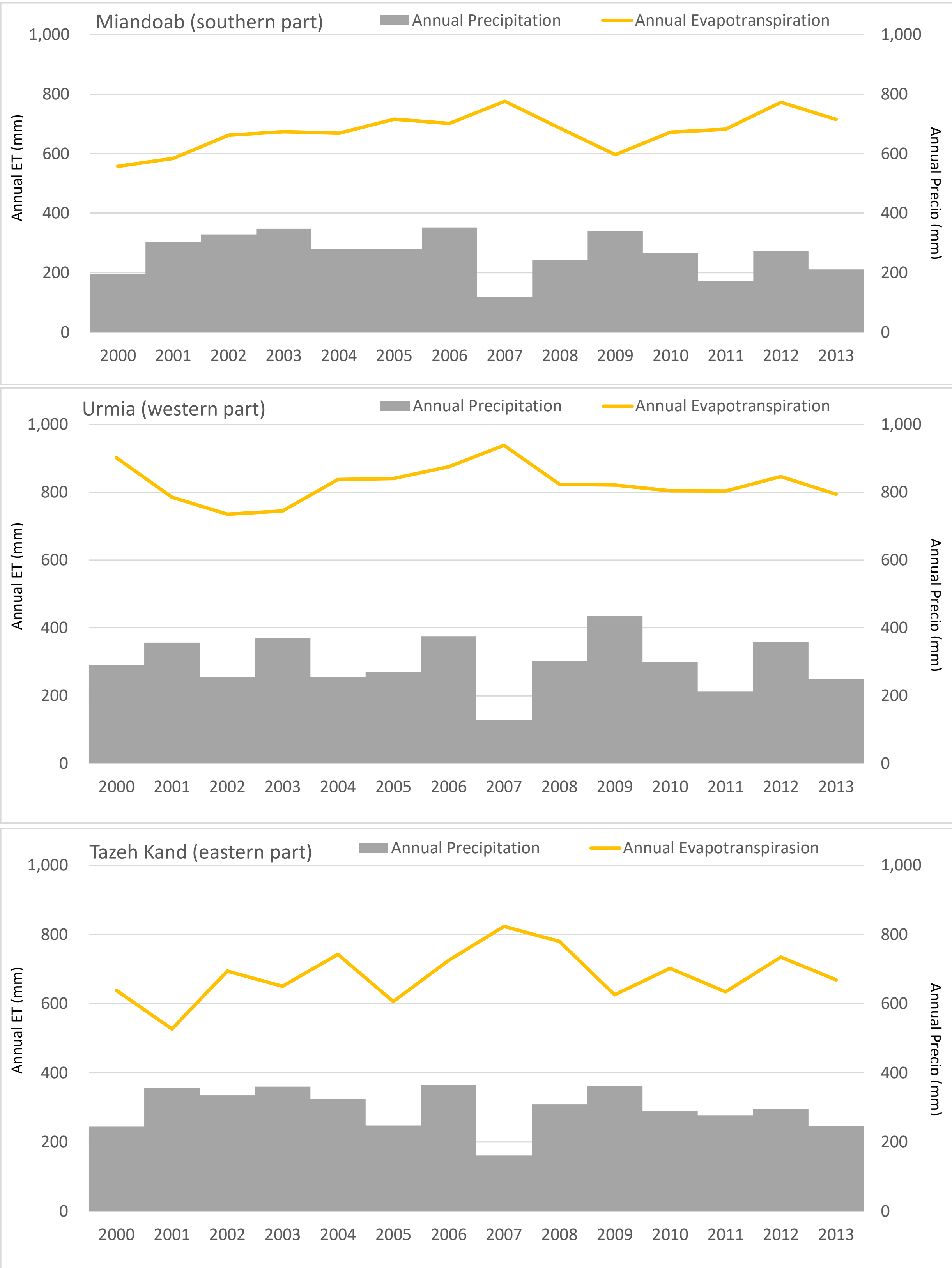


Figure 5.11.7 Annual precipitation and Evapotranspiration for each irrigation area

5.12 Improvement of the Model in Comparison with the Previous Model

The model established in the previous survey (the previous model) is improved in this Survey through the calibration and verification of the current model described above in this chapter. Table 5.12.1 shows NSE of discharge hydrographs in the representative hydrological stations (See Figure 5.12.1) in major rivers at Nazam Abad (Zarineh Rud), Abajalu Sofla (Nazlo Chay) and Akhoola (Aji Chay).

In particular, the western area of model is much improved in comparison with the other areas. The southern area has a high NSE value in both the previous and current model. The eastern area is improved slightly. Overall, the previous model is improved in terms of the higher NSE values than that of the previous model in the whole basin.

Table 5.12.1 Extracted Elements for Water Balance (unit: MCM)

River Basin	Southern Area		Western Area		Eastern Area	
Model	Previous	Current	Previous	Current	Previous	Current
NSE	0.89	0.82	0.40	0.71	0.48	0.50

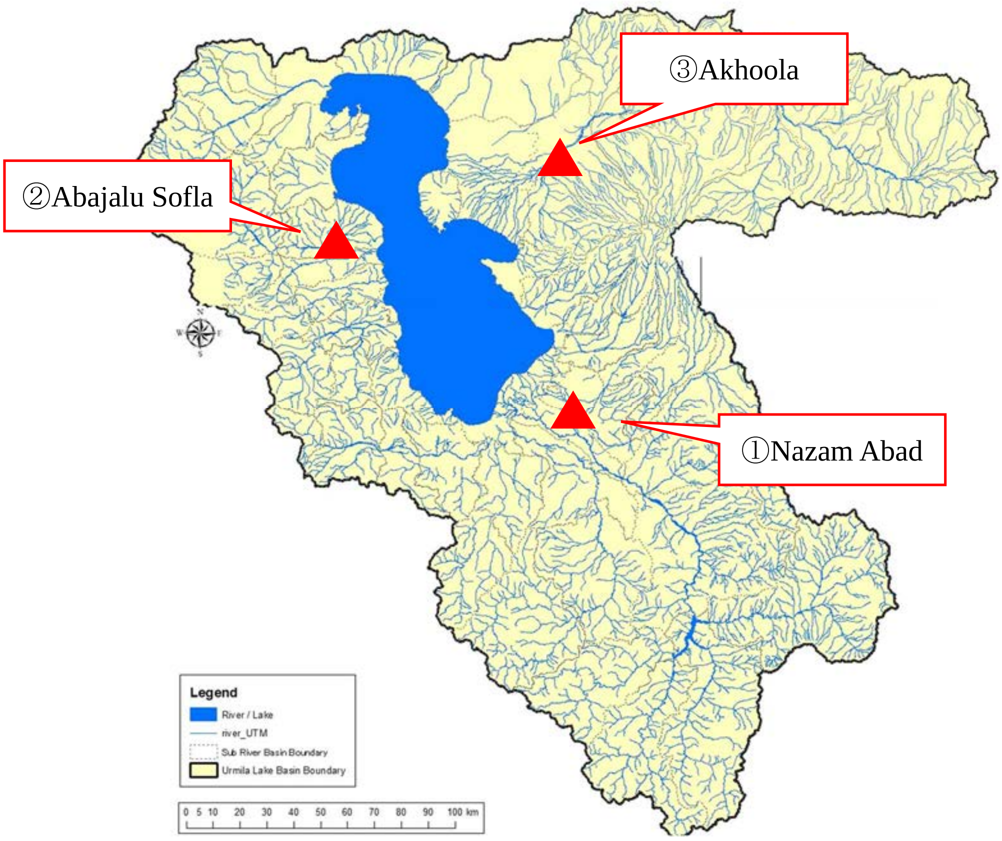


Figure 5.12.1 Location of Hydrological Stations

CHAPTER 6 SIMULATION RUN BASED ON THE SCENARIO

6.1 Target Scenario for the Simulation of Hydrological Cycle Model

In accordance with the discussions between ULRP and the Survey Team, conditions of scenario simulation were determined considering currently undertaken countermeasures and ULRP's plan.

6.1.1 Basic Conditions of Scenario Simulation

Table 6.1.1 shows conditions for scenario simulation. The simulation was executed for 14 years simulation period to confirm the effects of "with" and "without" proposed countermeasures on the presumption that the hydro-met conditions will continue in the same tendency as the period from 2000 to 2014.

The each scenario consist of some of five countermeasures which are summarized in the description of Table 6.1.1 (see (a) to (e) of countermeasures proposed by ULRP) and described in detail in the Subsection 6.1.2.

Table 6.1.1 Basic Conditions for Scenario Simulation

<table>
<tr><th></th><th>Item</th><th>Description</th></tr>
<tr><td>1</td><td>Simulation period</td><td>14 years (based on the observed data of September 2000 –December 2014)</td></tr>
<tr><td>2</td><td>Meteorological Conditions</td><td>Observed data during the above-mentioned simulation period is used as boundary conditions.</td></tr>
<tr><td>3</td><td>Countermeasures proposed by ULRP</td><td>The five countermeasures are proposed by ULRP as shown the table below. These countermeasures are components the components of boundary conditions in the scenario simulation. The details of countermeasures are described in Subsection 6.1.2.
<table>
<tr><th>No</th><th>Item</th><th>Approach to Modelling</th></tr>
<tr><td>(a)</td><td>Improvement of Irrigation Efficiency</td><td>➢ Irrigation efficiency is improved stepwisely (from 0.3 to 0.6, 0.7 then 0.85).
➢ Location: Irrigated area in lowland around Urmia Lake
*See Table 6.1.2 of Subsection 6.1.2</td></tr>
<tr><td>(b)</td><td>Dredging channel between the lowest hydrological station and lake (buffer zone evaluation)</td><td>➢ In total, 27 km of channel is dredged for decreasing water loss by flooding and evaporation before reaching Urmia Lake. Out of total length, outlet is moved to 8.2 km downstream in 1D hydraulic model.
*See Figure 6.1.1 of Subsection 6.1.2</td></tr>
<tr><td>(c)</td><td>Inter-basin transfer</td><td>➢ 623 MCM per year of water is input into the model as inter-basin transfer from Class River Basin (Zaab River Basin) to Gedar Chay. Inflow pattern is evenly divided by month during snowmelt season (March - June).
*See (3) of Subsection 6.1.2</td></tr>
<tr><td>(d)</td><td>Return flow of treated wastewater to lake</td><td>➢ 2.4 MCM per month of treated water from Urmia City is input into Rose Chay River, 5.7 km upstream from Urmia Lake.
➢ 64 MCM per year of treated water from Tabriz City is input into Aji Chay River, upstream Akhola hydrological station.
*See (4) of Subsection 6.1.2</td></tr>
<tr><td>(e)</td><td>Improvement / Change of Dam operation</td><td>➢ 25.12 MCM per year of water is released from Derik Chay Dam, which is converted into daily basis based on existing dam operation pattern.
*See Figure 6.1.5 of Subsection 6.1.2</td></tr>
</table></td></tr>
<tr><td>4</td><td>The Number of Simulation Cases</td><td>Eight scenarios are prepared with ULRP to confirm the effects of combination of countermeasures and utilize the results for future decision making (See Subsection 6.1.3)</td></tr>
</table>

6.1.2 Description of Countermeasures

(1) Improvement of Irrigation Efficiency

Irrigation efficiency (IE) is calculated by multiplying two efficiencies, Conveyance Efficiency (EC) with Field Application Efficiency (EA). These three types are defined as follows:

- **Conveyance Efficiency (EC)** which represents the efficiency of water transport in canals.
- **Field Application Efficiency (EA)** which represents the efficiency of water application in the field.
- **Irrigation Efficiency (IE)** = EC･EA

FAO defines indicative values of conveyance efficiency and field application efficiency with channel types and irrigation types, as described below.

Table 7. INDICATIVE VALUES OF THE CONVEYANCE EFFICIENCY (ec) FOR ADEQUATELY MAINTAINED CANALS

	Earthen canals			Lined canals
Soil type	**Sand**	**Loam**	**Clay**	
Canal length				
Long (> 2000m)	60%	70%	80%	95%
Medium (200-2000m)	70%	75%	85%	95%
Short (< 200m)	80%	85%	90%	95%

Table 8. INDICATIVE VALUES OF THE FIELD APPLICATION EFFICIENCY (ea)

Irrigation methods	**Field application efficiency**
Surface irrigation (border, furrow, basin)	60%
Sprinkler irrigation	75%
Drip irrigation	90%

*Source: FAO Training Manual no.4 (http://www.fao.org/3/t7202e/t7202e00.htm#Contents)

ULRP’s plan on improvement of irrigation efficiency is to modernize the current traditional irrigation system with IE ranges approximately from 0.3 to 0.4, which consists of earth channel and surface irrigation. In scenario simulation, irrigation efficiency was improved stepwisely by applying different types of channel and field application along the FAO’s definition. In scenario simulation, improved irrigation efficiency described in Table 6.1.2 was evenly applied to irrigated area around Urmia Lake.

Table 6.1.2 Irrigation Efficiencies with Improvement of Irrigation Method

No	Irrigation Channel (EC)	Irrigation Type (EA)	Irrigation Efficiency (IE)
1	Lined channel (0.95)	Surface Irrigation (0.60)	0.6
2	Lined channel (0.95)	Sprinkler Irrigation (0.75)	0.7
3	Lined channel (0.95)	Drip Irrigation (0.90)	0.85

*EC: Conveyance efficiency, EA: Field application efficiency

<u>Necessity of Long-Term Vision for Improvement of IE</u>

Improving the irrigation efficiency of whole irrigated area requires a lot of cost and time. Specifically, as summarized in Table 6.1.3, Up to IE of 0.6 costs USD17 million and IE of 0.7 and 0.85 is USD66 million. For reference, the MOJA as the implementing agency for development projects of improvement of IE have invested so far about 1,782,550 million rials (USD 42 million) for a recent decade, especially, in southern area. Therefore, it will take a considerable time and cost to improve the irrigation efficiency without the preparation of special budget.

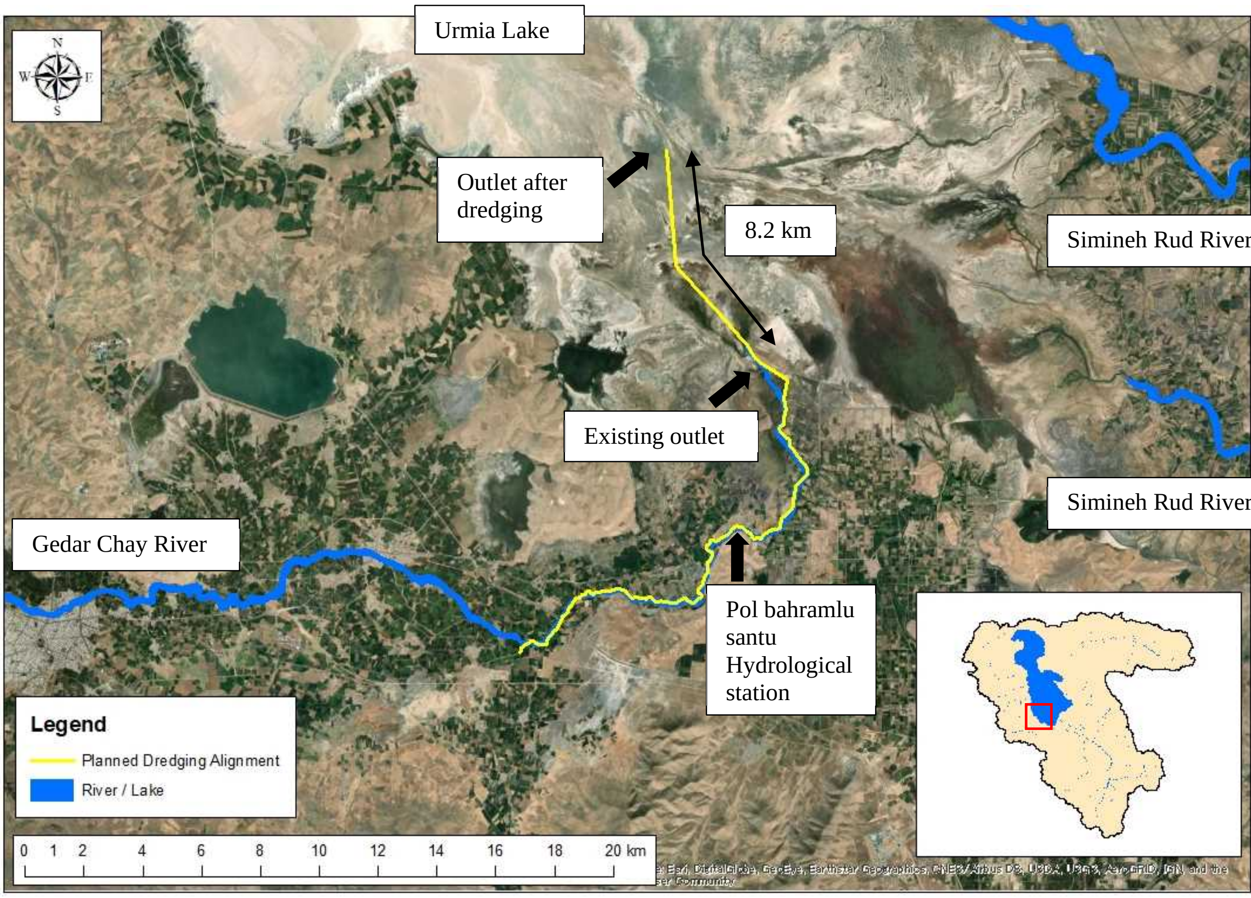
Table 6.1.3 Cost of Improvement of Irrigation Efficiency for All Irrigation Areas

No.	Improvement Level (IE rate)	Existing Irrigation Area (ha)	Project Cost per 1ha (Rials)					Project Cost	
			Lined Channel	SuI*	SpI*	DI*	Total	Million Rial	Million USD
1	0.6	4,245	150	20			170	721,650	17
2	0.7	4,245	150	-	500	-	650	2,759,250	66
3	0.8	4,245	150	-	-	500	650	2,759,250	66

* SuI:Surface Irrigation, SpI: Sprinkler Irrigation, DI: Drip Irrigation

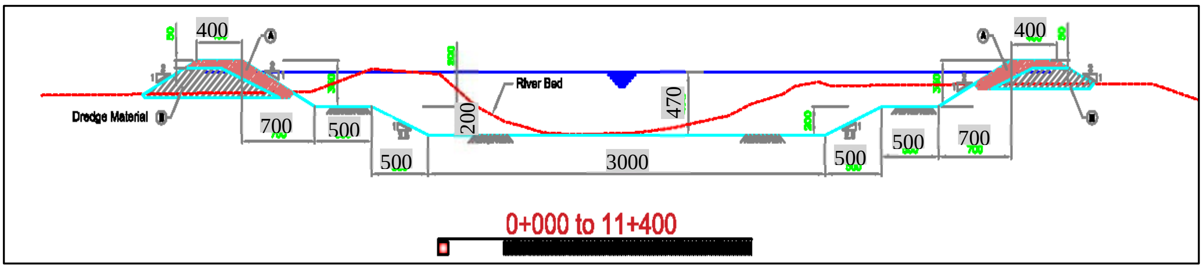
(2) Dredging Channel between the Lowest Hydrological Station and Lake

ULRP has a plan to dredge existing channels of rivers into Urmia Lake, in the context that huge water loss occurs due to flooding and evaporation before river water reaches the lake. Out of these rivers, ULRP designated Gedar Chay River with 27 km of total dredging channel length as one of countermeasure of the scenario simulation. In the model, dredging river channel was modeled by enlarging the discharge capacity near outlet, which enables more water conveyed closer to water area of Urmia Lake.



*Location of dredging channel is provided by ULRP

Figure 6.1.1 Planned Dredging Channel on Gedar Chay River



*Source: ULRP, *Unit: cm

Figure 6.1.2 Planned River Cross Section after Dredging

(3) Inter-basin Transfer

As transboundary diversion channel, ULRP has been implementing the construction works from 2018 to transfer water from Class Basin (Zaab River Basin) with 623 MCM of annual discharge volume. The construction will be completed in 2021. Since there is no information on the operation of inter-basin transfer considering seasonal variation of runoff, operation pattern was assumed by the Survey Team and ULRP as shown in Table 6.1.4, which was obtained by evenly dividing water amount to be conveyed with four months of snowmelt season (March – June). According to ULRP, discharge flow for inter-basin transfer was inflow into the specified location shown in Figure 6.1.3 and deemed to be conveyed through existing channel into Gedar Chay River. In scenario simulation, discharge with the assumed pattern by JET and ULRP is input into river channel at 20 km from outlet of Gedar Chay River.

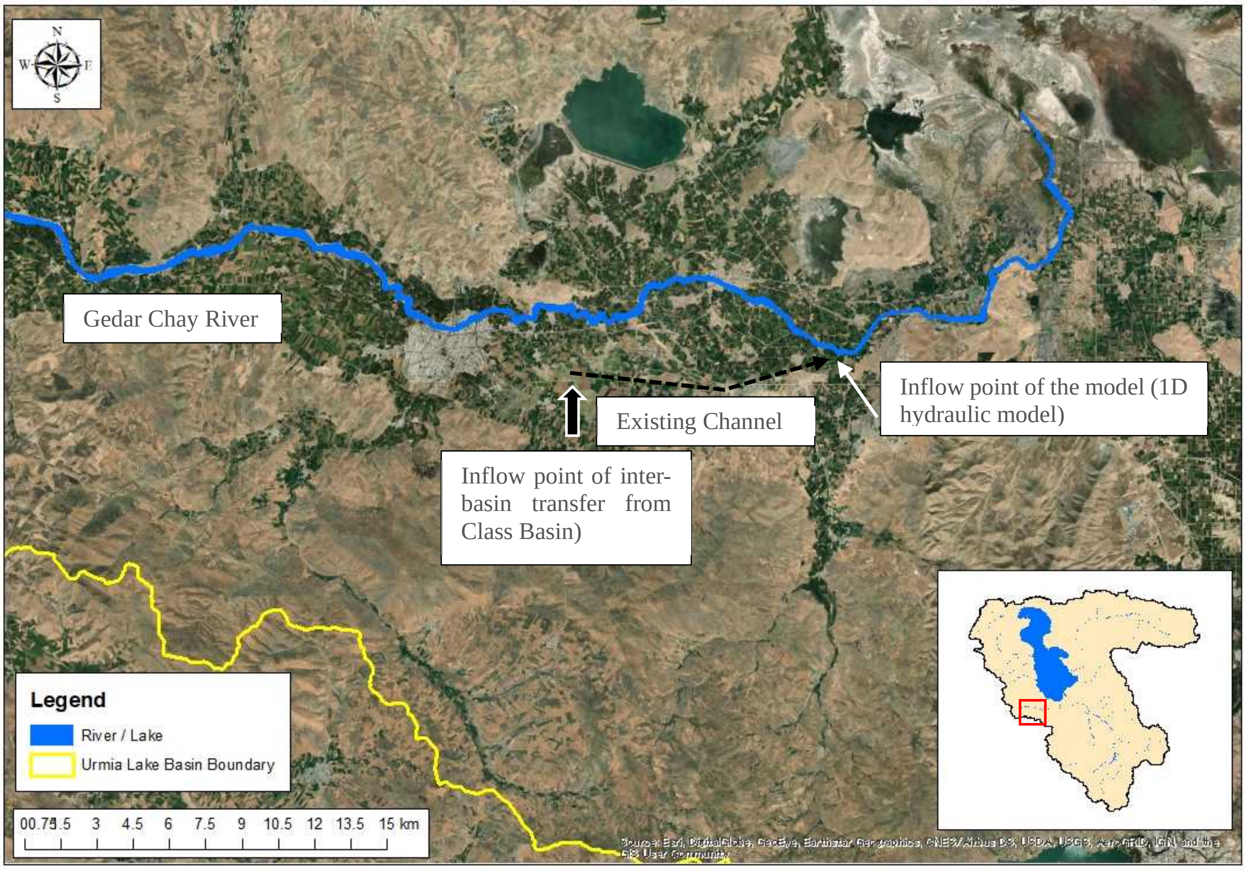


Figure 6.1.3 Location of Inflow Point of Inter-Basin Transfer from Class River Basin

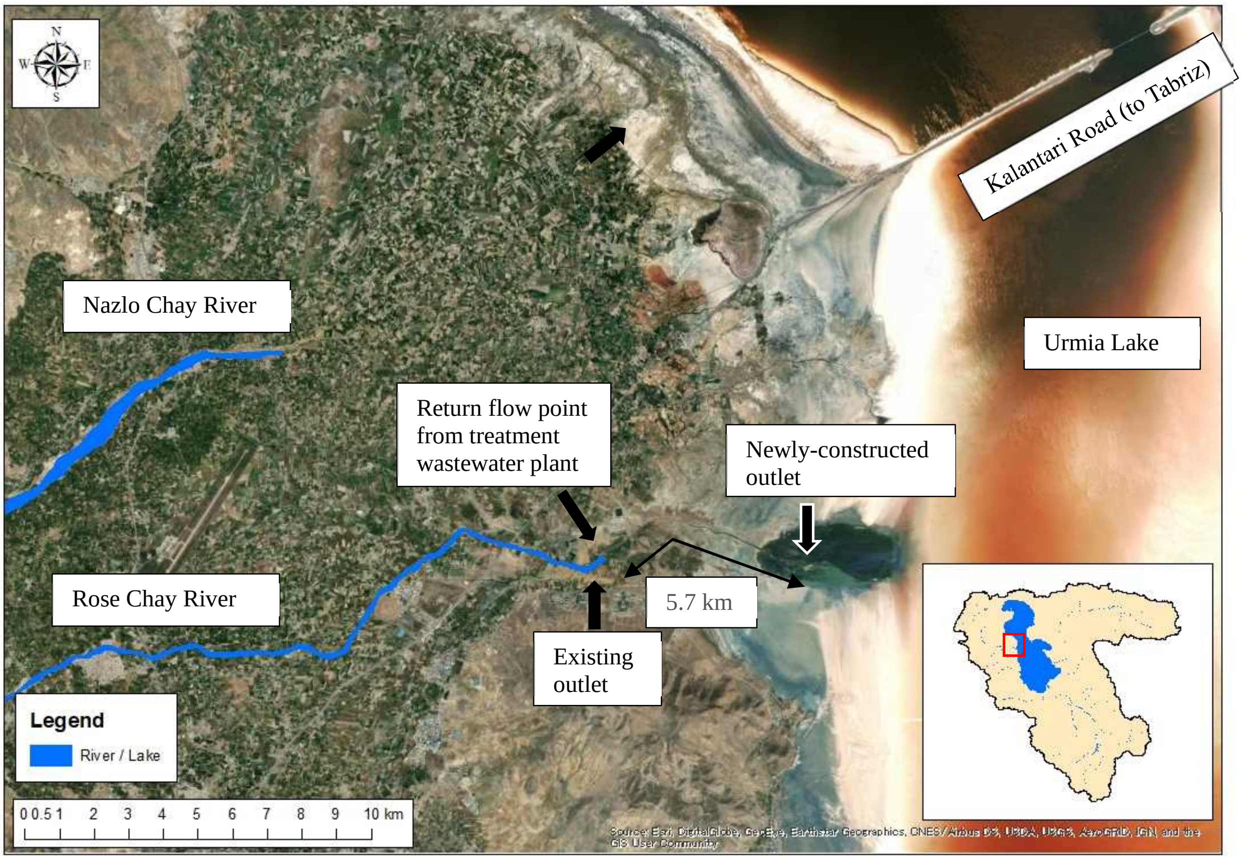
Table 6.1.4 Assumed Pattern of Daily Discharge of Inter-Basin Transfer

March	April	May	June	Total
59 m^3/s (155.75 MCM)	59 m^3/s (155.75 MCM)	59 m^3/s (155.75 MCM)	59 m^3/s (155.75 MCM)	623 MCM

(4) Return Flow of Treated Wastewater to River / Urmia Lake

(a) Return of Treated Wastewater from Urmia City

According to ULRP, 2.4 MCM (equivalent to 0.08 m^3/s for daily-basis) of treated wastewater from Urmia City was released every month into Rose Chay River, whose location of return flow is 5.7 km from Urmia Lake (see Figure 6.1.4). In scenario simulation, 0.08 m^3/s of return flow is directly added to the modeled river channel. Outlet of Rose Chay River is also extended toward Urmia Lake.



*Location of return flow point is provided by ULRP

Figure 6.1.4 Location of Return Point from Treatment Wastewater Plant

(b) Return of Treated Wastewater from Tabriz City

Return flow of treated wastewater from Tabriz City into Aji Chay was considered in the scenario simulation by adding the water amount 64 MCM per year at Akhola hydrological station upstream of Aji Chay River.

Table 6.1.5 Modelled Treated Wastewater Inflow

Added to	Amount
Rose Chay River from Urmia City	288MCM per year (2.4MCM per month)
Aji Chay River from Tabriz City (upstream Akhola hydrological station)	64 MCM per year

*Source: ULRP

(5) Improvement/Change of Dam Operation

Scenarios regarding change in dam operation proposed by ULRP are: (1) all water stored in Shahid Madani Dam (i.e. Vanyar Dam, the location of dam is indicated in the Point No.4 of Figure 2.4.1) on the Aji Chay River is utilized for Urmia Lake restoration; and (2) released discharge to Urmia Lake from Derik Dam on Derik Chay River (branch of Zola Chay River) is doubled. As of March 2020, because the concrete dam operation rule has not decided by relational organization, the doubled discharge was added to the inflow point of Derik Dam on Derik Chay River in the modelled river channel (see Figure 6.1.5).

Based on the released discharge record from Derik Chay River during the period (2012-2016), water release is mainly conducted from May to November as shown in Figure 6.1.6, and average of annual released discharge is 12.56 MCM (see Table 6.1.6). In the scenario simulation, the doubled released water amount set 25.12 MCM . Monthly discharge volume in the scenario simulation is determined by dividing the annual volume with the monthly ratio, which was obtained based on existing dam operation. Prepared daily discharge pattern of Derik Chay Dam is as shown in Figure 6.1.7.

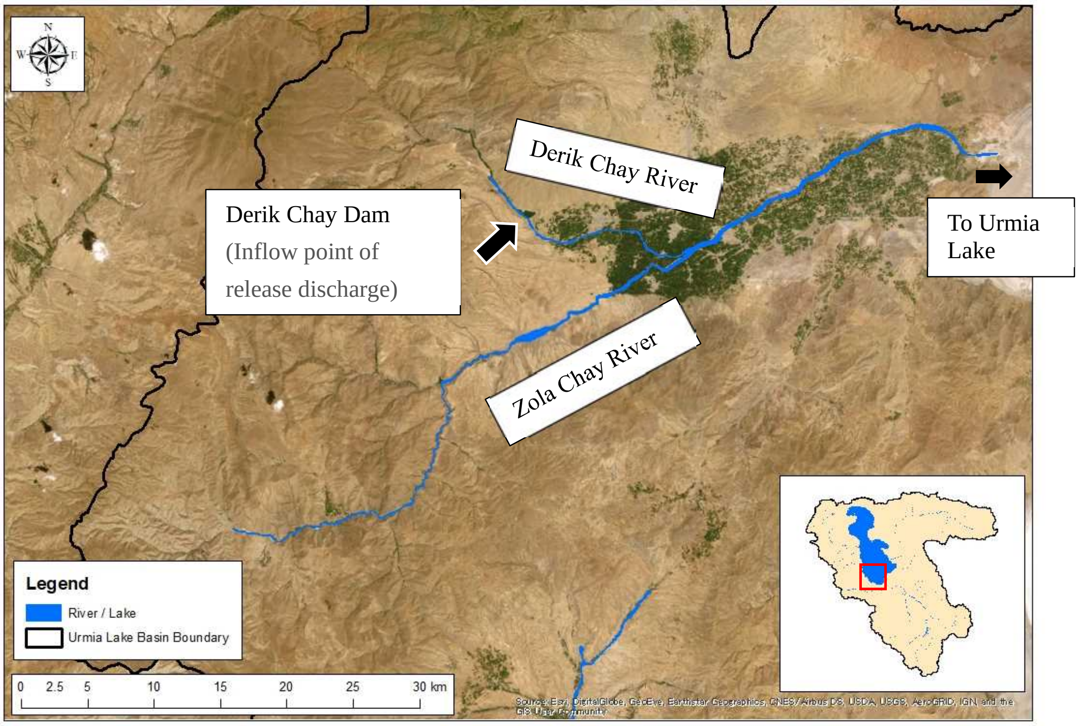
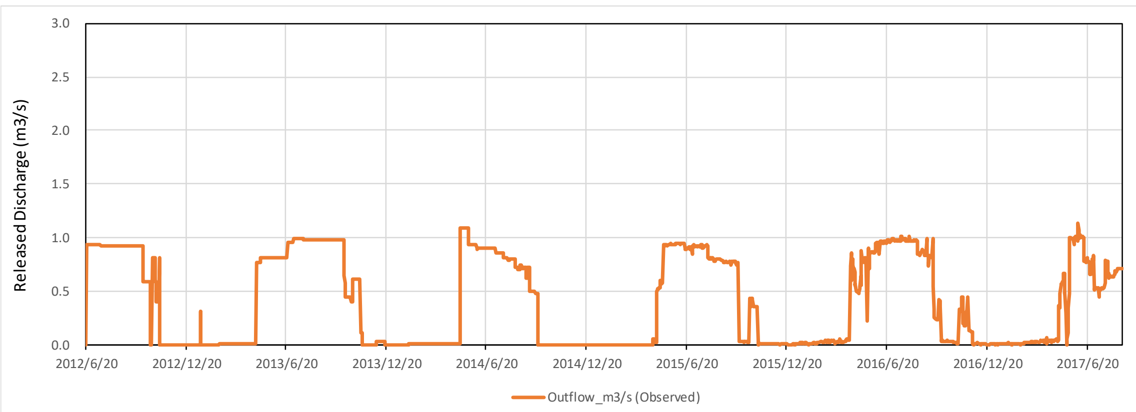


Figure 6.1.5 Location of Derik Chay Dam



*Source: ULRP

Figure 6.1.6 Observed Discharge Released from Derik Chay Dam

Table 6.1.6 Annual Discharge Volume for Urmia Lake in Derik Chay Dam between Observed and Prepared for Scenario Simulation

Year	2012	2013	2014	2015	2016*	Average (2012-2015*)	Annual Discharge Volume for Scenario Simulation
Annual Discharge Volume (MCM)	14.1	12.8	10.9	12.5	8.1	12.56	25.12

*Aggregation period is between September and next year's September.
*Data of dam operation record exists until 2016 August, therefore, the data of annual discharge volume in 2016 is omitted from the period for calculating average volume.

Table 6.1.7 Monthly Ratio and discharge Released from Derik Chay Dam in the Scenario Simulation

Month	Jan	Feb	Mar	Apr	May	Jun	
Monthly ratio of released water in scenario simulation	0.00	0.00	0.00	0.03	0.18	0.20	
Monthly released discharge volume in scenario simulation (MCM)	0.00	0.00	0.00	0.70	4.59	5.06	
Month	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Monthly ratio of released water in scenario simulation	0.19	0.17	0.14	0.06	0.03	0.00	1.0
Monthly released discharge volume in scenario simulation (MCM)	4.82	4.35	3.62	1.45	0.48	0.05	25.12

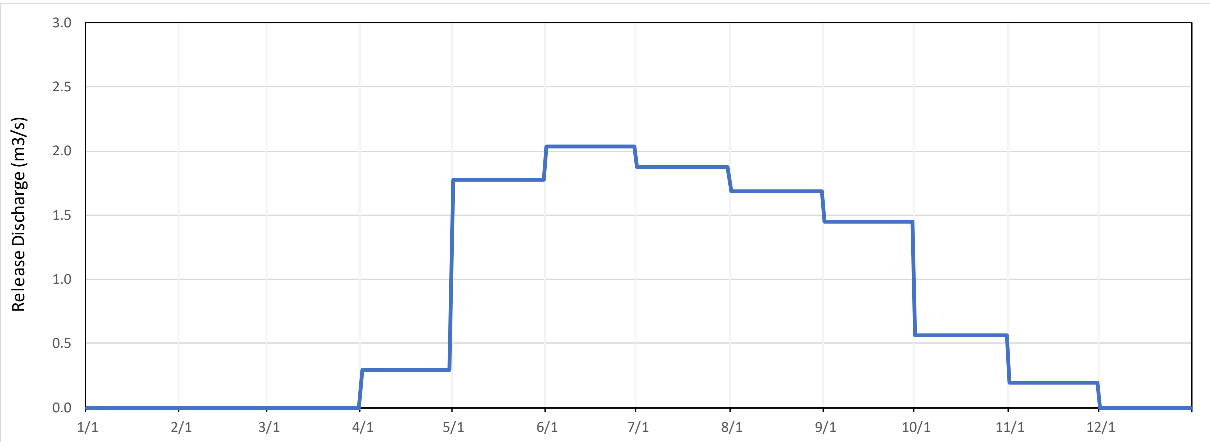


Figure 6.1.7 Discharge Pattern of Derik Chay Dam in the Scenario Simulation

6.1.3 Location (Target Rivers) of Countermeasures

Table 6.1.8 summarizes the location (target rivers) of the countermeasures proposed by ULRP. While irrigation efficiency improvement was applied to irrigated area along most of the rivers, other countermeasures were currently applied only for 4 rivers: Zola Chay, Gedar Chay, Aji Chay and Rose Chay Rivers.

Table 6.1.8 Location (Target Rivers) of the Countermeasures

Counter-measures / Rivers	Improvement of Irrigation Eficiency in lowland area	Dredging Channel (ref. 6.1.1(2)(b))	Interbrain Transfer (ref. 6.1.1(2)(c))	Return flow of treated wastewater (ref. 6.1.1(2)(d))	Improvement/Change of Dam Operation (ref. 6.1.1(2)(e))
Zola Chay	●	-	-	-	●
Nazlu Chay	●	-	-	-	-
Rose Chay	●	-	-	●	-
Shahr Chay	●	-	-	-	-
Baranduz Chay	●	-	-	-	-
Gedar Chay	●	●	●	-	-
Mahabad Chay	●	-	-	-	-
Simuneh Rud	●	-	-	-	-
Zarineh Rud	●	-	-	-	-
Mardugh Chay	●	-	-	-	-
Lirang Chay	●	-	-	-	-
Sufi Chay	●	-	-	-	-
Ghaleh Chay	●	-	-	-	-
Azar Shahr Chay	●	-	-	-	-
Aji Chay	●	-	-	●	-
Varkash Chay	-	-	-	-	-

6.1.4 Combination of Countermeasures for Scenario Simulation

In order to evaluate the countermeasures, eight cases of scenario simulation were conducted with combination of current-proposed countermeasures, as shown in Table 6.1.9. The cases from the first to forth were simulated to confirm the effectiveness of improvement of irrigation efficiency (IE). The cases from fifth to eighth were executed to confirm the effect of other ULRP's proposed countermeasures by degree of IE.

Table 6.1.9 Components by Case of Scenario Simulation

Target Area	Whole Basin	Specific River Basin			
Counter Measures	Improvement of Irrigation Efficiency (ref. 6.1.1(2)(a))	Dredging Channel in Gedar Chay (ref. 6.1.1(2)(b))	Interbrain Transfer to Gedar Chay (ref. 6.1.1(2)(c))	Return flow of treated wastewater to Aji Chay and Rose Chay (ref. 6.1.1(2)(d))	Improvement/Change of Dam Operation in Aji Chay (ref. 6.1.1(2)(e))
Case001	0.30	-	-	-	-
Case002	0.60	-	-	-	-
Case003	0.70	-	-	-	-
Case004	0.85	-	-	-	-
Case005	0.30	✓	✓	✓	✓
Case006	0.60	✓	✓	✓	✓
Case007	0.70	✓	✓	✓	✓
Case008	0.85	✓	✓	✓	✓

6.2 Result of Scenario Simulation

6.2.1 Annual Inflow Water Volume Necessary to Restore the Lake

As described in Subsection 5.11, in order to obtain the recovery trend of the lake water level toward 1274.1m (Minimum Ecological Balance Level), the required river inflow volume to the lake is estimated at about 4,200MCM per year. On the other hand, the recent inflow volume during the period from 2000 to 2013) was reduced to about 1,900 MCM on yealy average even with some implemented countermeasures. Therefore, on the assumption that the meteorological condition of the basin will continue as set in the simulation period (annual average of baisn rainfall is 287mm and ranges between 223 to 442mm), the increment of water volume of about 2,300 MCM per year should be secured through the addistional countermeasures in order to attain the increment tendency of the lake water level.

The results of ramp-sum water balance calculation using the results of hydrological cycle model shows that in case the required inflow volume with around 4,200 MCM per year are secured by restoration measures in the future, it takes 30 years at a maximum to reach the target water level (See Figure 6.2.1). To shorten the restoration time span up to about 10 years, further countermeasures should be conducted to earn the total annual inflow volume around 5,000 MCM. The ramp-sum model uses almost same conditions in terms of the data input to the improved hydrological cycle model in this Survey, especially in amount of rainfall and evaporation corresponding to the rake surface and the lakebed condition.

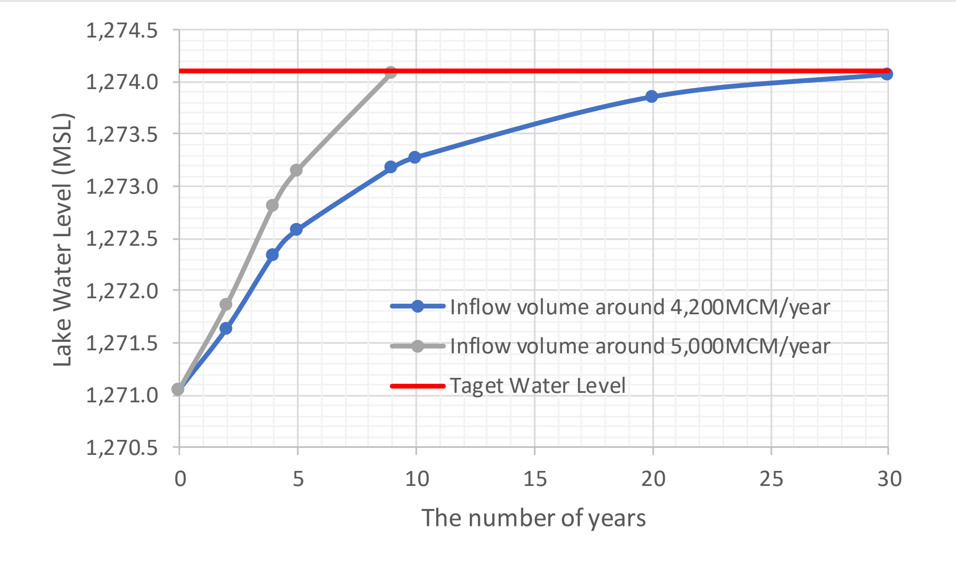


Figure 6.2.1 Time Scale of Lake Water Level Restoration

Figure 6.2.2 shows the variation of lake water level for the several annual river inflow volumes for 500, 1,900, 2500, 3,000 and 4,200MCM. If the annual river inflow volume will continue with less than 4,200MCM for a long time, the lake water level will be settled without reaching the target water level. The current annual river inflow volume (1,900MCM) still cause a low stable water level with around 1,270.5m securing equilibrium especially with the evaporation from the lake surface, and in case of 500 MCM, the water level may be close to the lakebed. The major conditions of this ramp-sum water balance calculation are as follows: (a) Rainfall to the lake surface: 287mm (average in the simulation period), (b) Evaporation from the lake surface: the same rate with the improved hydrological cycle model, (c) Elevation of lakebed: the same condition with the improved model and (4) River Inflow volume to the lake: given condition.

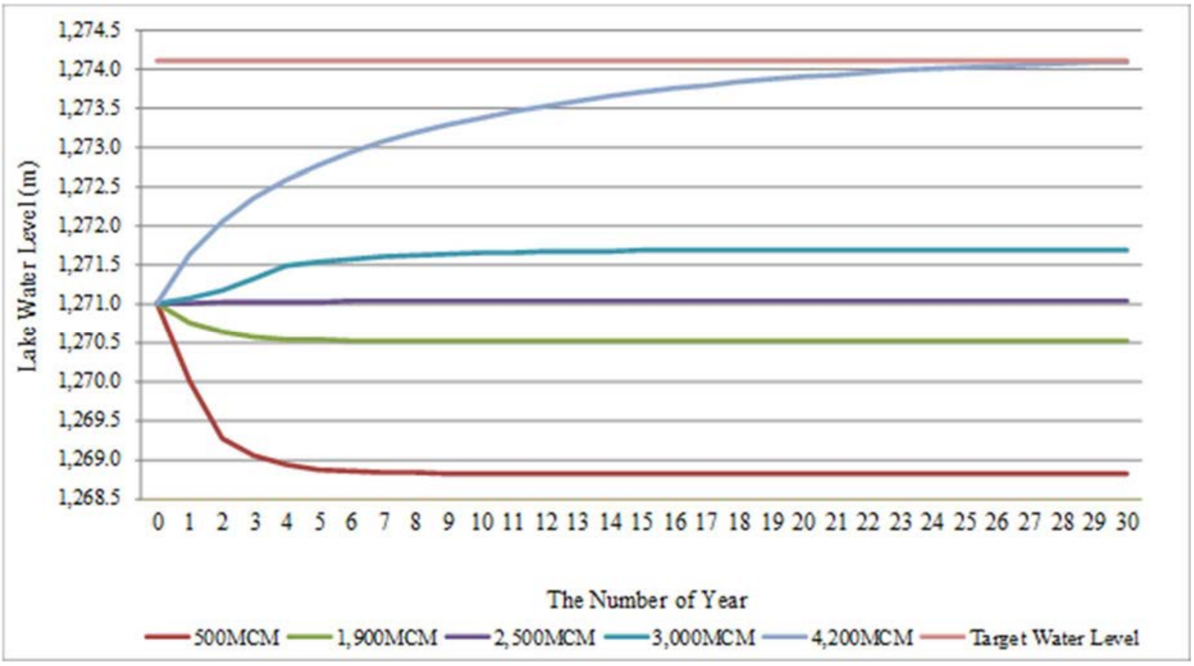


Figure 6.2.2 Lake Water Level Corresponding to Annual Inflow Volume

In Iran researches have an idea of partial restoration of the Urmia Lake, especially in north of the Urmia Lake road which runs between the Urmia and Tabriz City. The maximum water surface area of the north part is approx. 1,665km^2 with the storage volume 6,900MCM at the target water level (1274.1m).

On the condition of setting the target restoration area in the north part, the simulation results by the ramp-sum calculation was presented in Figure 6.2.3. The figure shows that the lake water level will reach the target water level within about 11 years in case of current annual average river inflow (1,900MCM) and within about 4 years in case of 2,500MCM. The river inflow volume of 2,500MCM per year is the total volume of current annual average river inflow volume with 1,900MCM plus the effect of proposed countermeasures with 600MCM (see Subsection 6.2.2). In reality, the limitation area should be examined in terms of topology, natural and social environment, etc.

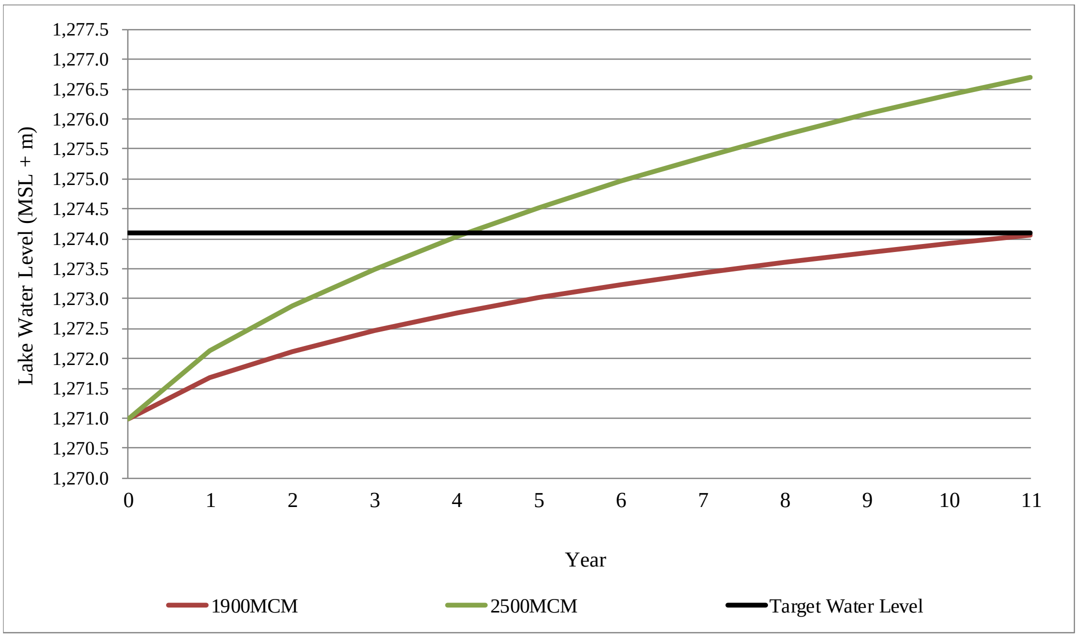


Figure 6.2.3 Lake Water Level Restoration in Case of North Part Limited

6.2.2 Effectiveness of Each Countermeasure

Restoration measures such as (i) Improvement of irrigation efficiency, (ii) River improvement, (iii) Interbasin transfer, (iv) Return flow of treated water, and (v) Improvement of dam operation are components of the scenarios pointed out by ULRP in Subsection 6.1.2. ULRP had indicated specific target areas and facilities for measures (ii), (iii), (iv) and (v), while measure (i) is for all irrigation areas.

Based on the 14 years hydrological simulation on the condition described in Table 6.1.1, the increment of inflow volume to the lake is summerized by countermeasure in Table 6.2.1 and Figure 6.2.4. The individual inflow is very low in comparison with the required inflow volume to attain the target water level. The simulation results by small basin in all cases were summarized in the Attachment 6-1 of this Report.

Table 6.2.1 Effect of Individual Countermeasures

Unit:MCM

Case Name	Current Condition (w/o proposed countermeasures)	Counter Measures except for (i)					(i)Improvement of Irrigation Efficiency with all the River Structural Measures		
		(ii) River Improvement	(iii)Interbasin transfer	(iii)Return flow of treated wastewater (Rose Chay)	(iv)Return flow of treated wastewater (Aji Chay)	(v)Improvement of dam operation			
Irrigation Efficiency / Year	Existing (≒0.3)	Existing (≒0.3)	Existing (≒0.3)	Existing (≒0.3)	Existing (≒0.3)	Existing (≒0.3)	IE=0.6 (Lined canal x Surface Irr.)	IE=0.7 (Lined canal x Sprinkler Irr.)	IE=0.85 (Lined canal x Drip Irr.)
1	1,634	1,761	1,883	1,637	1,652	1,642	1,781	1,814	1,875
2	2,575	2,732	2,776	2,578	2,593	2,585	2,700	2,739	2,798
3	3,248	3,454	3,393	3,251	3,266	3,263	3,402	3,435	3,491
4	2,716	2,880	2,906	2,719	2,733	2,726	2,860	2,904	2,962
5	2,285	2,409	2,543	2,288	2,296	2,292	2,379	2,414	2,466
6	2,364	2,527	2,558	2,367	2,378	2,373	2,475	2,503	2,544
7	2,794	2,936	3,022	2,796	2,812	2,802	2,943	2,974	3,018
8	648	697	988	651	655	655	671	678	690
9	938	989	1,271	940	942	943	1,056	1,097	1,156
10	2,023	2,148	2,274	2,026	2,042	2,034	2,146	2,182	2,239
11	1,644	1,763	1,903	1,647	1,654	1,652	1,733	1,761	1,805
12	1,265	1,356	1,564	1,268	1,276	1,269	1,378	1,406	1,446
13	1,307	1,393	1,616	1,310	1,316	1,313	1,455	1,487	1,535
14	701	759	1,044	703	705	704	810	841	881
Average Inflow	1,867	1,986	2,124	1,870	1,880	1,875	1,985	2,017	2,065
Averaged Increment	0	119	257	3	13	8	117	149	197
Total of River Structural Measures	-	398					-	-	-
Target Scenario	Case001	Case006, 007, and 008					Case003&006	Case004&007	Case005&008

*Aggregation period is between September to August (hydrological year)

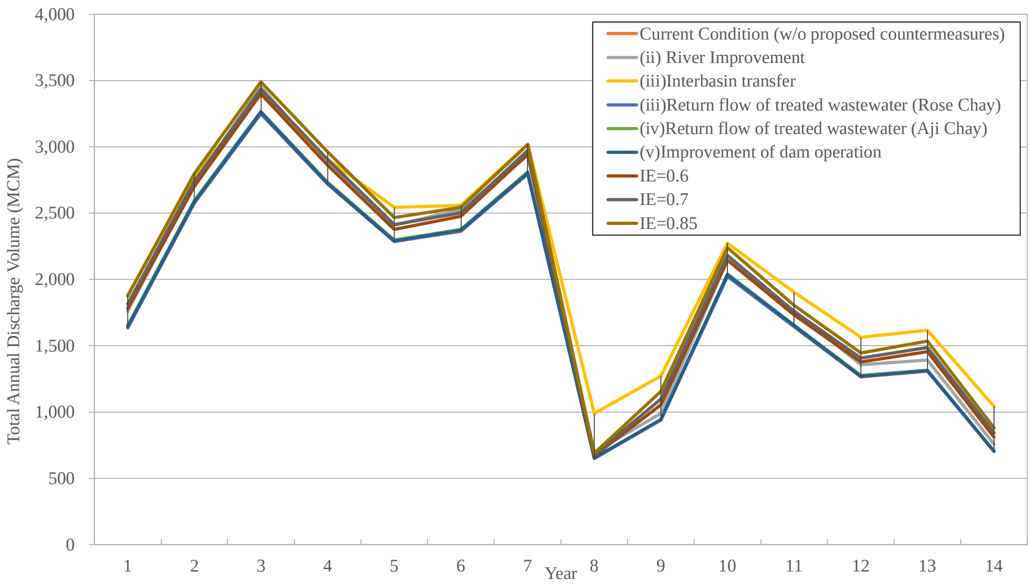


Figure 6.2.4 Inflow Volume with Individual Counter Measures

6.2.3 Effectiveness of the Countermeasures Components

As arranged in Table 6.2.2 and Figure 6.2.5, the results of simulation based on the scenarios (see Subsection 6.1.4) indicate the yearly river inflow volume was estimated at about 2,462 MCM (Case 008: countermeasures proposed by ULRP with irrigation efficiency 0.85) at a maximum from exisiting yealy average 1,867 MCM (Case 001: Existing Measures). The volume of each scenario can not secure the required inflow volume mentiond in Subsection 6.2.1, which cause lower water level than 1,270 m (initial condition of the simulation) to the lake bed in several years even with the all restoration measures (see Figure 6.2.6). The average water level would gradually decrease and settle at lower level on the condition of recurrence of the past decade rainfall volume/pattern and water use (see Figure 6.2.6).

Table 6.2.2 Annual Inflow to the Lake in the Countermeasures Components

Unit:MCM

Case Name	Case001	Case002	Case003	Case004	Case005	Case006	Case007	Case008
Irrigation Efficiency	Existing (≒0.3)	IE= 0.6 (Lined canal x Surface Irr)	IE= 0.7 (Lined canal x Sprinkler Irr)	IE=0.85 (Lined canal x Drip Irr)	Existing (≒0.3)	IE= 0.6 (Lined canal x Surface Irr)	IE= 0.7 (Lined canal x Sprinkler Irr)	IE=0.85 (Lined canal x Drip Irr)
Countermeasures	wo/ other countermeasures				w/ other countermeasures			
1	1,634	1,781	1,814	1,875	2,039	2,181	2,219	2,279
2	2,575	2,700	2,739	2,798	2,962	3,085	3,125	3,184
3	3,248	3,402	3,435	3,491	3,636	3,775	3,810	3,864
4	2,716	2,860	2,904	2,962	3,101	3,242	3,286	3,344
5	2,285	2,379	2,414	2,466	2,689	2,782	2,815	2,867
6	2,364	2,475	2,503	2,544	2,745	2,854	2,881	2,921
7	2,794	2,943	2,974	3,018	3,194	3,344	3,365	3,408
8	648	671	678	690	1,053	1,076	1,086	1,101
9	938	1,056	1,097	1,156	1,333	1,460	1,504	1,568
10	2,023	2,146	2,182	2,239	2,432	2,549	2,580	2,637
11	1,644	1,733	1,761	1,805	2,044	2,126	2,154	2,199
12	1,265	1,378	1,406	1,446	1,672	1,783	1,810	1,848
13	1,307	1,455	1,487	1,535	1,717	1,891	1,900	1,944
14	701	810	841	881	1,113	1,223	1,254	1,294
Average	1,867	1,985	2,017	2,065	2,267	2,382	2,414	2,462

*Aggregation period is between September to August (hydrological year)

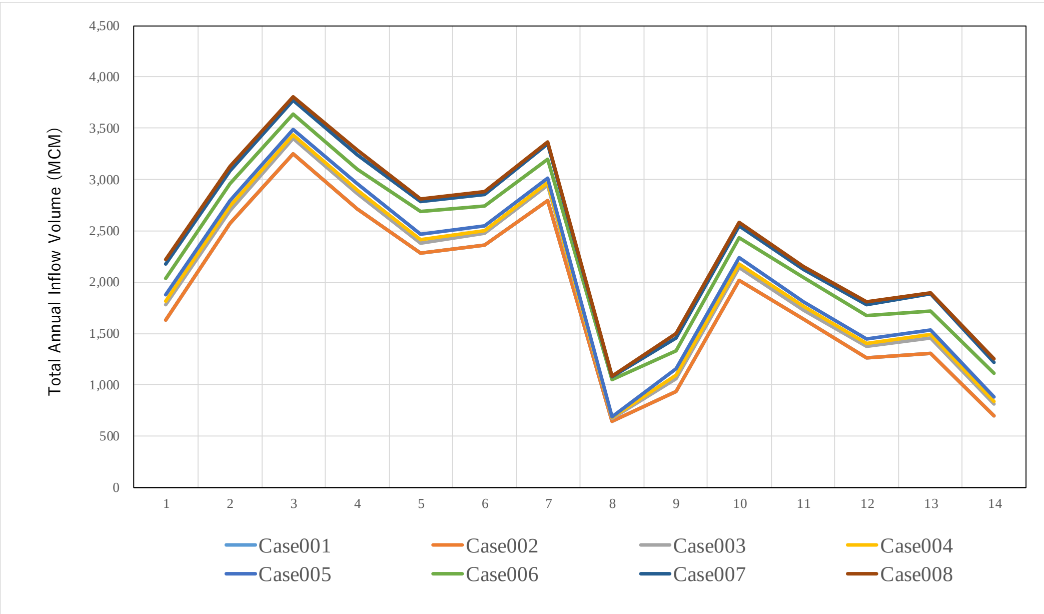


Figure 6.2.5 Annual Inflow in Each Scenario Simulation

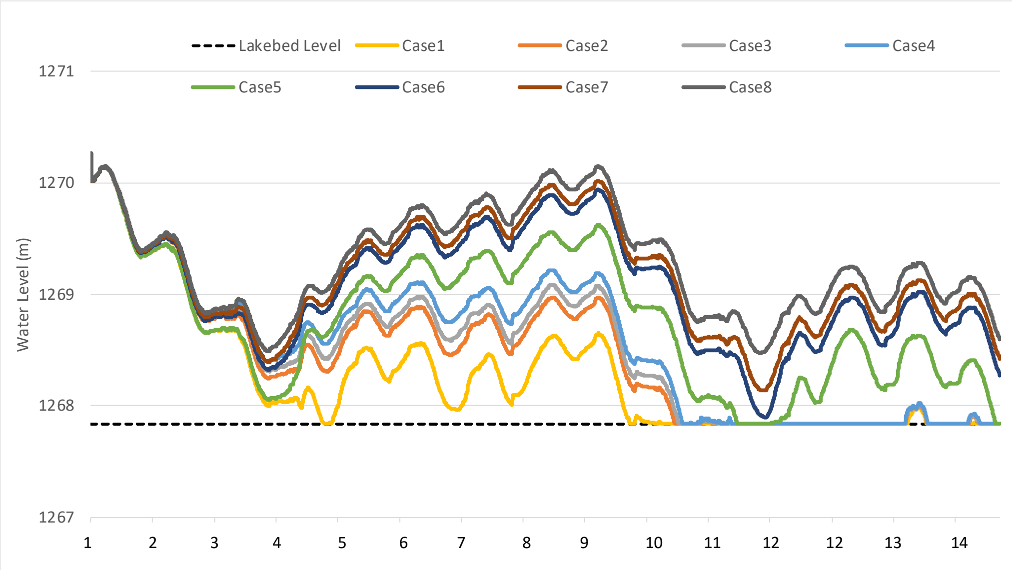


Figure 6.2.6 Lake Water Level in Each Simulation

Based on Table 6.2.2, the condition of inflow water volume is summarized in Table 6.2.3. The differences of inflow volume between the required water volume (4,200MCM per year) and the cases (Case006, 007 and 008) are 1,818, 1,786 and 1,738 MCM per year respectively. The difference volume should be coverd by other additional measures in the future so as to reach the target water level (1274.1m: Minimum Ecological Balance Level).

Table 6.2.3 Yearly Average Inflow Volume to the Urmia Lake

Items		Case006	Case007	Case008
①	Increment by improvement of irrigation efficiency	117	149	197
②	Increment by River Structural Countermeasures	398	398	398
③	Subtotal (①+②)	515	547	595
④	Recent Inflow without the proposed countermeasures	1,867	1.867	1.867
⑤	Total Inflow(③+④)	2,382	2,414	2,462
⑥	Difference from required increment (4,200 MCM-⑤)	1,818	1,786	1,738

*IE0.60:Irrigation Efficiency with the rate

CHAPTER 7 Conclusion and Recommendations

7.1 Conclusion

7.1.1 Establishment of Improved Hydrological Cycle Model

The hydrological cycle model established in the previous survey was improved in the Survey and numerical calculations were performed in accordance with the scenario presented by ULRP. The Survey Team also monitored situations in the construction of Decision Support System to be built by ULRP in the future, and arranged information for introducing the hydrological cycle model as a water balance analysis engine into the system. The accuracy of the model was improved by focusing on the keys pointed out by ULRP as follows:

(1) Well Estimation of Irrigation Water Use

The amount of irrigation water, which accounts for 80% of the water use in the basin, were calculated based on inverse calculation from actural evapotranspiration (ET) amount estimated by the METRIC energy balance method (herein after referred to as METRIC method) and irrigation efficiency provided by ULRP. The adoption of satellite-based evapotranspiration estimations is a primary of the Survey. The accuracy of the computed ET maps was evaluated as excellent in the irrigated agriculture area by Remote Sensing Research Center (RSRT) of the Sharif University and Agricultural Water Management Journal of ELSEVIER). The evaluation is carried out by the comparison with the FAO standard values (See Subsection 3.3.4 (1))

(2) Setting the Target Indicators on All Primary Water Balance Elements

The target hydro-meteorological elements for the model calibration were set in (a) river flow discharge at hydrological stations and total inflow of the rivers, (b) behavior and tendency of groundwater level at monitoring wells in irrigation area, and (c) evapotranspiration in irrigation areas. The three elements are primary phenomenon in water balance and if the all three elements can be well calibrated, the model will closely simulate in accordance with realistic hydrological cycle conditions in the basin.

As to the results of calibration of the model based on the three indicators, the Survey Team and ULRP attained excellent results as follows (see Chapter 5 in detail):

- The relatively high Nash Sutcliffe efficiency of river flow discharge is achieved in the downstream of major rivers.
- The similarity in temporal and seasonal variation is obtained between the observed and simulated groundwater level at monitoring wells in irrigation areas.
- The actual evapotranspiration estimated through the METRIC method was input in the model (see Subsection 7.1.4). The daily-based realistic amount of intake water for the irrigation also well estimated based on the actual evapotranspiration.

7.1.2 Effect of Measures

The results will help to determine priorities of restoration countermeasures and decide whether the measures are to be implemented in the future taking care of related water sectors. Lake Urmia restoration measures consist of (i) Improvement of irrigation efficiency, (ii) Normalization of river channels, (iii) Inter-basin diversion, (iv) Transfer of pacificated water, and (v) Increase of dam release discharge are components (Refer to Chapter 6).

The recovery of lake water level requires the yearly river inflow water volume of about 4,200 MCM per year at a minimum (on the condition of current lakebed and average rainfall amount of 287mm), which should be obtained by two types of inflow such as the current total river inflow to the lake of about 1,900 MCM/year with the effects of past restoration measures and the increment river inflow of about 2,300 MCM/year by future restoration measures. However, since the total increment of inflow volume by the above-proposed countermeasures in the Survey was just about 600 MCM/year. Therefore, in order to attain the target average lake water level of 1274.1 m (Minimum Ecological Balance Level), further countermeasures should be planned and implemented to attain 2,300 MCM per year of additional inflow, namely increasing 600 MCM per year of the planned countermeasures plus the inflow by additional countermeasures with 1,500 MCM/year.

7.1.3 Conceivable Future Direction

Based on discussions with the related agencies, the expected recovery situation on the lake water level is described as follows::

- River inflow volume to the lake about 4,200MCM/year is a minimum requirement as to prepare the recovery tendency for the lake water level with the recent degree of direct average rainfall (414mm) to the lake. In case of less than 4,200MCM, the lake water level will be settled in a lower water level than the target water level (1274.1m).
- Preparation of more than 4,200MCM/year river inflow volume bring an effect to accelerate the recovery of water level. It may take about 30 years to recover with 4,200MCM/year river inflow volume and 10 years with 5,000MCM/year (see Figure 6.2.1).
- The total inflow volume will approach about 2,500MCM/year if the proposed countermeasures are implemented; however, the water level will not reach the target water level (see Figure 6.2.2).
- If the restoration area is limited in north part of the Urmia Lake, the lake water level will reach the target water level in a few years by the recent river inflow volume of about 1,900MCM per year (See Figure 6.2.3)

7.1.4 Grasp of Actual Evapotranspiration (ET)

(1) Background of ET Estimation

Improving agricultural water management is essential for achieving sustainable use of water in the basin. However, collecting data for the irrigation water use (withdrawal) from surface and subsurface water was not realistic in the Urmia Lake Basin, because currently farmers can easily access water without registration and regulation. Lack of irrigation withdrawal data makes inadequate water accounting and difficulty in decision makings in the region. Under the circumstances, the Survey has enabled to account for the irrigation by unregistered water for the whole basin by adopting satellite-based evapotranspiration estimation. The agricultural water withdrawal from the surface and subsurface aquifers are primarily consumed as ET, and the rest of the water returns to aquifers or the lake. The estimated ET will tell the "net" amount of withdrawal (including unregistered irrigation water), which is more important for considering basin-scale hydrology.

(2) Effects of Metric Energy Balance Method on the Modeling

The calculated ET maps were adopted as input of the hydrological cycle model. The total irrigation withdrawal from rivers was set by dividing the evapotranspiration amount by the irrigation after the consumption of permitted groundwater withdrawal. When contradiction occurs on the water balance computation of the model, the model extracts extra water from aquifer to attain the evapotranspiration suggested by the ET map, if the contradiction on water balance computation was the result of the unregistered withdrawals by farmers. By this approach, the hydrological cycle model achieved to incorporate the impact of irrigation, without using quality data for irrigation withdrawal. The model computes water balance with the resolution of 2 km. Thus, it is not supposed to monitor or capture individual farmer's activity of irrigation.

(3) Accuracy of the Actual ET and Partially Compensation by the Model

While the ET map developed and adopted in this Survey enables to account volume of water use in irrigated agriculture, the ET map has several limitations on accuracy. It has been evaluated as less accurate in non-irrigated rangeland and mountainous regions, while the accuracy for irrigated agriculture is potentially superior than that for actual ground measurements of ET. An intelligent design of the hydrological cycle model developed in the Survey is to compensate for a weakness of current version of the ET map. In non-irrigated rangelands and mountainous areas where the ET map is less reliable, the hydrological cycle model evaluates the adequacy of the ET values via water balance computation, and revises ET values if necessary. This structure of the hydrological cycle model makes the water simulation results the most reliable with available dataset and the quality although there are several rooms to improve the estimation accuracy of ET in future, especially for non-irrigated areas and for high elevation regions.

7.2 Recommendations

7.2.1 Way forward to Restore Urmia Lake

In order to implement the restoration based on ULRP scenario/activity effectively in accordance with 25 solutions (ULRP proposed 25 projects in 2014 and Urmia Lake Restoration Committee was approved), main plans, impacts on natural, social and economic sector should be assessed before the implementation. Therefore, ULRP has been challenging to establish the decision support system (DSS). In parallel with the DSS, the several projects and various researches on the restoration are conducted by industrial, governmental and academic organizations of Iran and outsourcing countries. In this circumstance, the Survey Team recommends to ULRP to conduct pilot projects or activities to prove or evaluate effects of the future restoration projects at the several target areas in the Urmia Lake Basin, and in order to effectively execute the activities for pilot projects, it is necessary to preliminary plan and design the projects based on past surveys/projects' results including the series of this Survey by JICA and research papers, etc. The established model in the Survey also help to confirm cost-effectiveness of the candidate of pilot projects.

7.2.2 Setting Up the Direction of the Restoration

The Survey Team recommends to re-examine the restoration scenario of Lake Urmia with a time span and restoration lake water level, based on the countermeasures' feasibility in the aspects of total project cost and O&M cost of facility, environmental and social impacts and so on taking care of the impact on all water sectors. To limit the recovery area of water surface less than the area achieved by the target water level (1274.1m) is also one of the ideas as other researchers suggested in Iran. Simply, there may be just two ways: (1) Step-wised and long-term implementation of countermeasures to achieve the target water level by further-additional countermeasures with considerable project cost and a certain level of impact on the other sectors, (2) Selective implementation of countermeasures to achieve a certain level of lake water level or area of lake water surface with the new land use plan in the area left behind from the restoration in the Urmia Lake Boundary.

7.2.3 Incorporation into Decision Support System and Model Maintenance

The established model is expected to mount into the DSS as a water balance simulation module. ULRP also had the vision that modules for analyzing climate change and socio-economic condition are built in. The data and results between each model should be linked in the DSS in order to analyze the effects and relevance of restoration measures.

However, the DSS is currently just built for its framework as a platform for other engines and has functions for information sharing/exchange system and GIS data creation, so that the above-mentioned modules are not yet incorporated. According to ULRP, the climate change analysis module will not be incorporated because ULRP recognized that it is premature to analyze the future climate of the Urmia Lake Basin with some climate change analysis model due to the existence of large uncertainty. The social system has not been completed as of December 2019, and the only engine that ULRP holds at present is the water balance module constructed in the Survey.

Therefore, the formats of input/output data and data conversion methods through conversion tools were explained in the Survey, so that the linkage of data and results between the modules could be implemented in the DSS in the future. To keep the proper function of the MIKE-SHE model as a hydrological cycle analysis engine in the DSS, it is advisable to pay for annual maintenance costs to software makers so that update services for the model and guidance to solve problems can be received, which are necessary to respond to changes in data storage structures and data formats.

7.2.4 Model Sensitivity and Data Handling in Case of Utilization of Model in the Pilot Projects

The hydrological cycle model established in the Survey covers a wide area of the Urmia Lake Basin. Therefore, the 2km mesh size was adopted in the model to properly set the balance between the calculation time and accuracy of results while considering the scale of the basin. In case simulations is to be conducted focusing on a smaller specific area (e.g., Miandoub irrigation area) for some of pilot project mentioned in Subsection 7.2.1, the mesh size should be set smaller in consideration of size/shape of irrigation area and irrigation channel network in order to express water movement in detail properly. In such a case, modeling may be conducted with a mesh of 50m to 200m and careful calibration in consideration of the sensitivity.

7.2.5 Regulation of Unauthorized Intake Water

The model calibration described in Chapter 6 indicates that groundwater is pumped up several times to attain the intake amount approved by IWRM Co. The simulation results indicate that in recent years the amounts were equivalent to about 6 times at the Miandoab Plain in the southern part and Urmia Plain in the western part, and twice in the eastern part. The level was the same as the unlicensed water intake stated by the concerned parties at the technical committee meetings held by the Survey Team, ULRP and related organizations concerning the southern and eastern areas. The unauthorized water use will lead to the difficulty of water resources management in the basin, especially for the control of river flow discharge to the lake and the maintenance of sustainability of groundwater. Therefore, the unauthorized water should be grasped and reduced in the basin.

Appendix

LIST OF APPENDIX

Appendix 3-1

Hydrological Data Check at Calibration Points

■Southern Part

Ref No.	River	Hydrological Station	Station Code	Catchment Area (km^2)
S-1	Saghez chay	Ghabghablu	33-007	660
S-2	Jighato chay	Pol anian (pol saheb)	33-015	1,221
S-3	Kherkhereh chay	Santeh	33-919	766
S-4	Sarugh chay	Safakhaneh	33-021	2,219
S-5	Zarineh rud	Bukan Dam (Inflow)	-	6,994
S-6	Zarineh rud	Nezam abad	33-917	11,578
S-7	Simineh rud	Dashband bukan	33-035	2,431
S-8	Simineh rud	Miandoab (Simine rud)	33-037	3,783
S-9	Mahad chay	Kuter	34-003	415
S-10	Mahabad chay	Gard yaghub	34-009	1,635
S-11	Gadar chay	Pi ghaleh	34-011	225
S-12	Gadar chay	Pol bahramlu santu	34-021	2,090

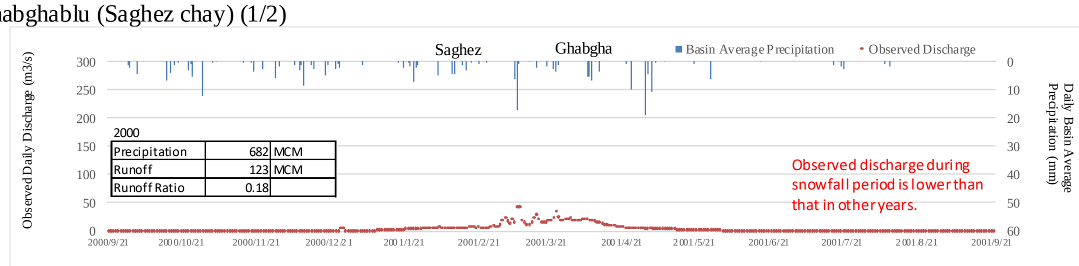
■Western Part

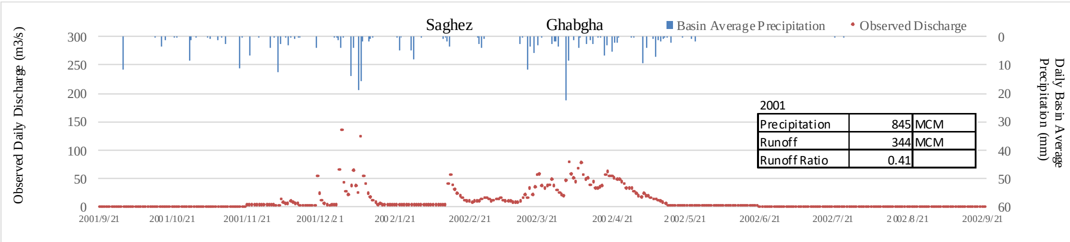
No.	River	Hydrological Station	Station Code	Catchment Area (km^2)
W-1	Zola chay	Yalghuz aghaj	36-011	2,204
W-2	Zola chay	Chehrigh olia	36-001	819
W-3	Nazlu chay	Abajalu sofla	35-033	1,965
W-4	Nazlu chay	Tapik	35-031	1,715
W-5	Arzin chay	Karim abad (arzin)	35-045	506
W-6	Rozeh chay	Guyjali aslan	35-037	331
W-7	Shahr chay	Kashtiban	35-013	670
W-8	Shahr chay	Band urmia	35-011	418
W-9	Shahr chay	Badasor	-	-
W-10	Baranduz chay	Babarud	35-007	1,160
W-11	Baranduz chay	Dizaj (orumieh)	35-005	618
W-12	Baranduz chay	Hashem abad bibakran	35-003	382
W-13	Balanj chay	Ghasemlu	35-001	287

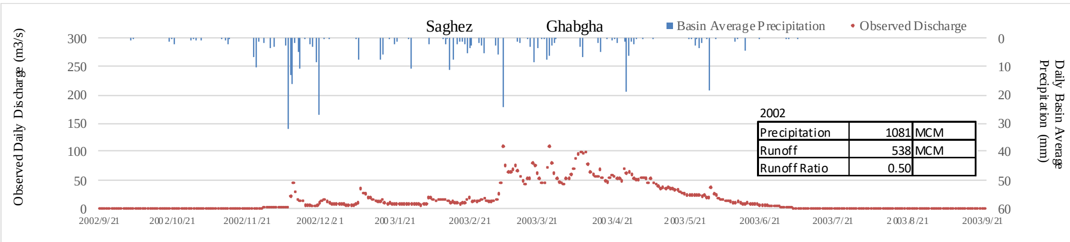
■Eastern Part

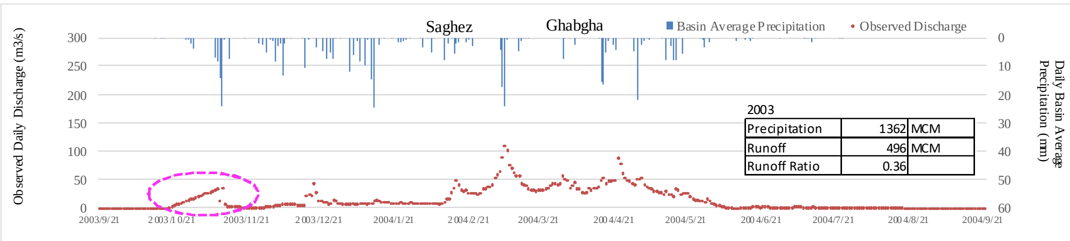
No.	River	Hydrological Station	Station Code	Catchment Area (km^2)
E-1	Aghmiun chay	Sahzab	31-001	73
E-2	Tajyar sarab	Mirkuh haji	31-032	128
E-3	Ajichay	Saransar	31-005	1,700
E-4	Mehrban (Chekeh chay)	Mehrban	31-109	391
E-5	Ojan chay	Bostan abad	31-007	575
E-6	Ajichay	Markid	31-117	5,619
E-7	Nahand chay	Nahand	31-011	216
E-8	Saiid abad	Saiid abad	31-013	224
E-9	Ajichay	Vanyar	31-015	7,432
E-10	Lighavan	Harvi	31-021	186
E-11	Gomnab chay	Anakhatun	31-017	396
E-12	Sardorud	Zinjenab	31-031	43
E-13	Ajichay	Akhola	31-045	9,752
E-14	Ajichay	Sarin dizaj	31-085	10,622
E-15	Azar Shahr	Ghermezigol	31-037	103
E-16	Sanikh chay	Pol sanikh	31-029	498
E-17	Sufi chay	Alavian Dam (Inflow)	-	314

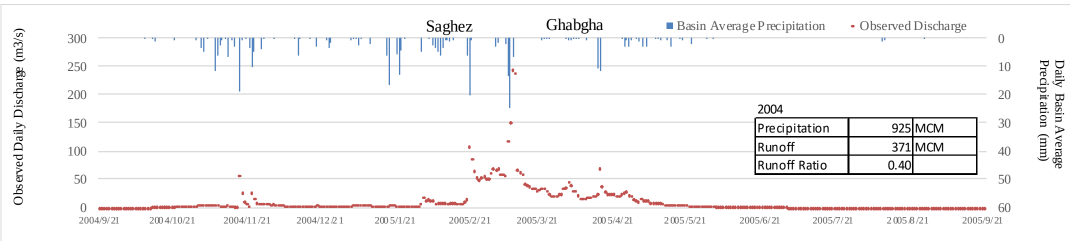
S-1 Ghabghablu (Saghez chay) (1/2)

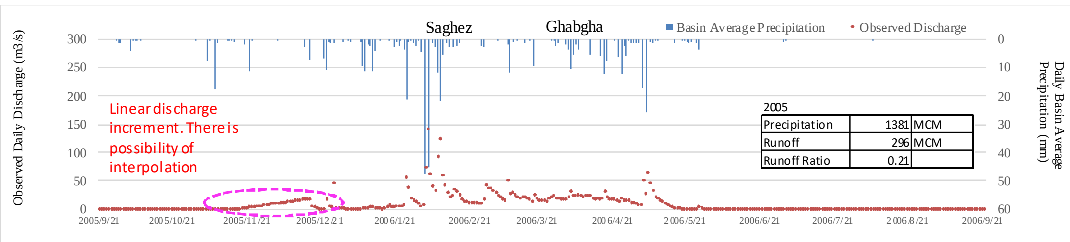


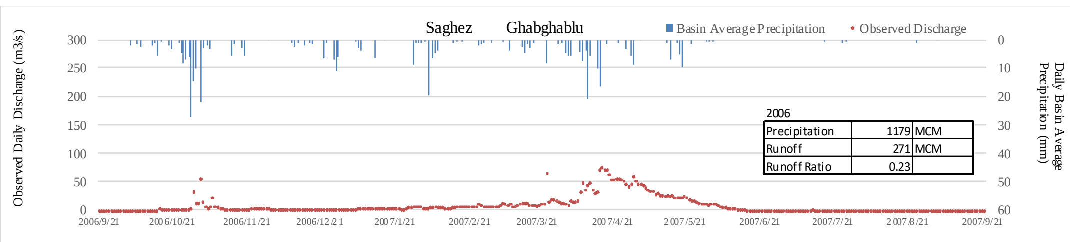




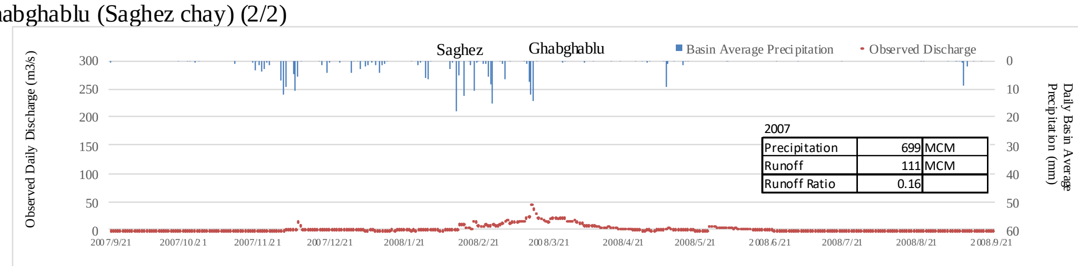


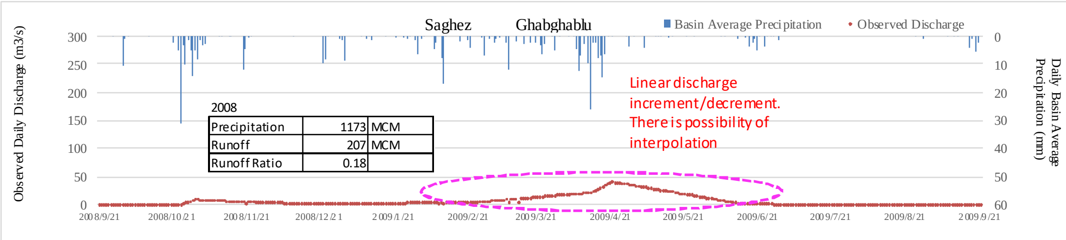


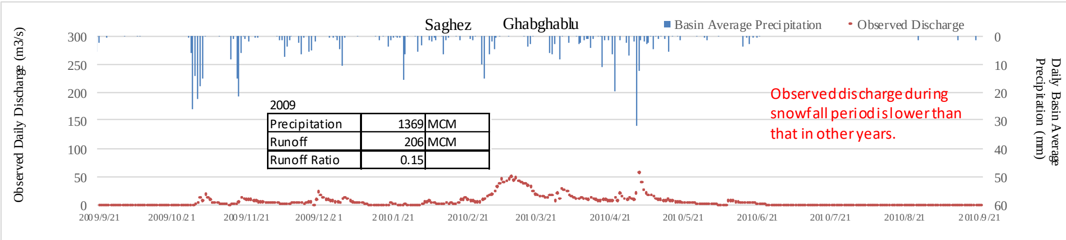


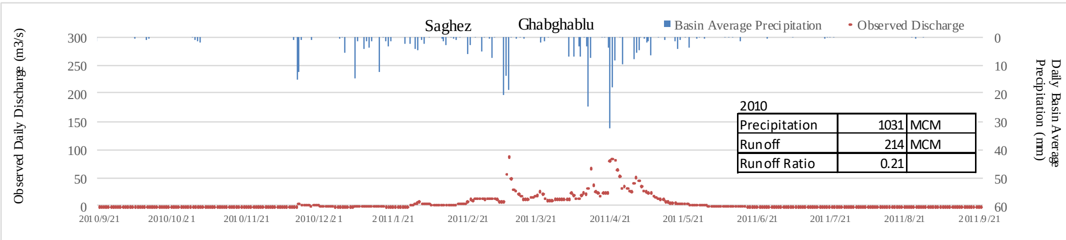


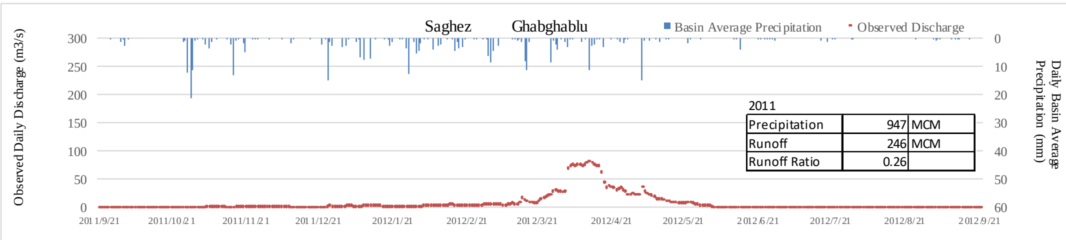
S-1 Ghabghablu (Saghez chay) (2/2)

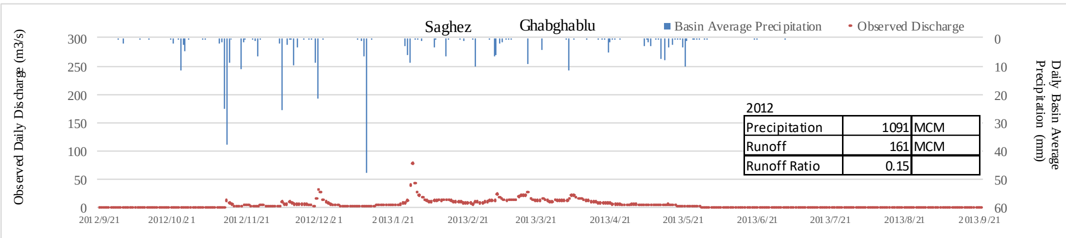


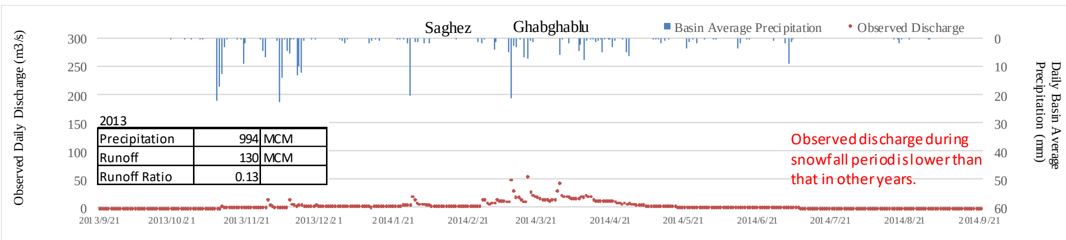




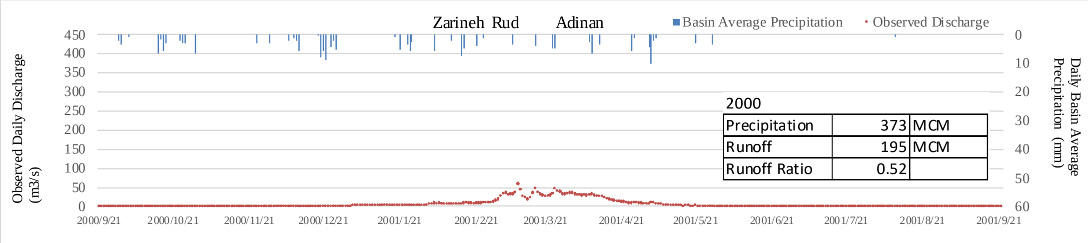


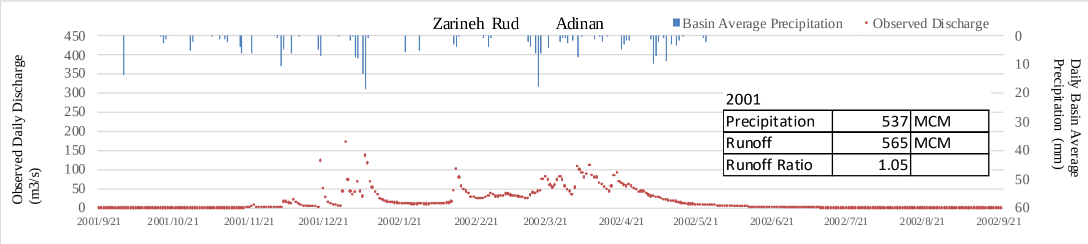


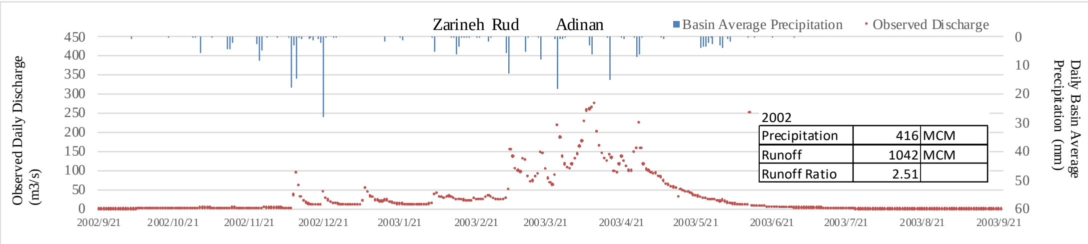


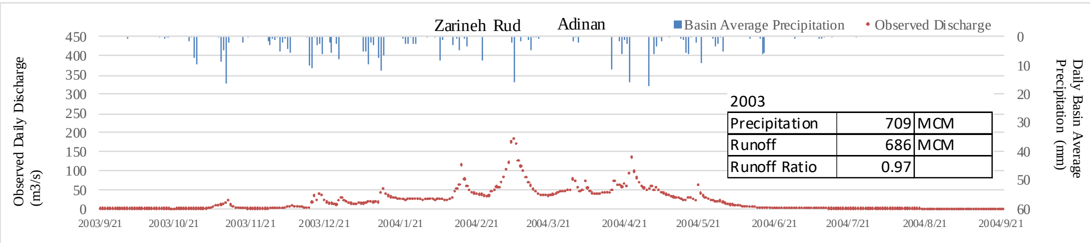


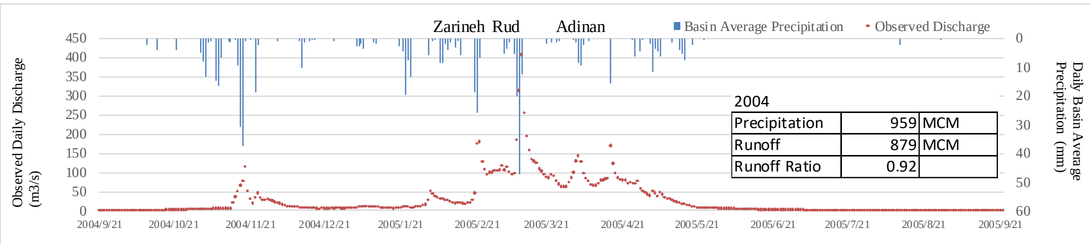
S-2 Pol anian (pol saheb) (Jighato chay) (1/2)

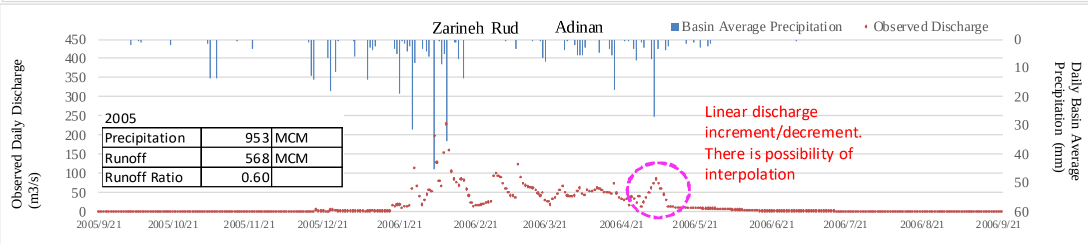


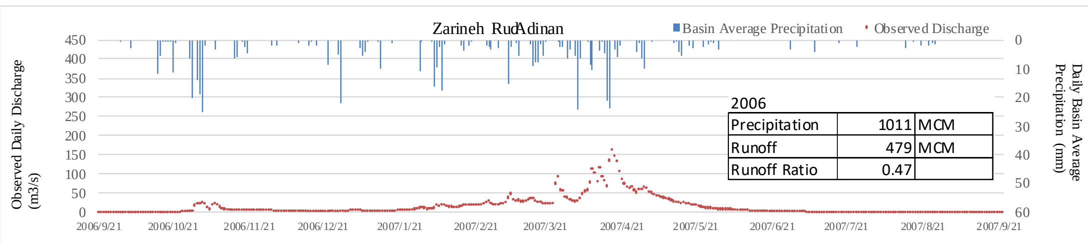




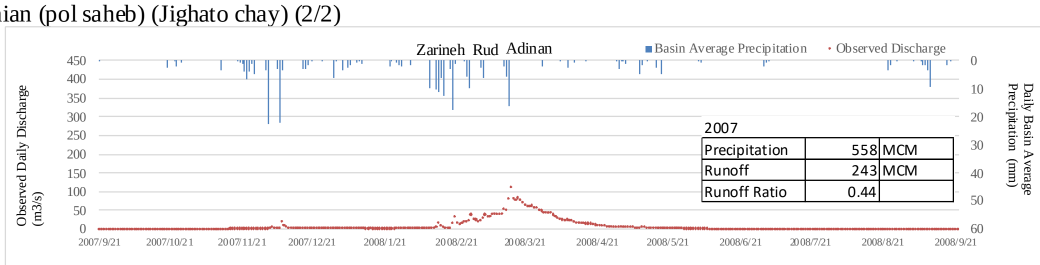


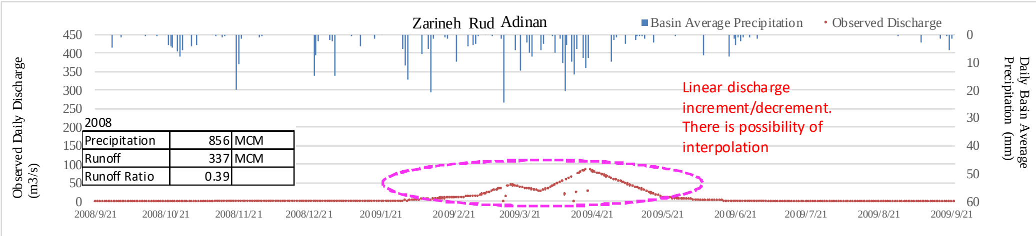


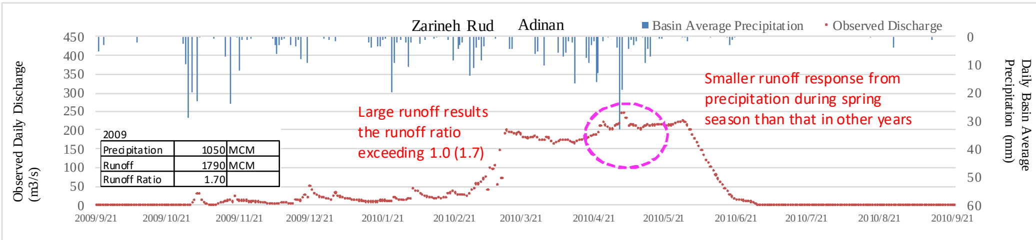


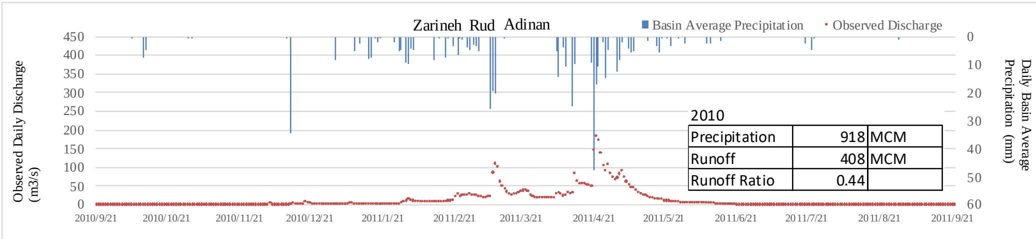


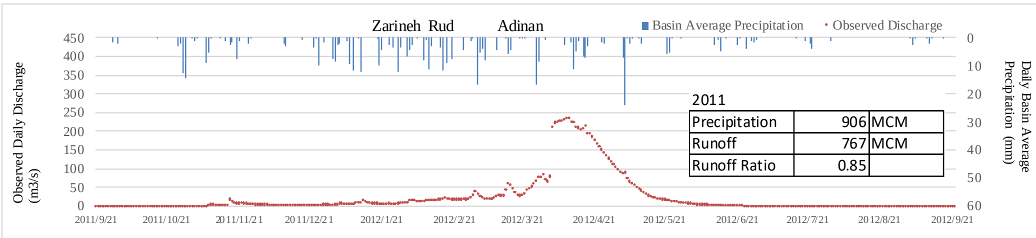
S-2 Pol anian (pol saheb) (Jighato chay) (2/2)

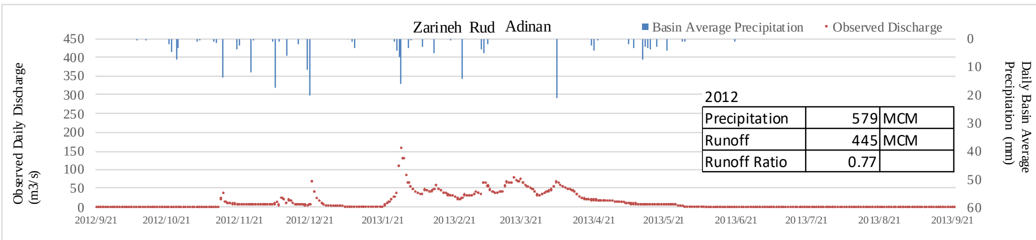


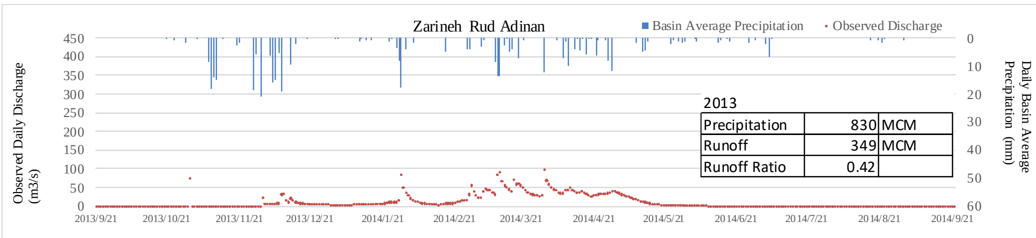




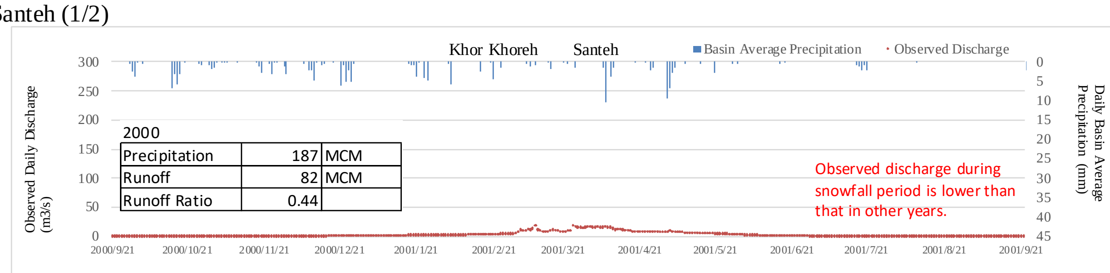


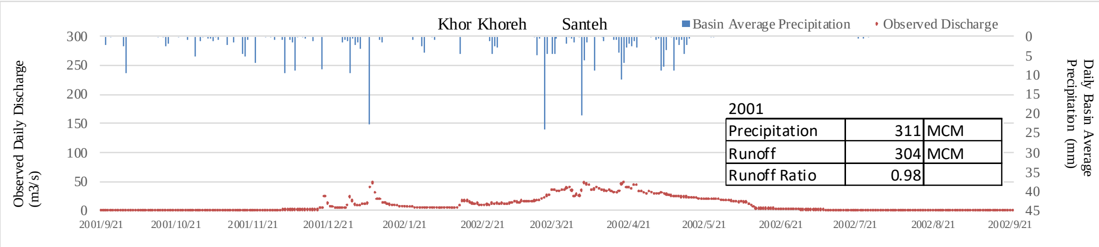


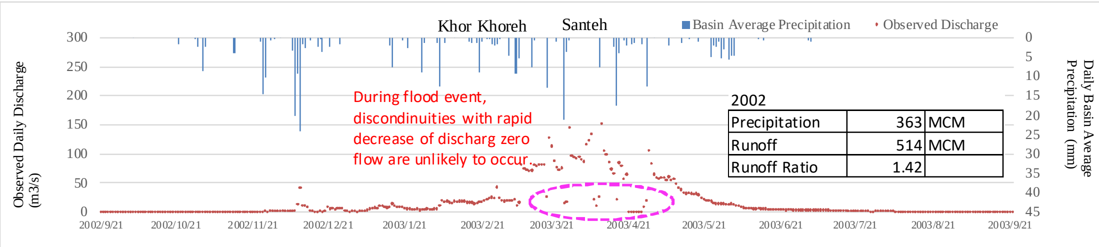


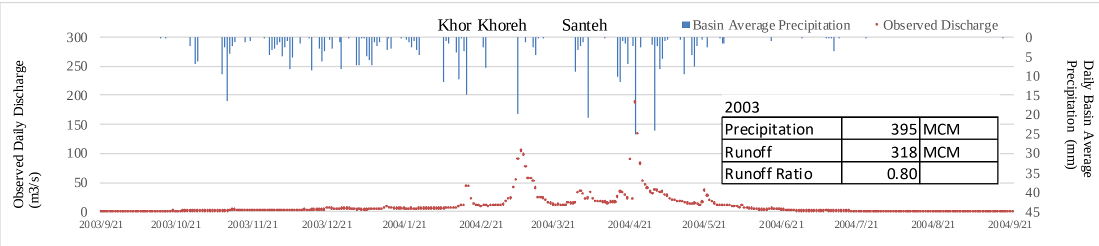


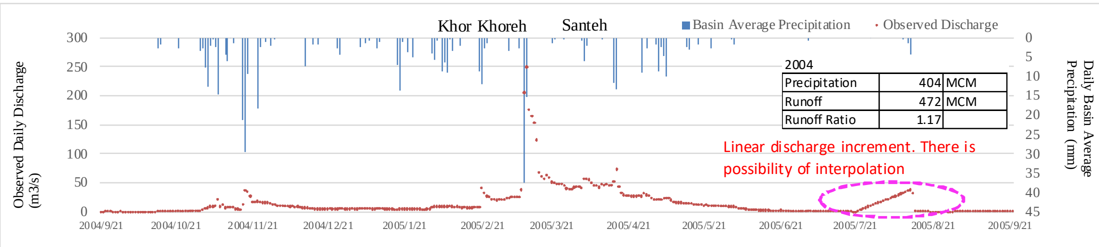
S-3 Santeh (1/2)

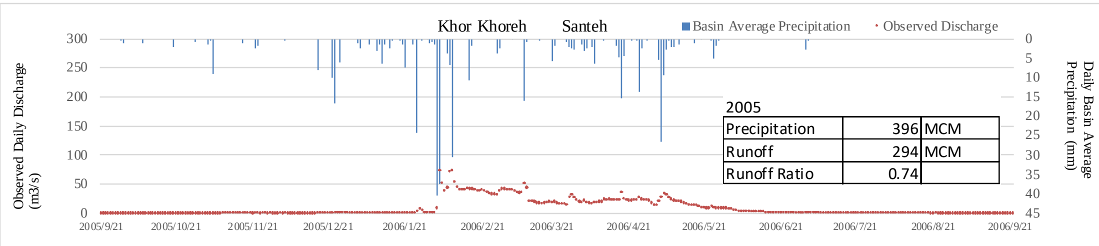

Khor Khoreh
Santeh
Basin Average Precipitation
Observed Discharge
Observed Daily Discharge (m3/s)
Daily Basin Average Precipitation (mm)
2000
Precipitation 187 MCM
Runoff 82 MCM
Runoff Ratio 0.44
Observed discharge during snowfall period is lower than that in other years.

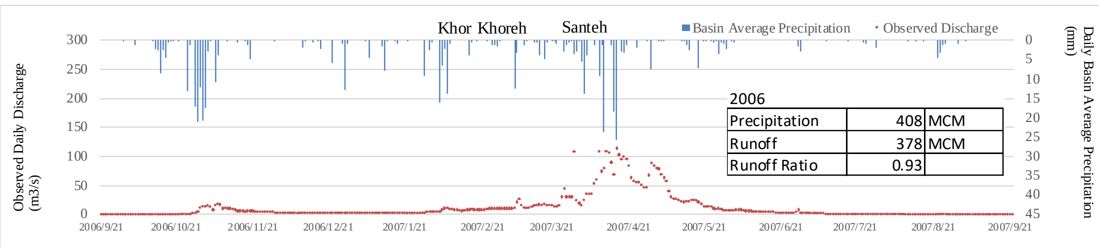

Khor Khoreh
Santeh
Basin Average Precipitation
Observed Discharge
Observed Daily Discharge (m3/s)
Daily Basin Average Precipitation (mm)
2001
Precipitation 311 MCM
Runoff 304 MCM
Runoff Ratio 0.98


Khor Khoreh
Santeh
Basin Average Precipitation
Observed Discharge
Observed Daily Discharge (m3/s)
Daily Basin Average Precipitation (mm)
During flood event, discontinuities with rapid decrease of discharg zero flow are unlikely to occur
2002
Precipitation 363 MCM
Runoff 514 MCM
Runoff Ratio 1.42

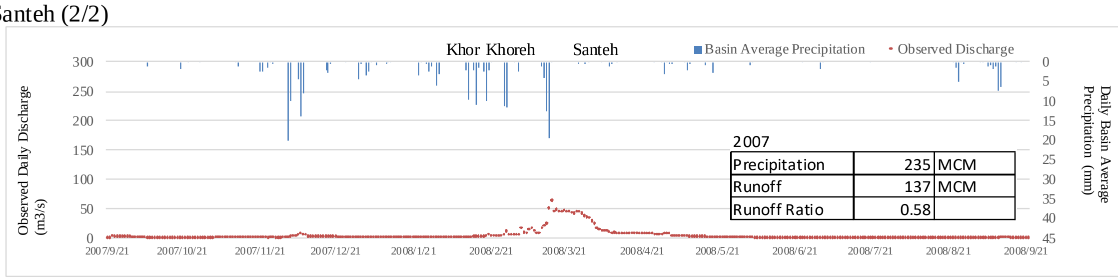

Khor Khoreh
Santeh
Basin Average Precipitation
Observed Discharge
Observed Daily Discharge (m3/s)
Daily Basin Average Precipitation (mm)
2003
Precipitation 395 MCM
Runoff 318 MCM
Runoff Ratio 0.80

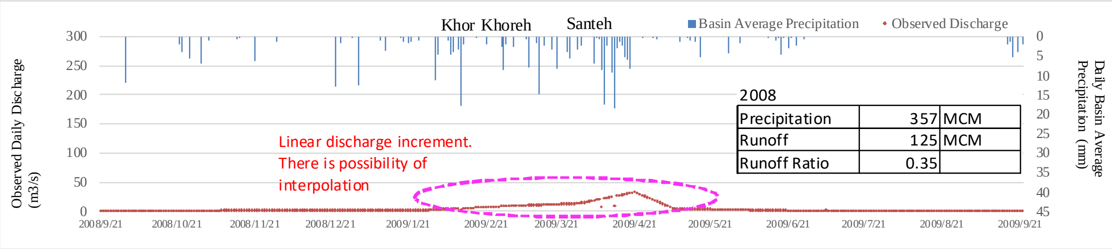

Khor Khoreh
Santeh
Basin Average Precipitation
Observed Discharge
Observed Daily Discharge (m3/s)
Daily Basin Average Precipitation (mm)
2004
Precipitation 404 MCM
Runoff 472 MCM
Runoff Ratio 1.17
Linear discharge increment. There is possibility of interpolation

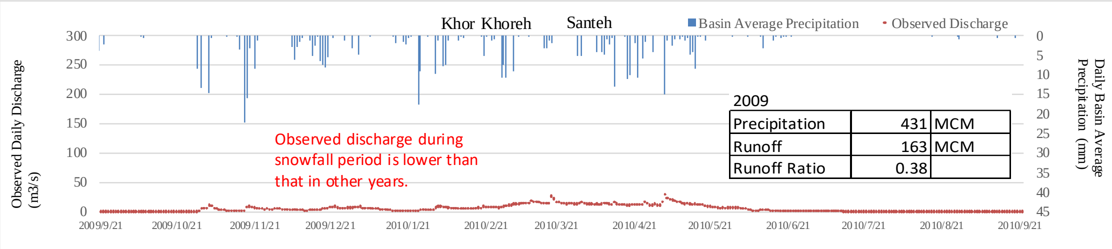

Khor Khoreh
Santeh
Basin Average Precipitation
Observed Discharge
Observed Daily Discharge (m3/s)
Daily Basin Average Precipitation (mm)
2005
Precipitation 396 MCM
Runoff 294 MCM
Runoff Ratio 0.74

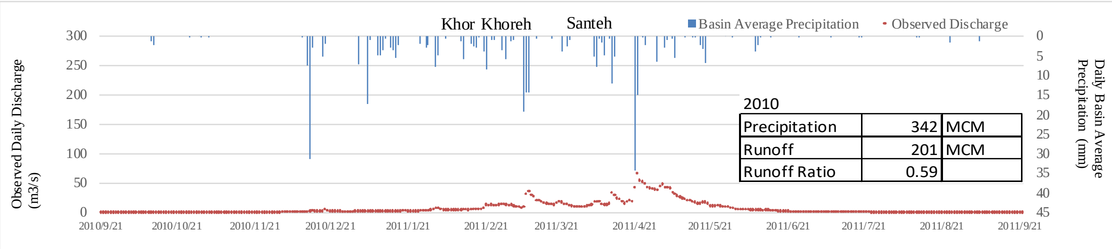

Khor Khoreh
Santeh
Basin Average Precipitation
Observed Discharge
Observed Daily Discharge (m3/s)
Daily Basin Average Precipitation (mm)
2006
Precipitation 408 MCM
Runoff 378 MCM
Runoff Ratio 0.93

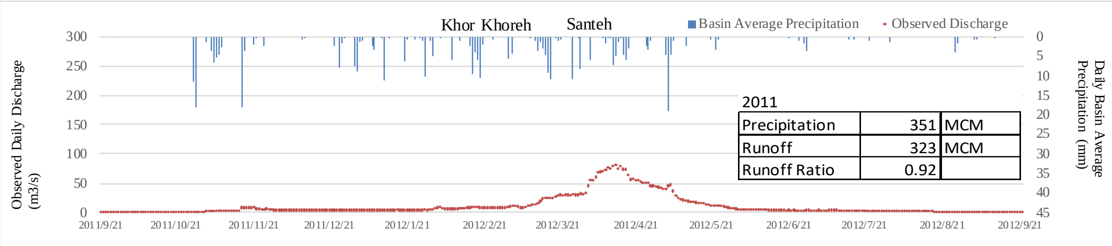
S-3 Santeh (2/2)

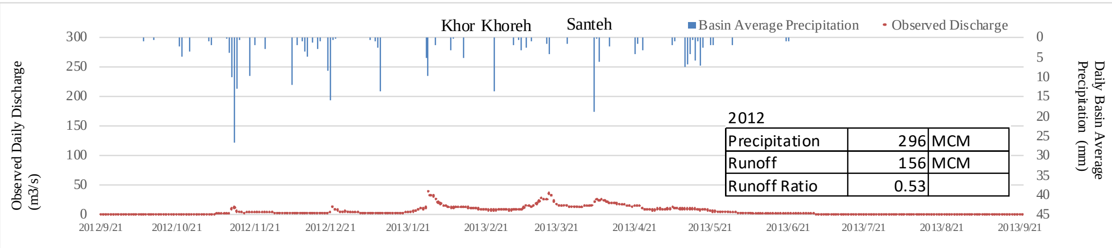

Khor Khoreh
Santeh
Basin Average Precipitation
Observed Discharge
Observed Daily Discharge (m3/s)
Daily Basin Average Precipitation (mm)
2007
Precipitation 235 MCM
Runoff 137 MCM
Runoff Ratio 0.58

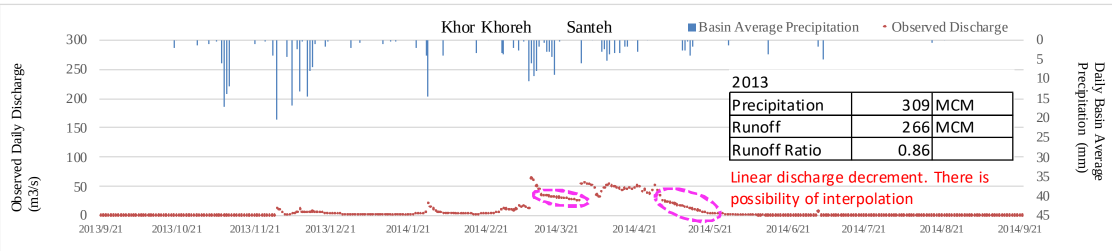

Khor Khoreh
Santeh
Basin Average Precipitation
Observed Discharge
Observed Daily Discharge (m3/s)
Daily Basin Average Precipitation (mm)
2008
Precipitation 357 MCM
Runoff 125 MCM
Runoff Ratio 0.35
Linear discharge increment.
There is possibility of
interpolation


Khor Khoreh
Santeh
Basin Average Precipitation
Observed Discharge
Observed Daily Discharge (m3/s)
Daily Basin Average Precipitation (mm)
2009
Precipitation 431 MCM
Runoff 163 MCM
Runoff Ratio 0.38
Observed discharge during
snowfall period is lower than
that in other years.

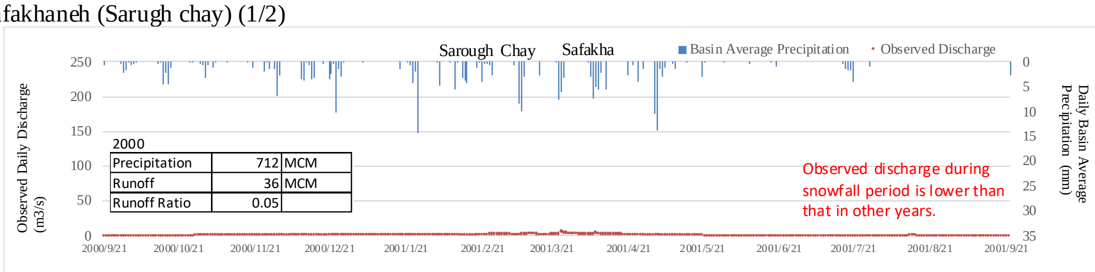

Khor Khoreh
Santeh
Basin Average Precipitation
Observed Discharge
Observed Daily Discharge (m3/s)
Daily Basin Average Precipitation (mm)
2010
Precipitation 342 MCM
Runoff 201 MCM
Runoff Ratio 0.59

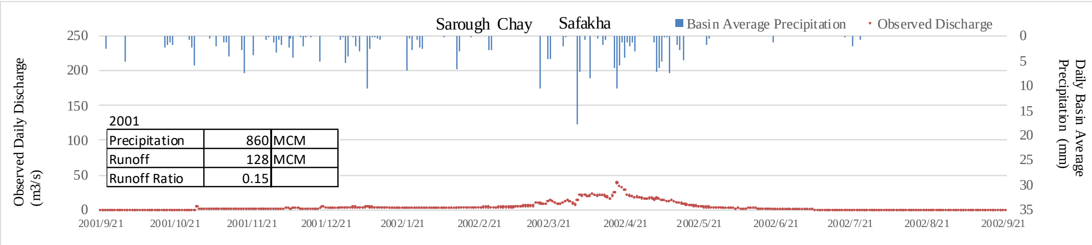

Khor Khoreh
Santeh
Basin Average Precipitation
Observed Discharge
Observed Daily Discharge (m3/s)
Daily Basin Average Precipitation (mm)
2011
Precipitation 351 MCM
Runoff 323 MCM
Runoff Ratio 0.92

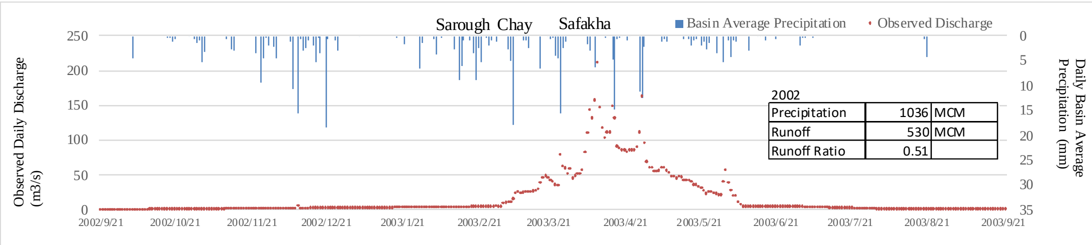

Khor Khoreh
Santeh
Basin Average Precipitation
Observed Discharge
Observed Daily Discharge (m3/s)
Daily Basin Average Precipitation (mm)
2012
Precipitation 296 MCM
Runoff 156 MCM
Runoff Ratio 0.53

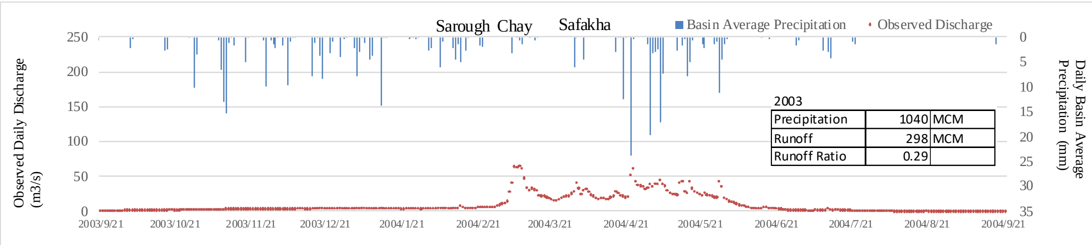

Khor Khoreh
Santeh
Basin Average Precipitation
Observed Discharge
Observed Daily Discharge (m3/s)
Daily Basin Average Precipitation (mm)
2013
Precipitation 309 MCM
Runoff 266 MCM
Runoff Ratio 0.86
Linear discharge decrement. There is
possibility of interpolation

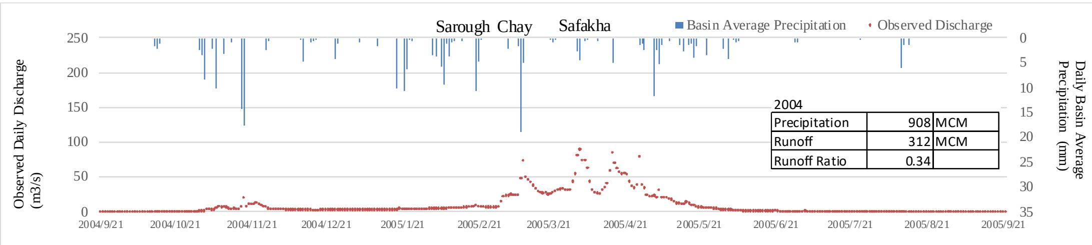
S-4 Safakhaneh (Sarugh chay) (1/2)

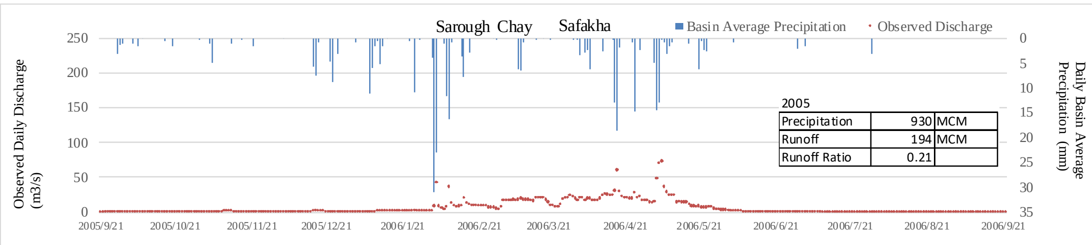


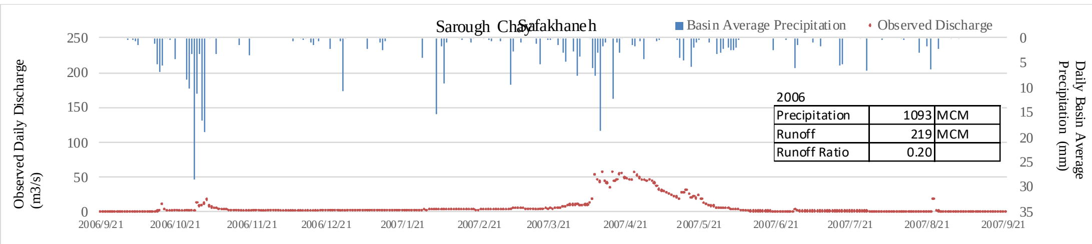




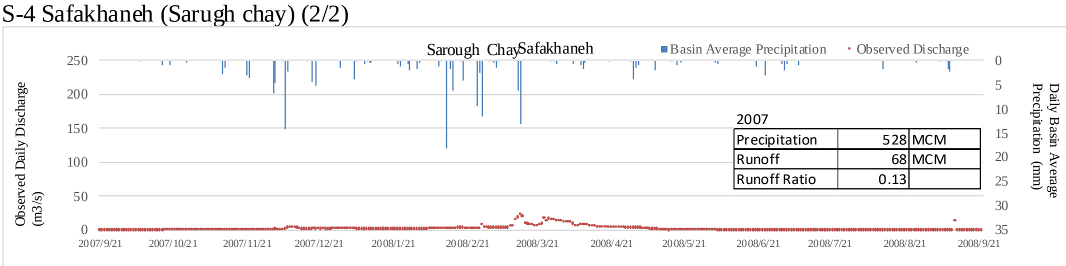


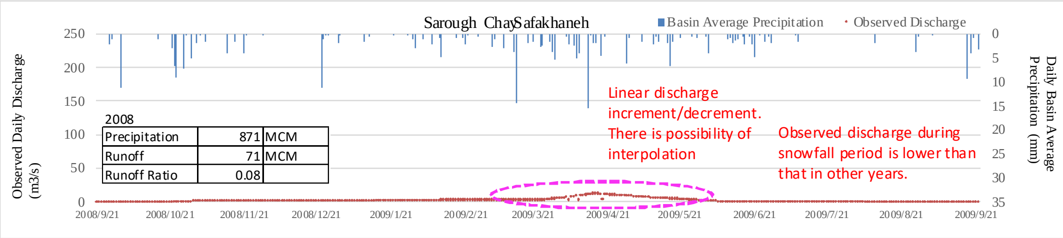


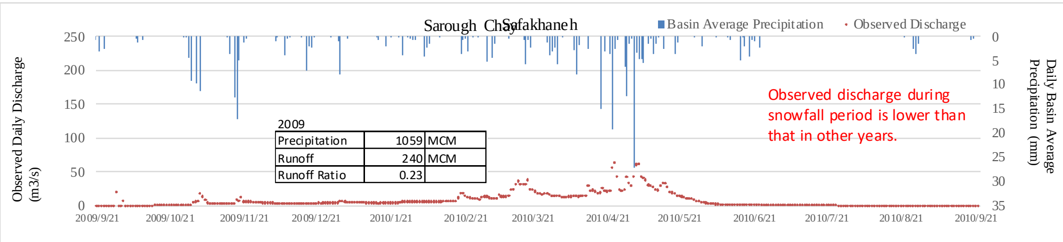


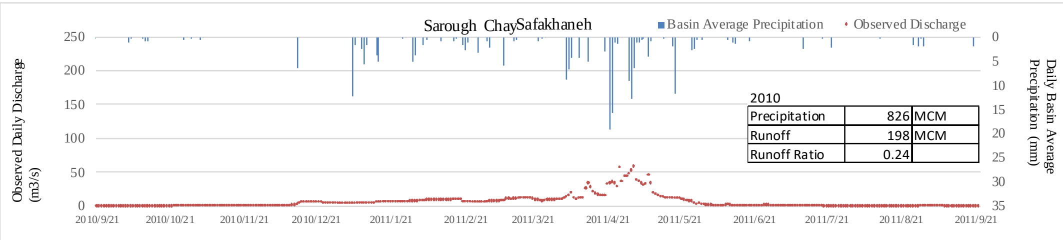


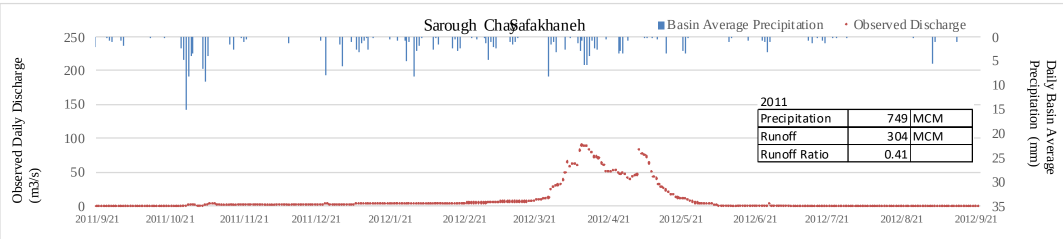
S-4 Safakhaneh (Sarugh chay) (2/2)

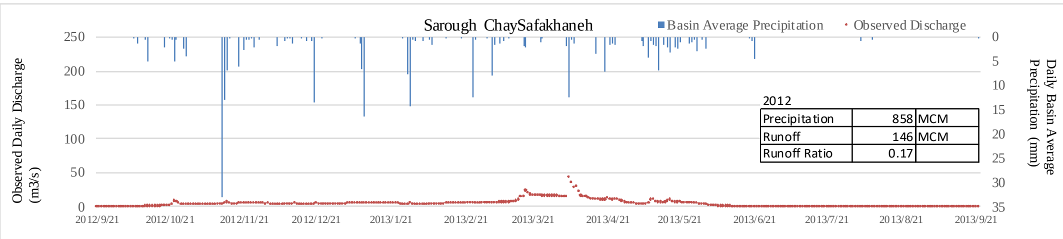


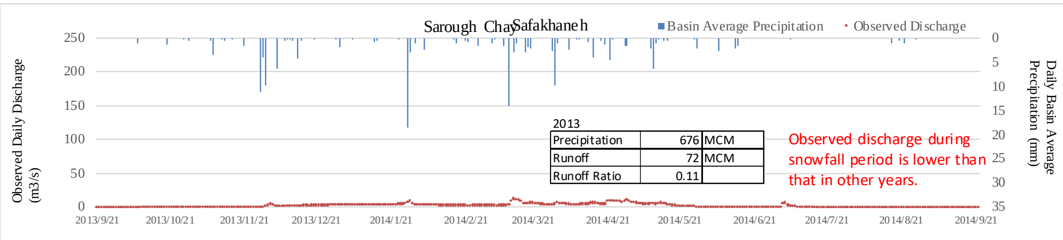




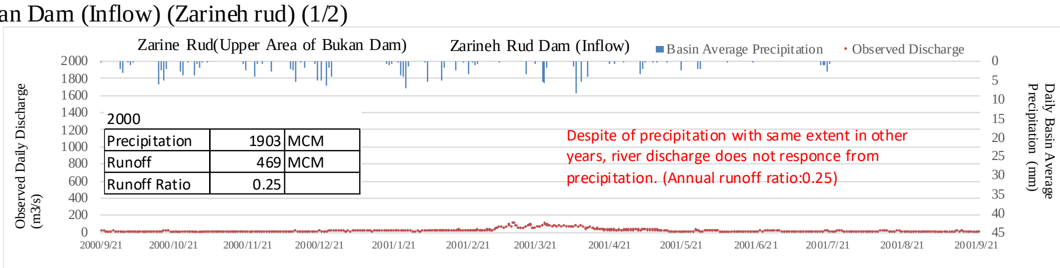


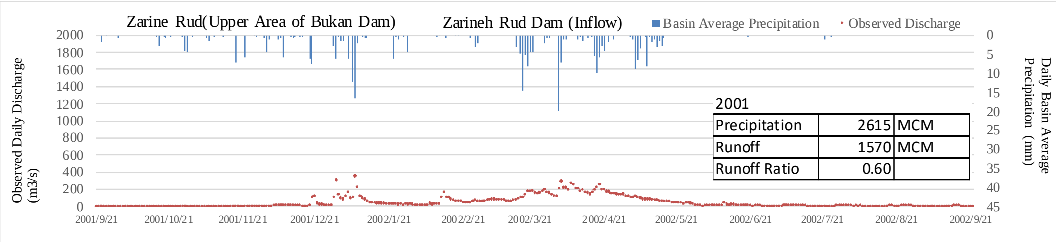


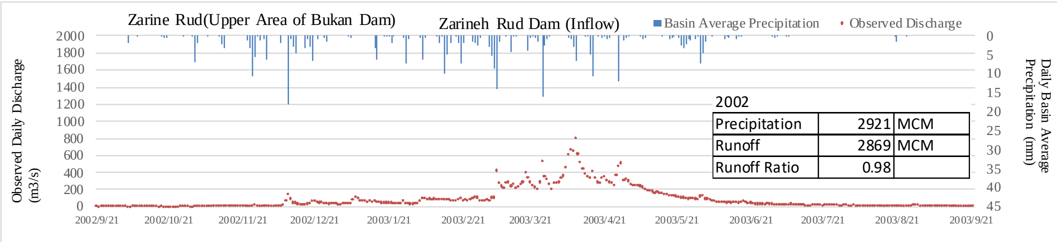


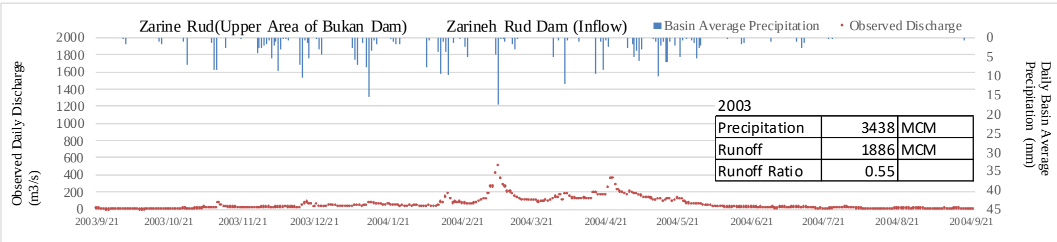


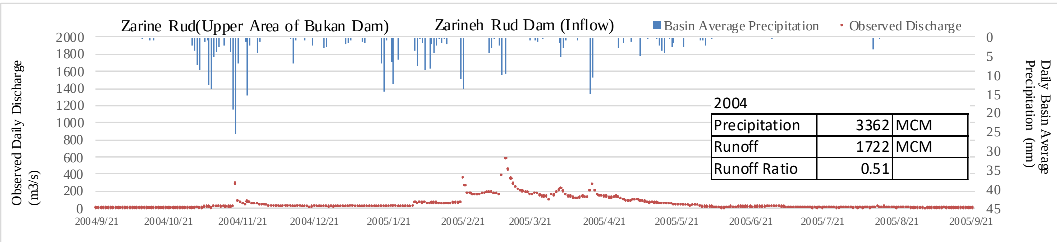
S-5 Bukan Dam (Inflow) (Zarineh rud) (1/2)

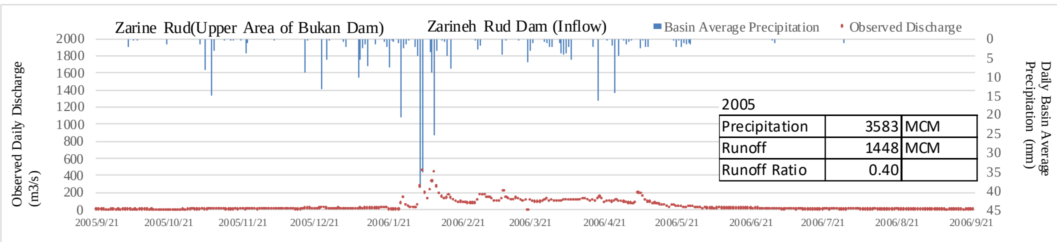


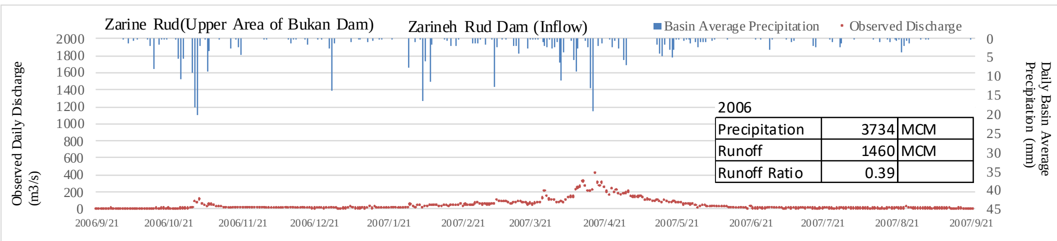




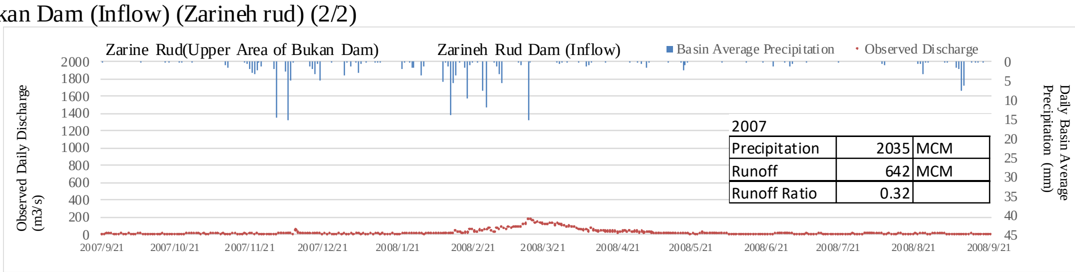


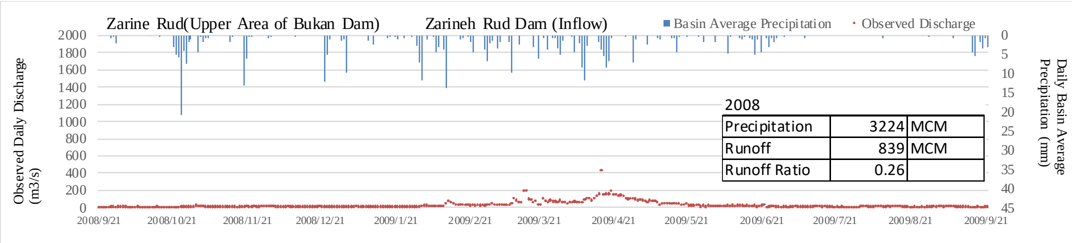


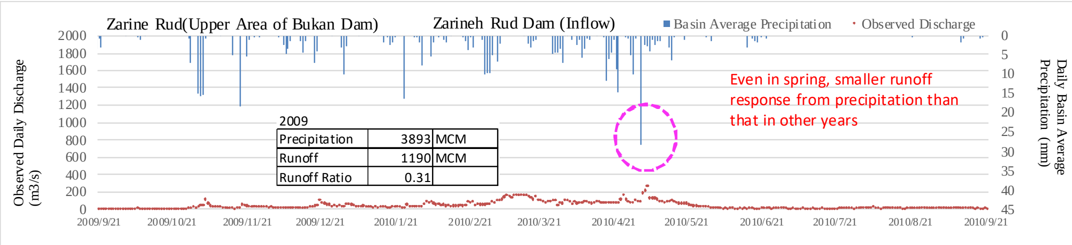


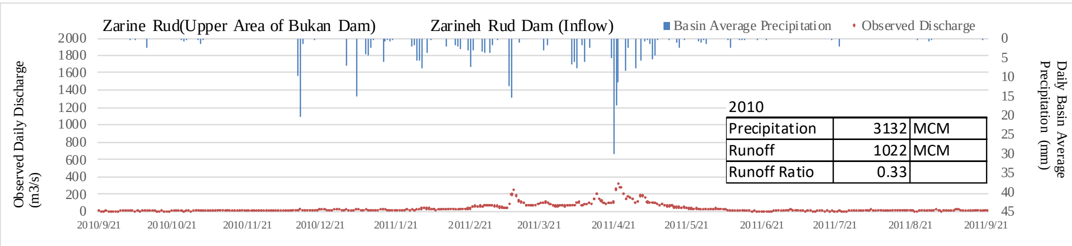


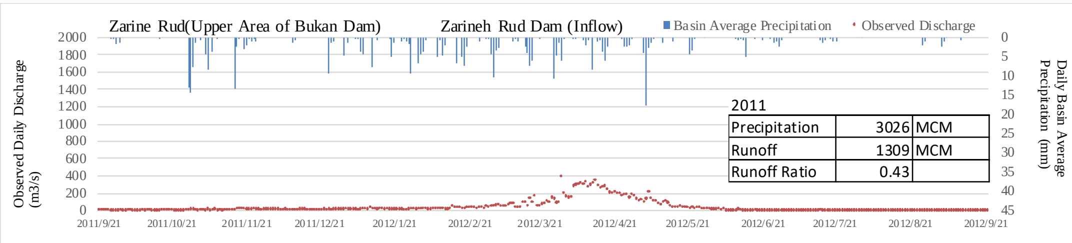
S-5 Bukan Dam (Inflow) (Zarineh rud) (2/2)

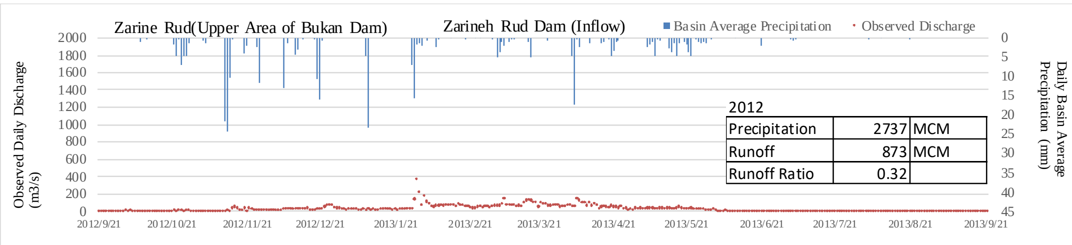


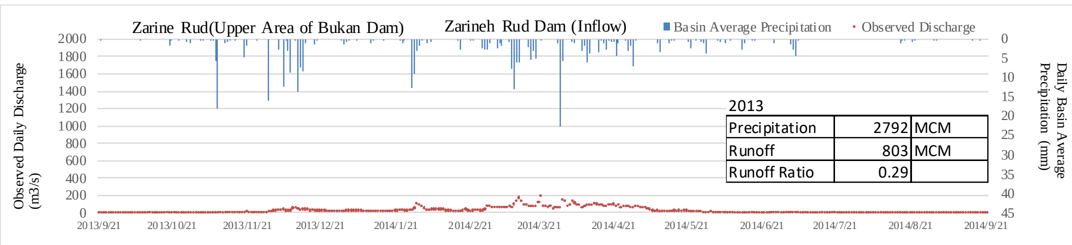




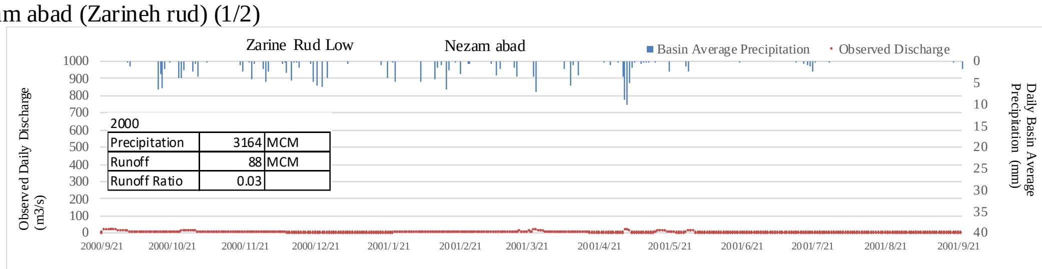


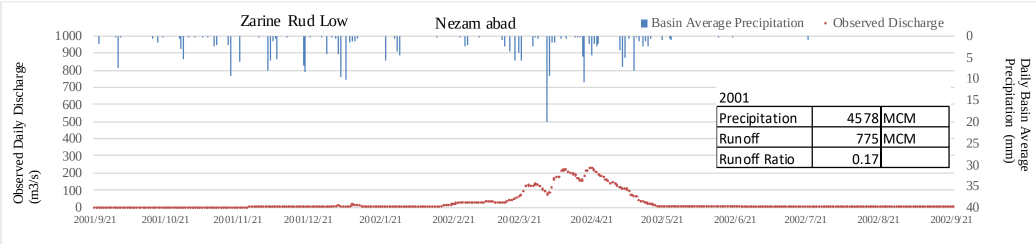


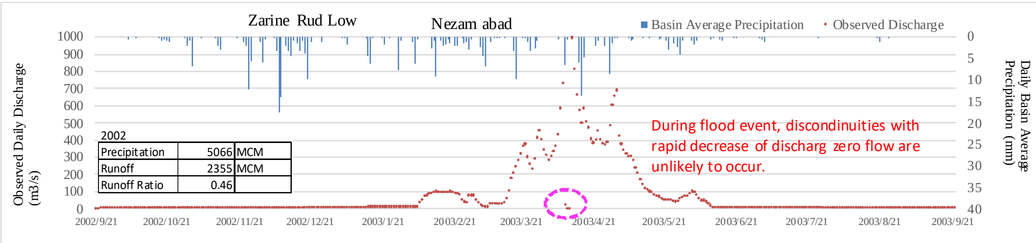


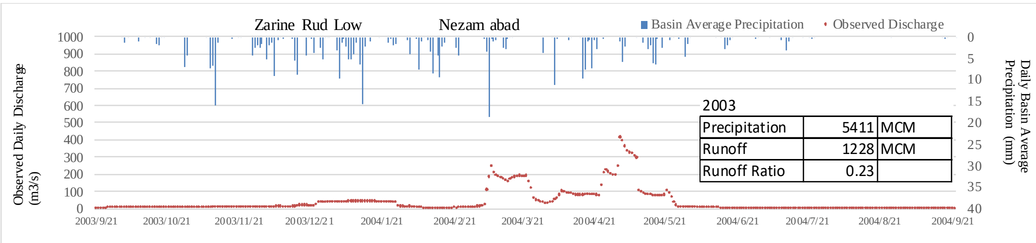


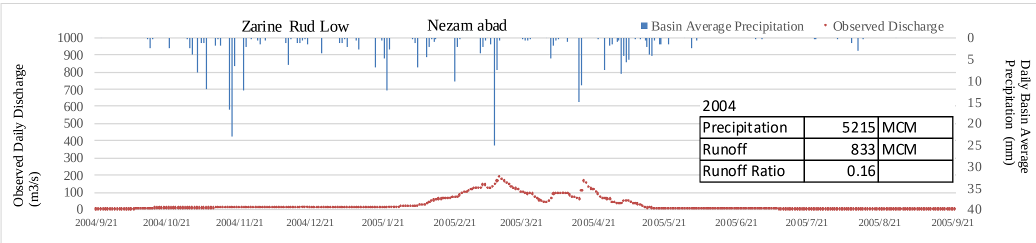
S-6 Nezam abad (Zarineh rud) (1/2)

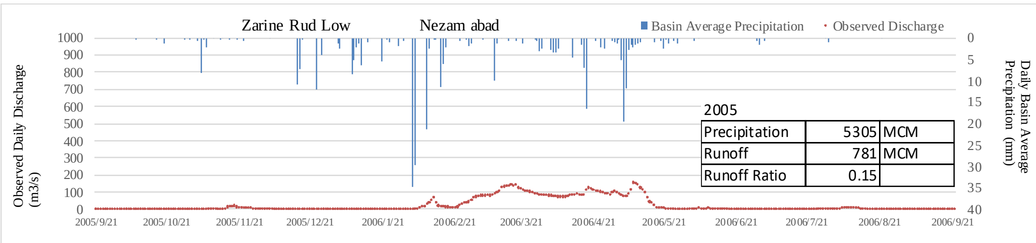


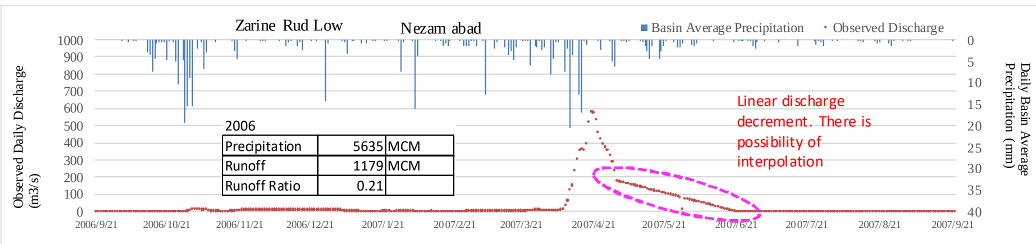




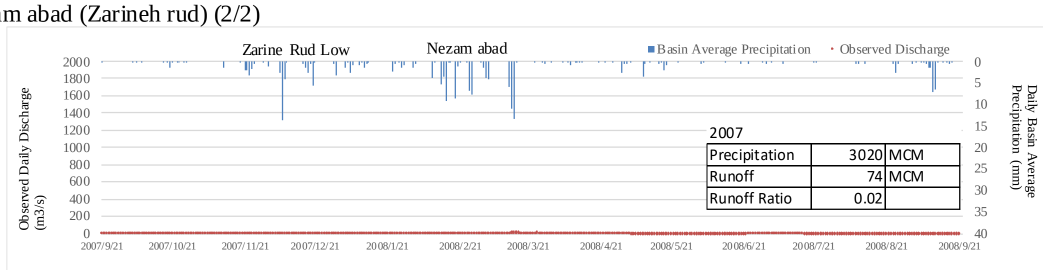


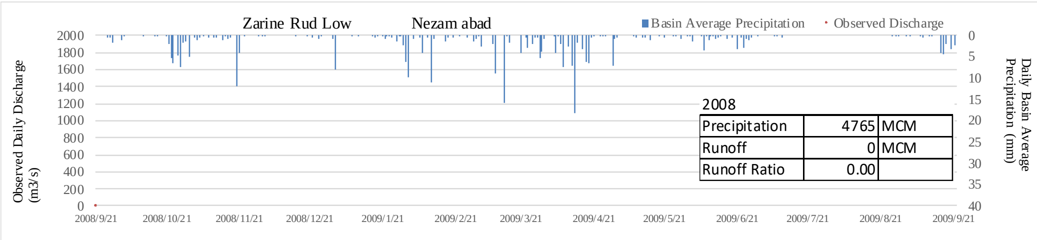


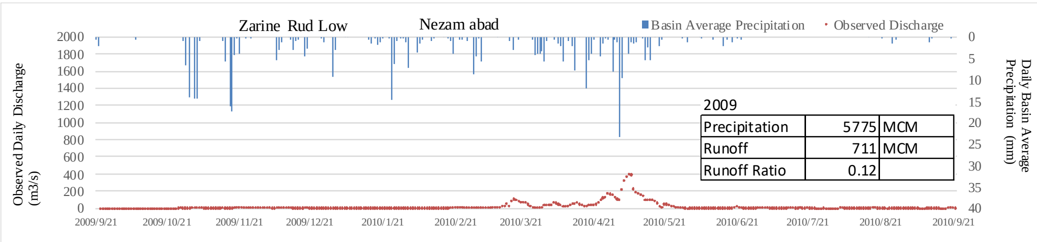


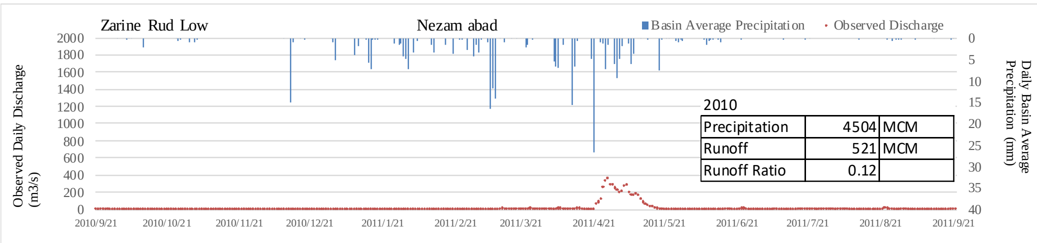


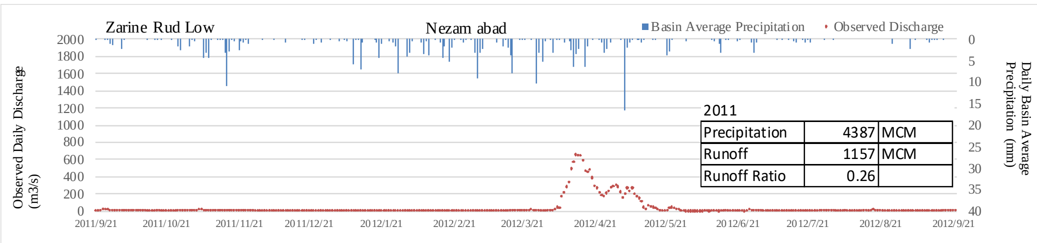
S-6 Nezam abad (Zarineh rud) (2/2)

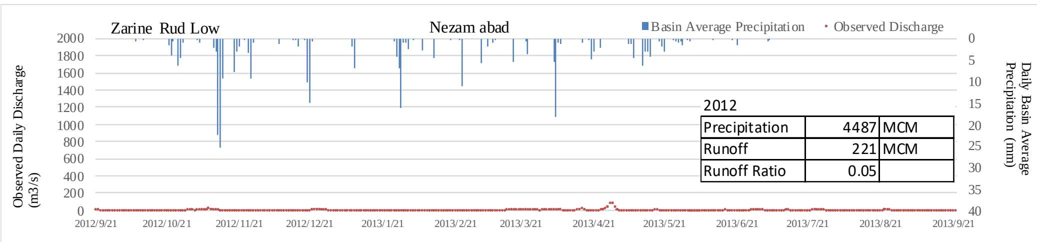


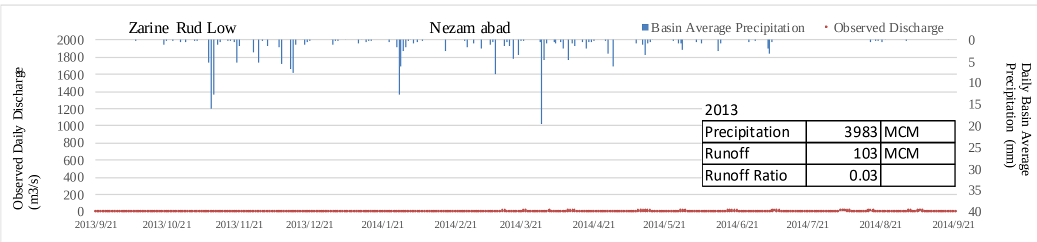




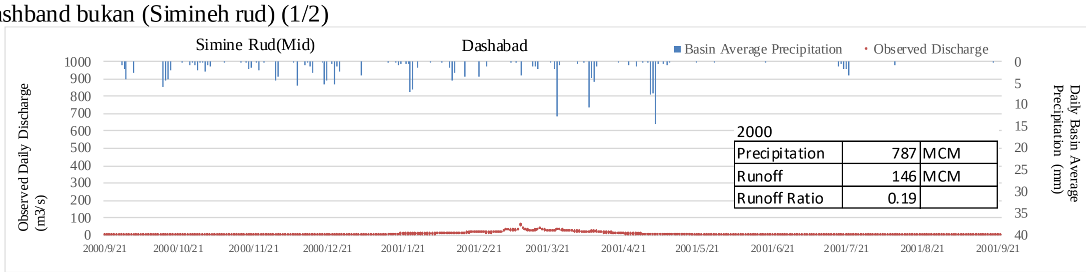


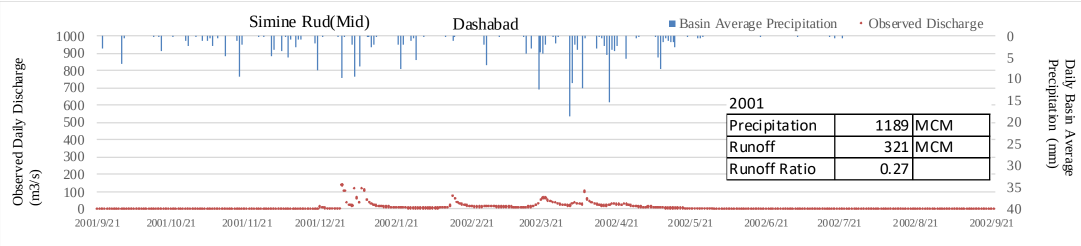


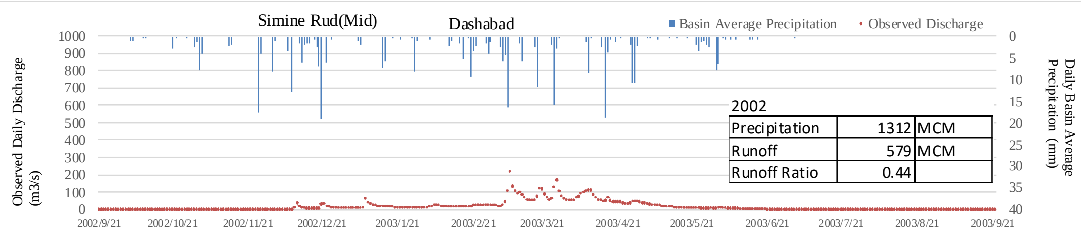


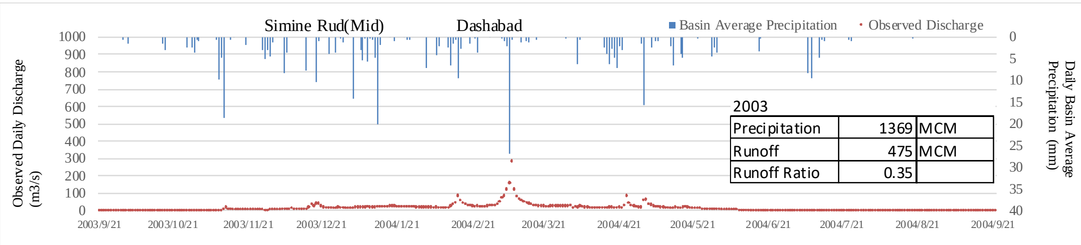


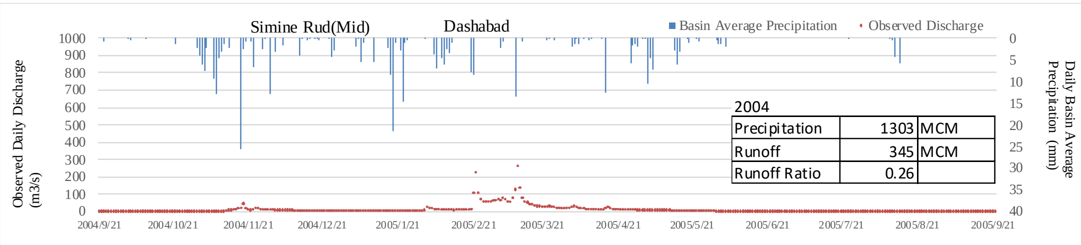
S-7 Dashband bukan (Simineh rud) (1/2)

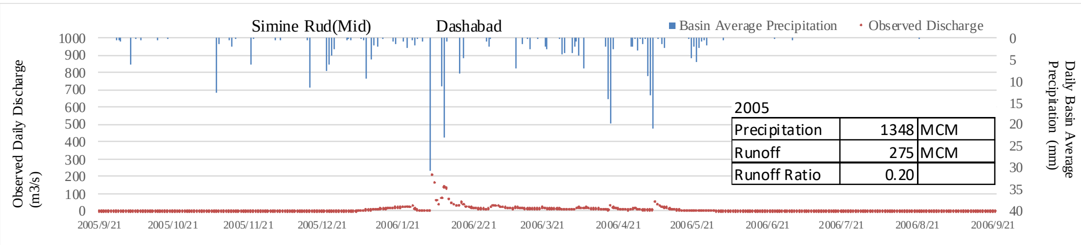


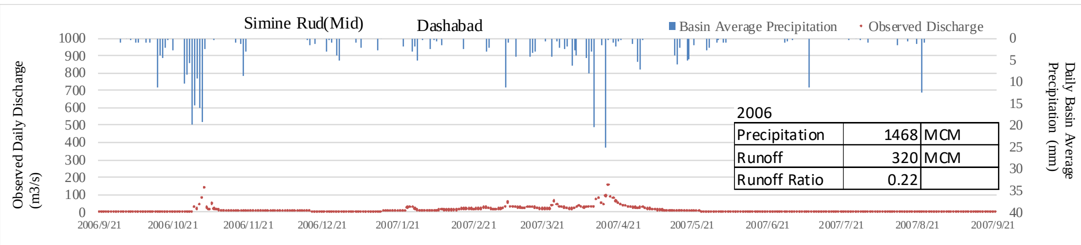




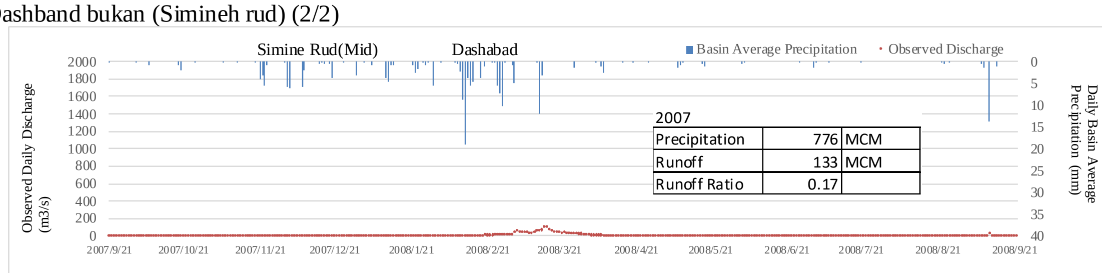


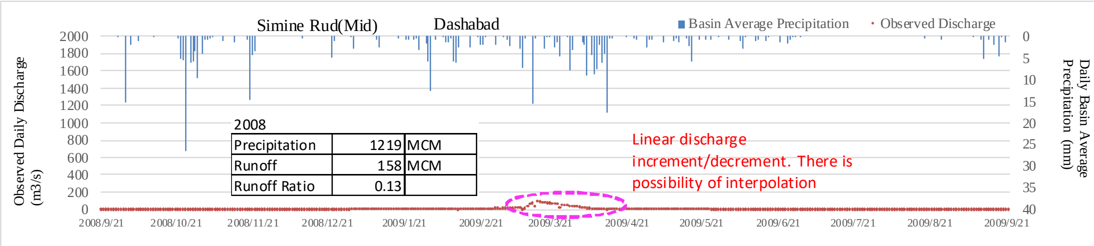


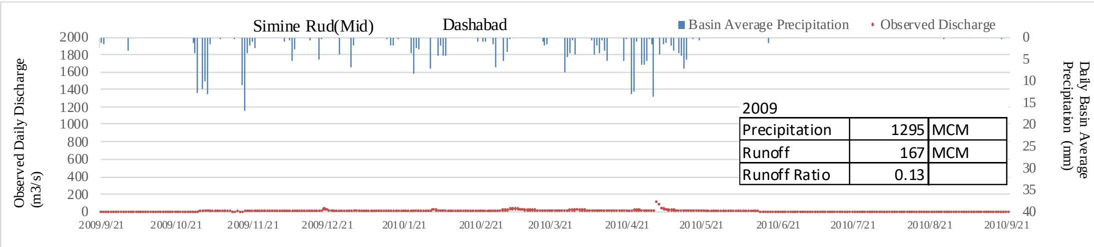


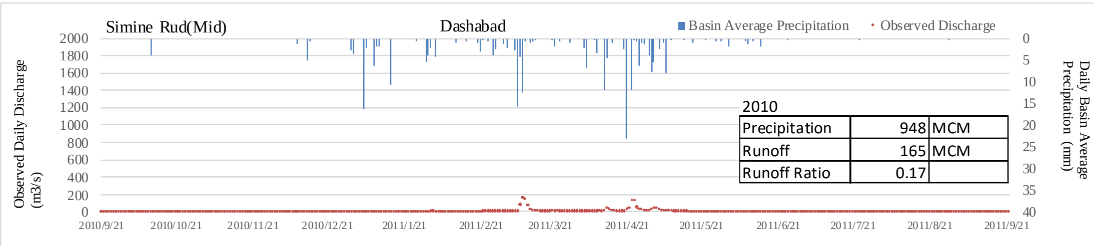


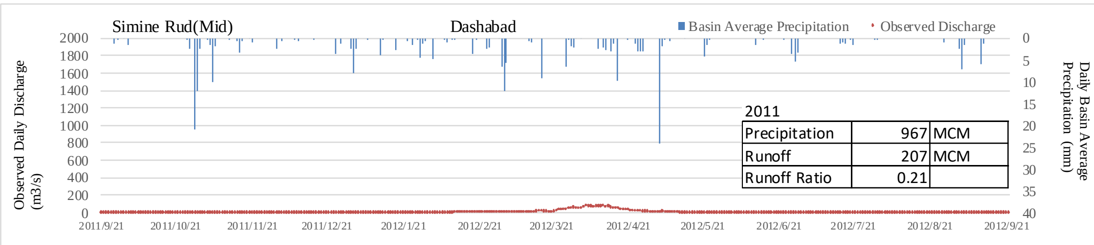
S-7 Dashband bukan (Simineh rud) (2/2)

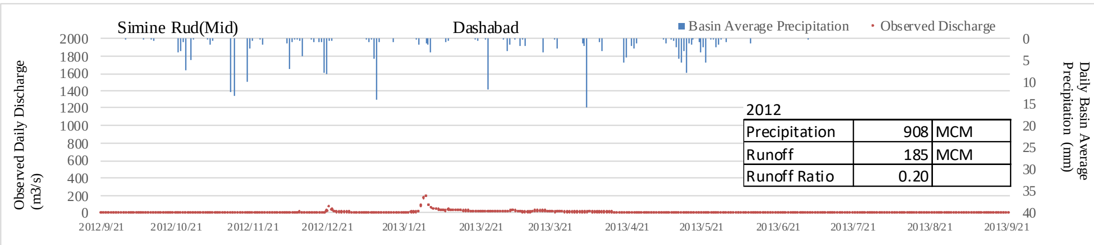


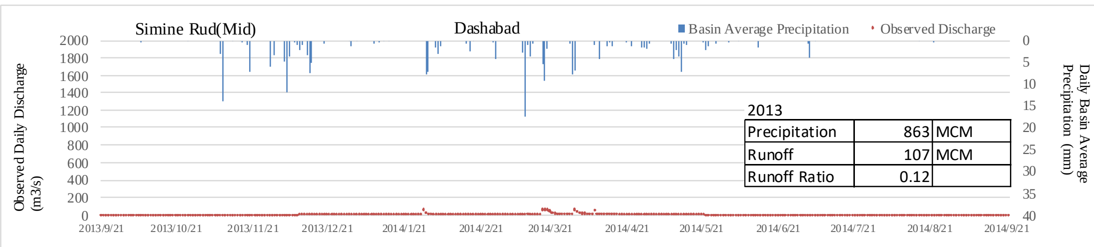




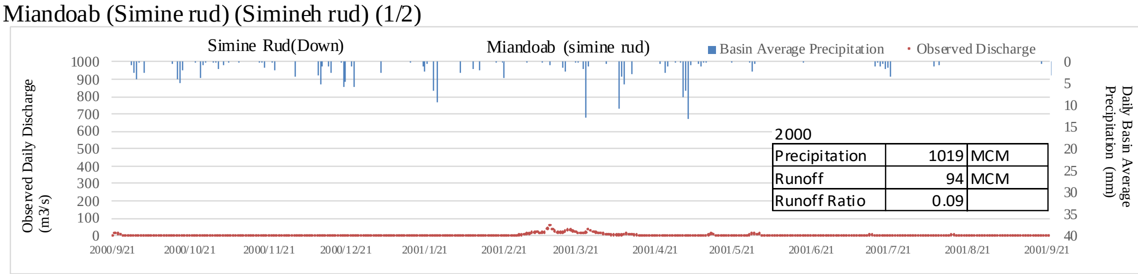


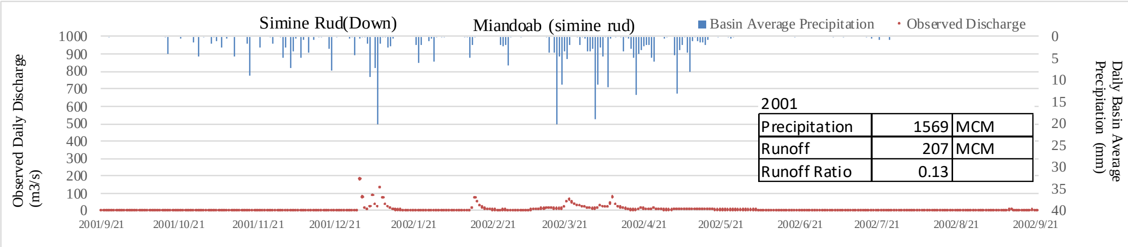


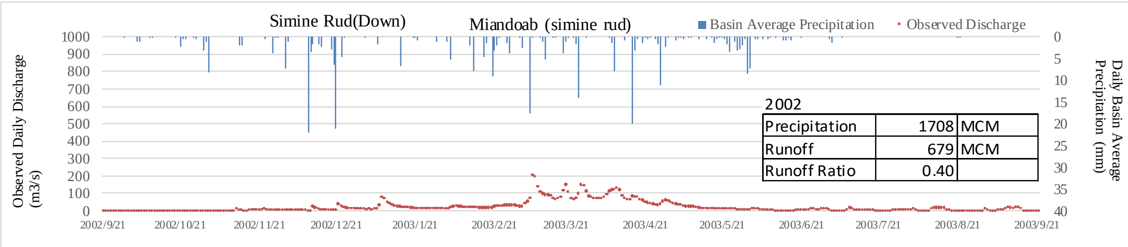


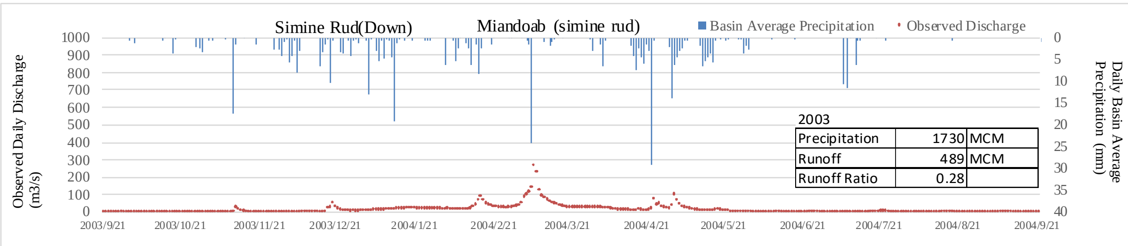


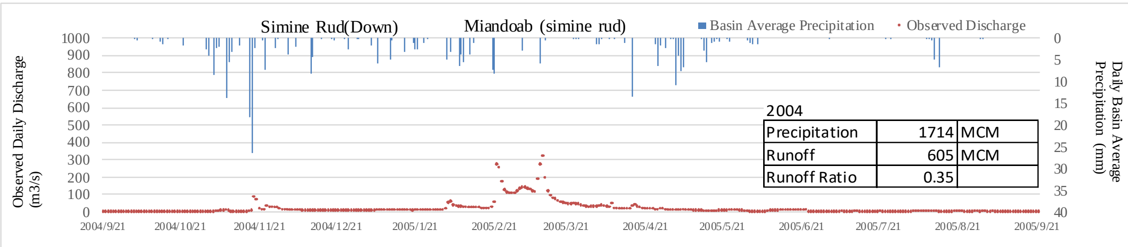
S-8 Miandoab (Simine rud) (Simineh rud) (1/2)

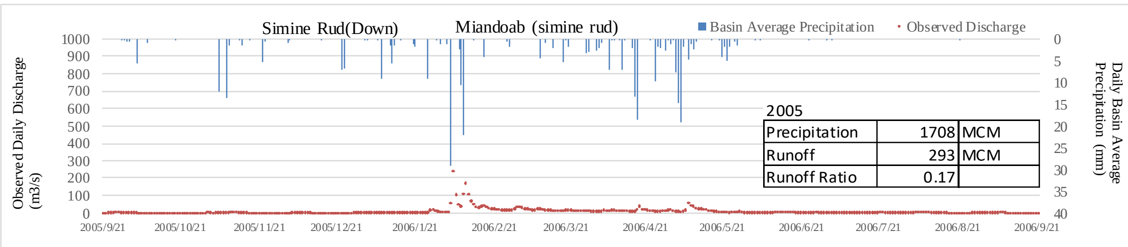


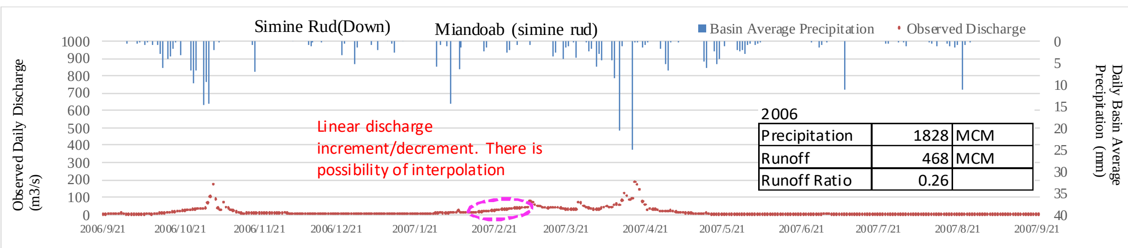




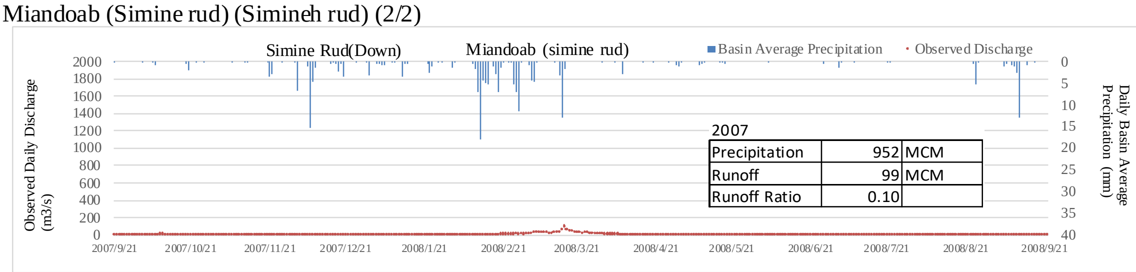


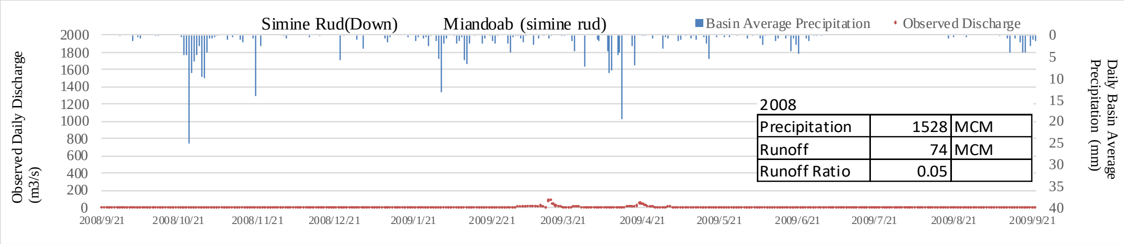


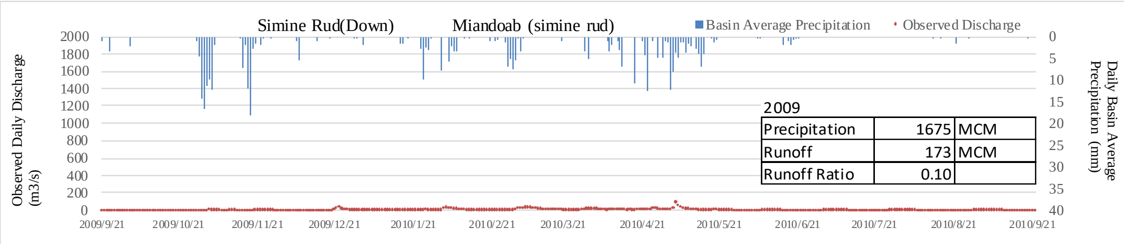


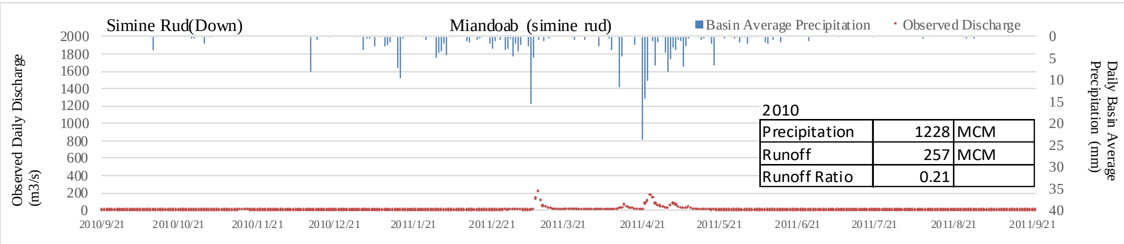


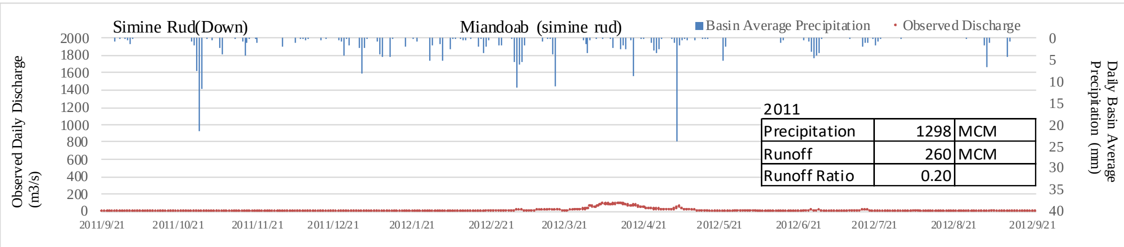
S-8 Miandoab (Simine rud) (Simineh rud) (2/2)

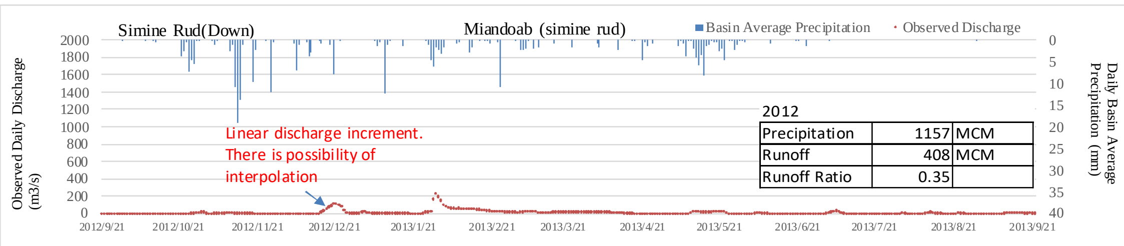


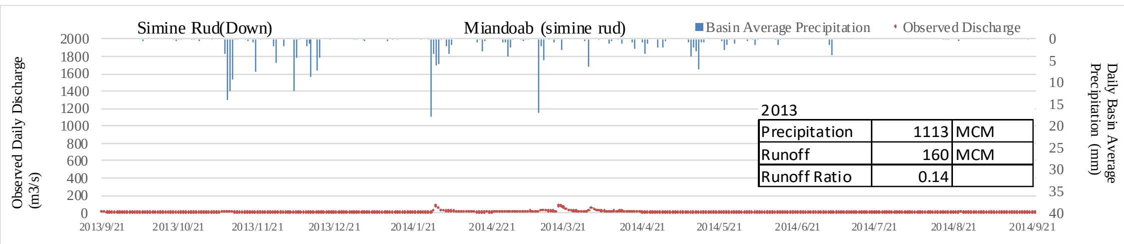




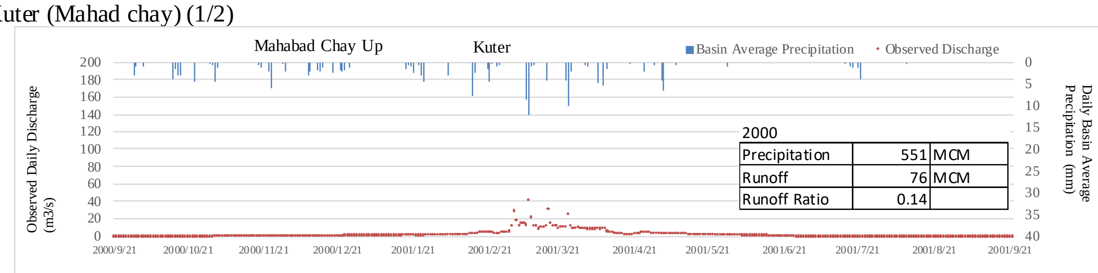


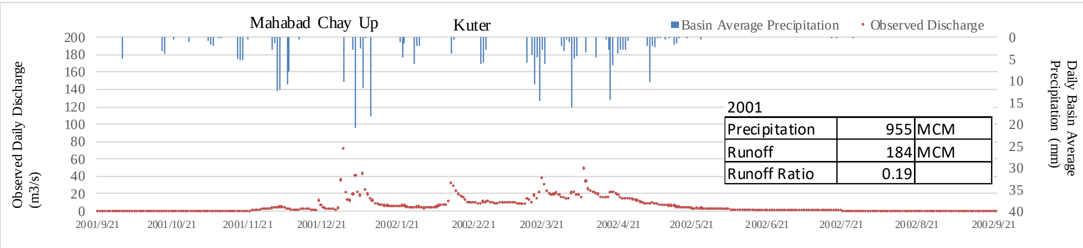


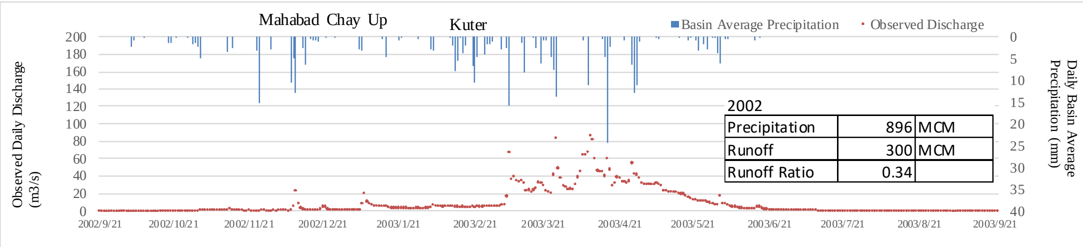


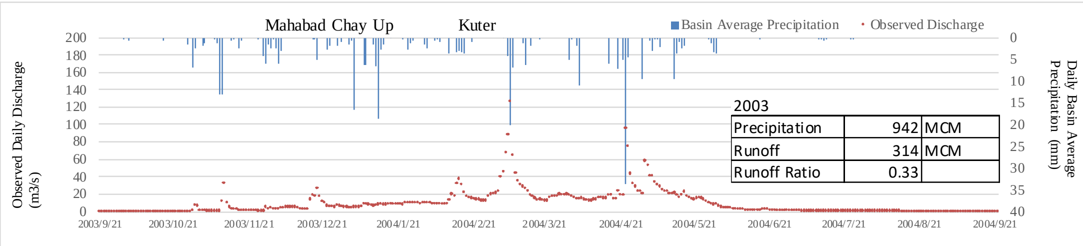


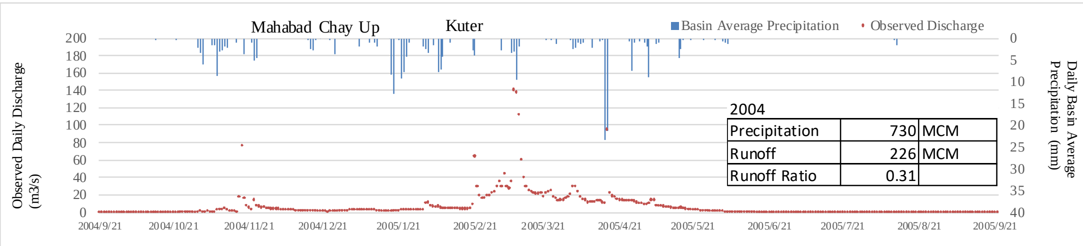
S-9 Kuter (Mahad chay) (1/2)

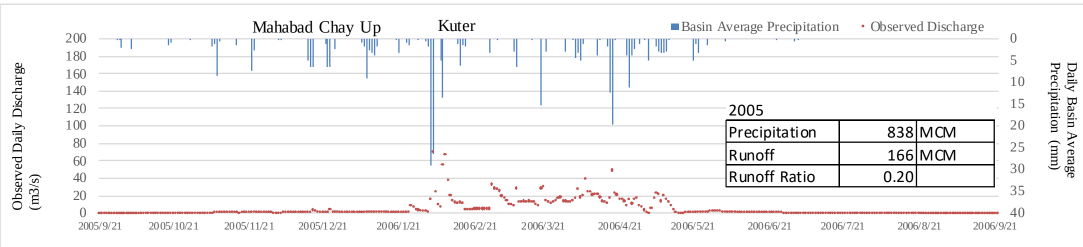


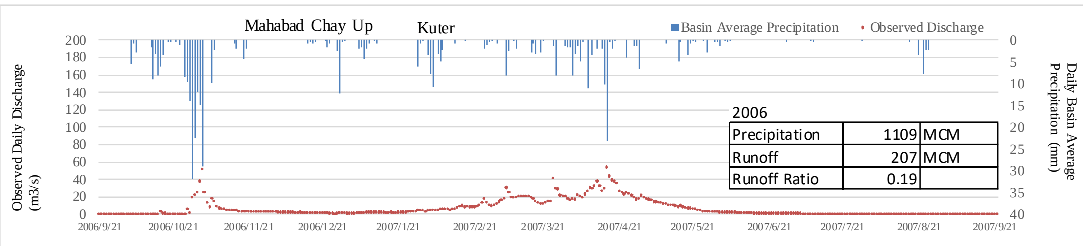




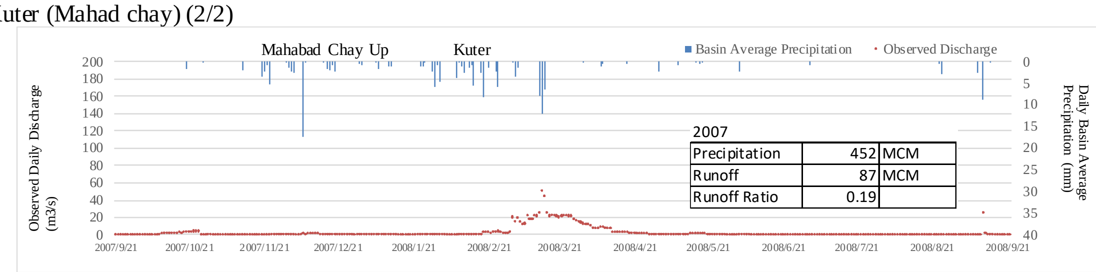


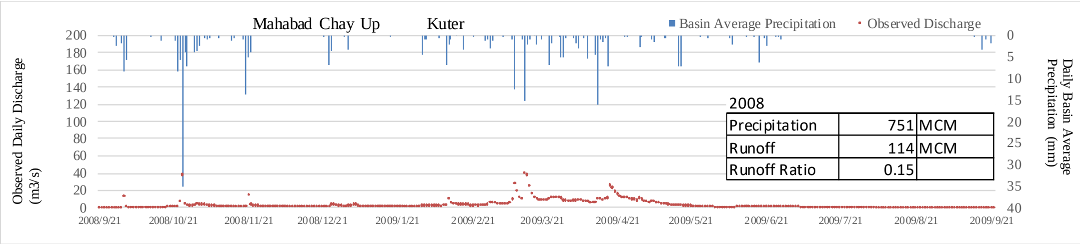


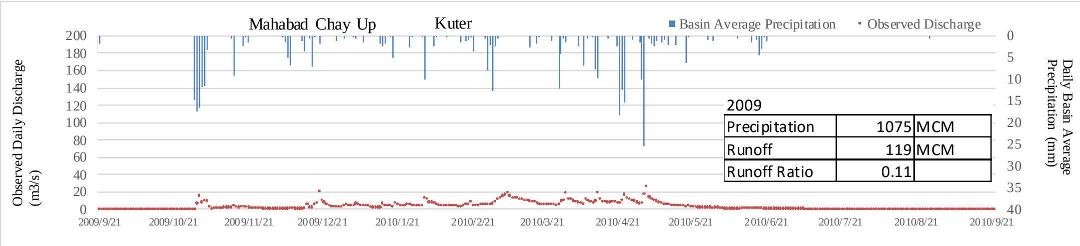


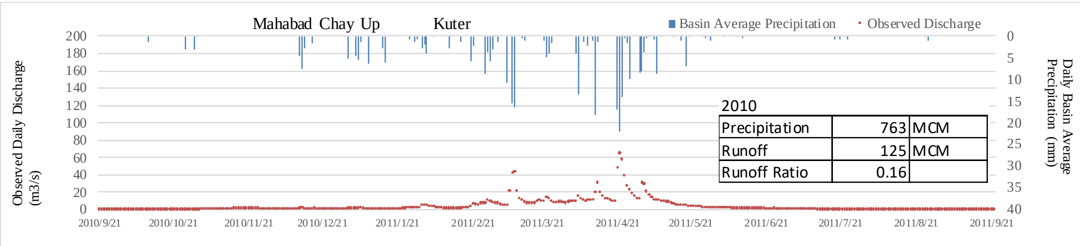


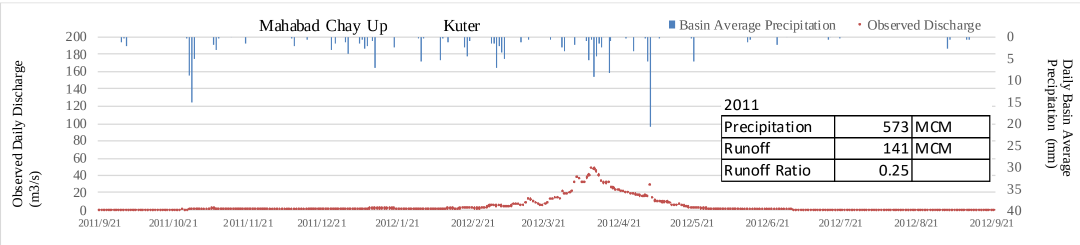
S-9 Kuter (Mahad chay) (2/2)

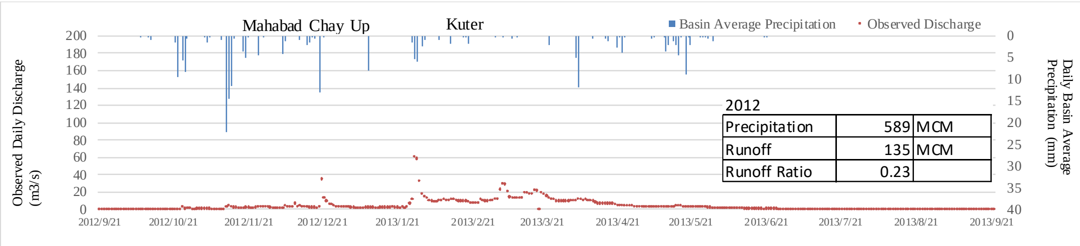


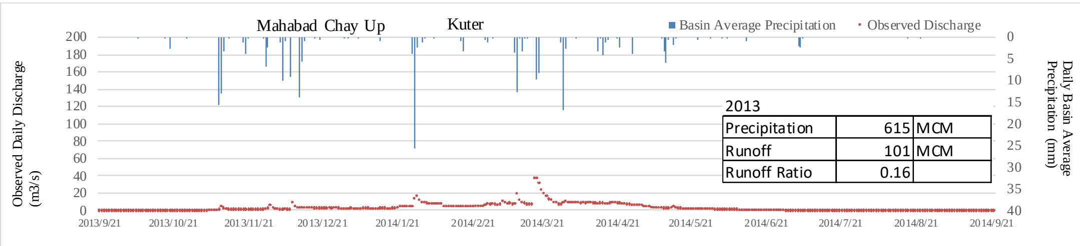




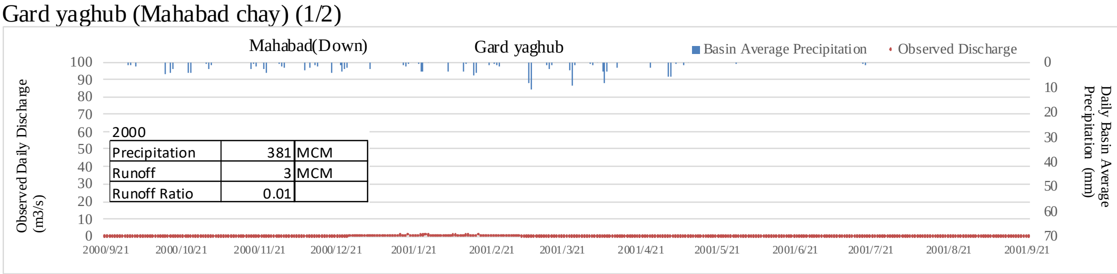


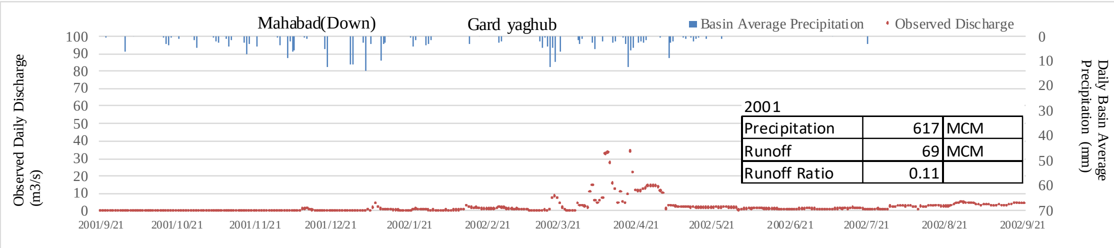


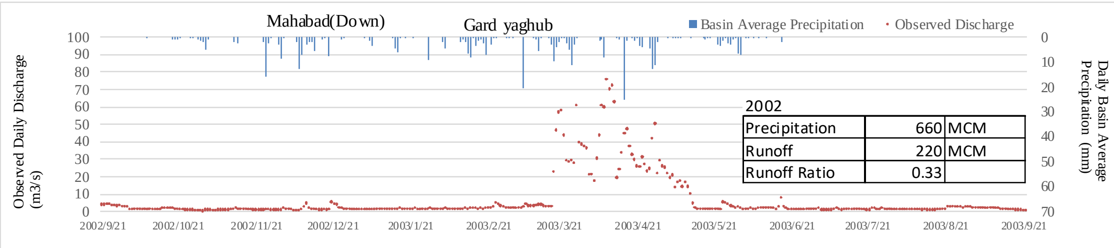


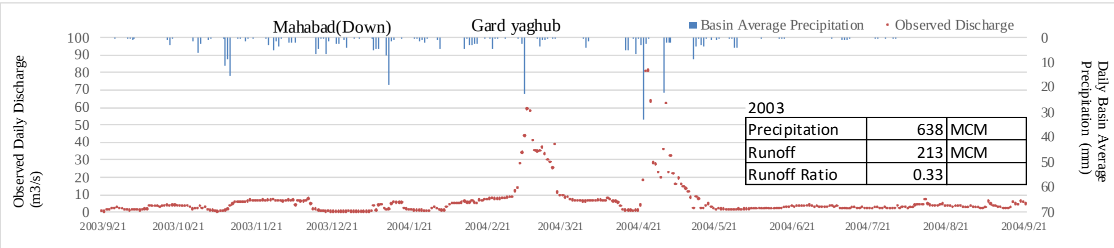


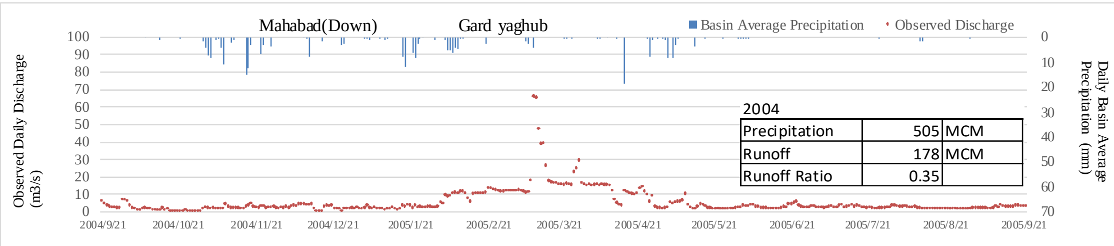
S-10 Gard yaghub (Mahabad chay) (1/2)

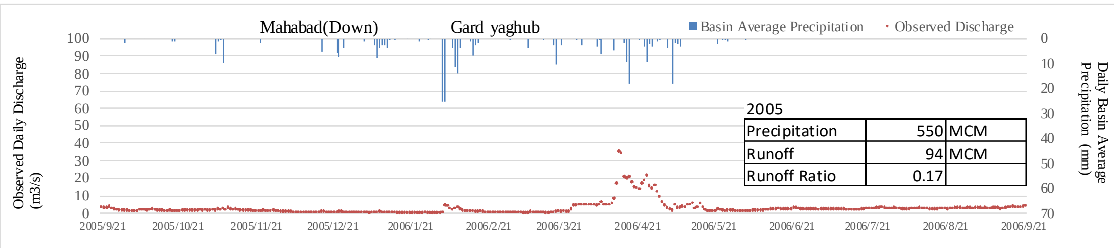


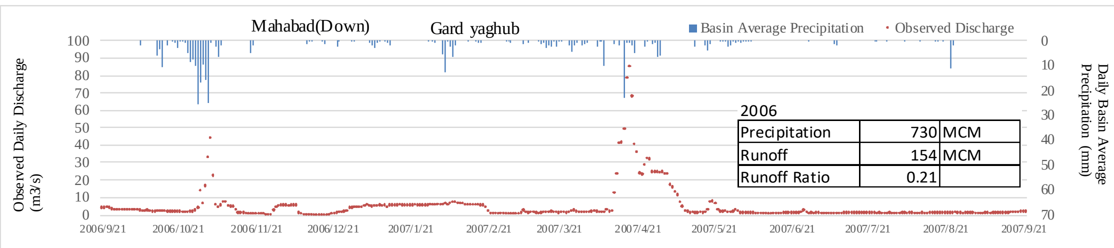




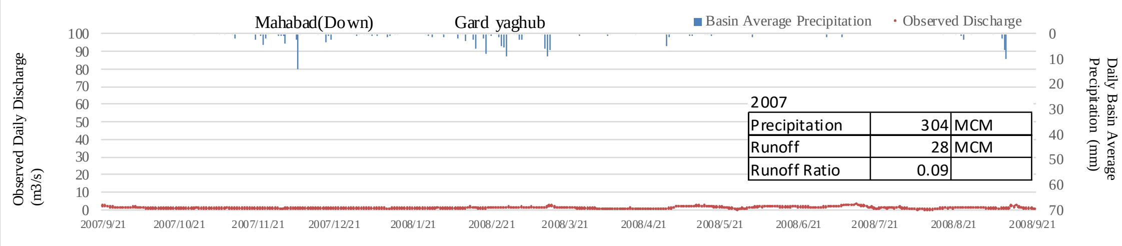


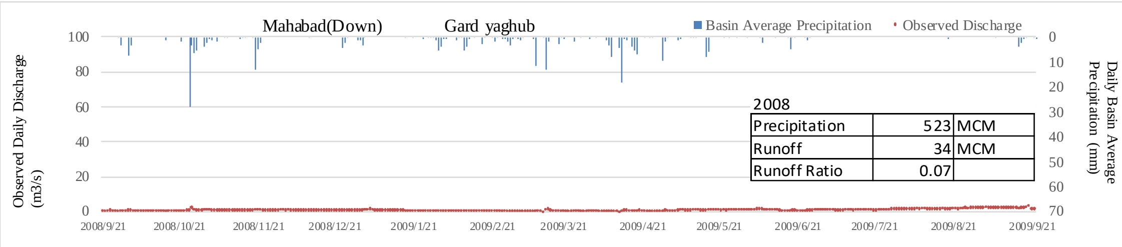


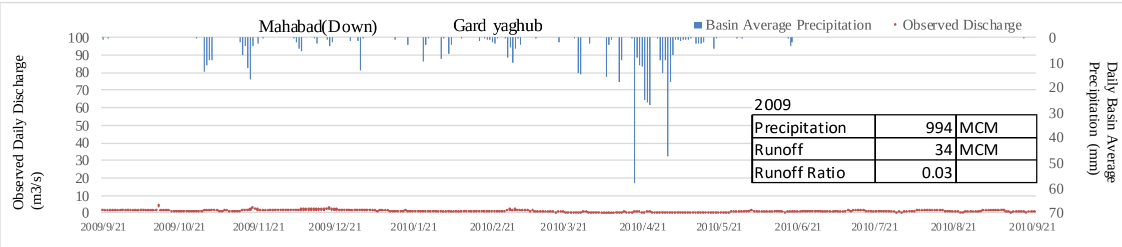


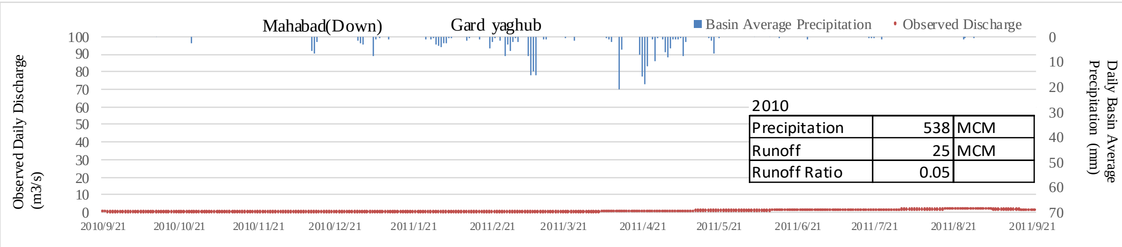


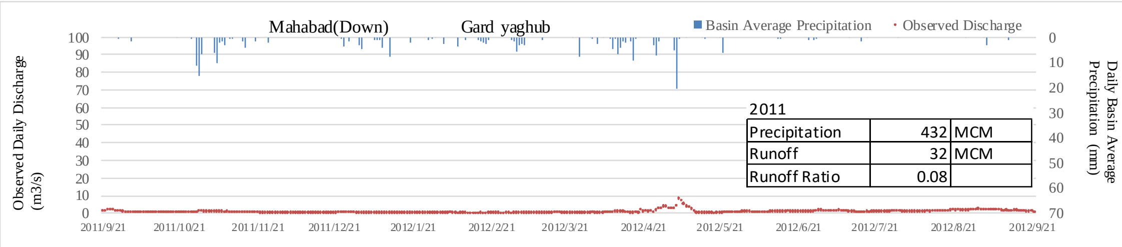
S-10 Gard yaghub (Mahabad chay) (2/2)

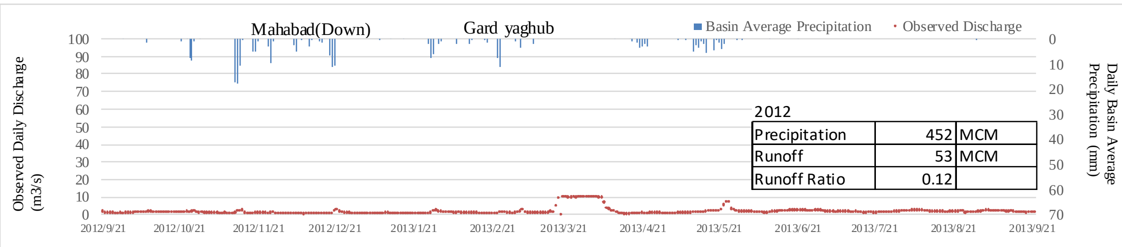


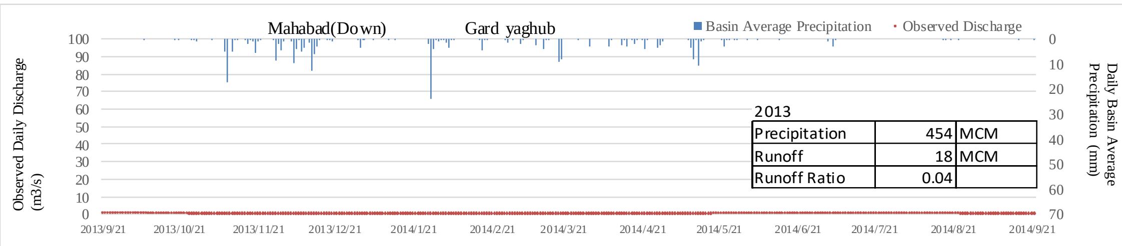




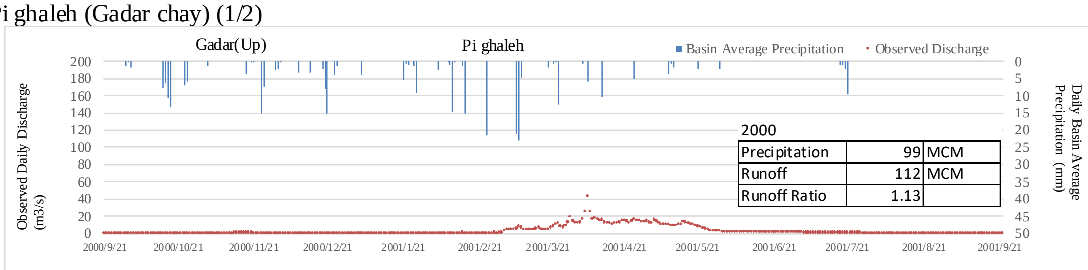


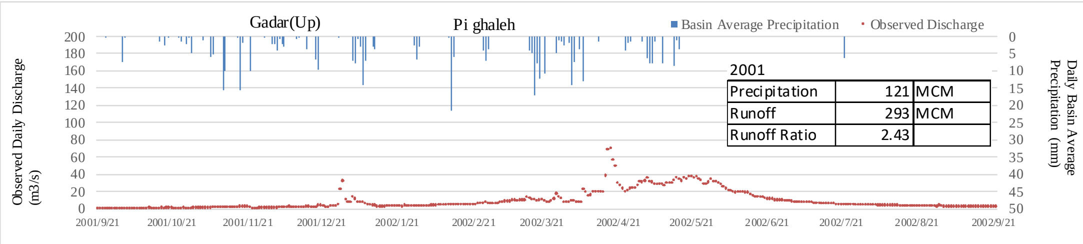


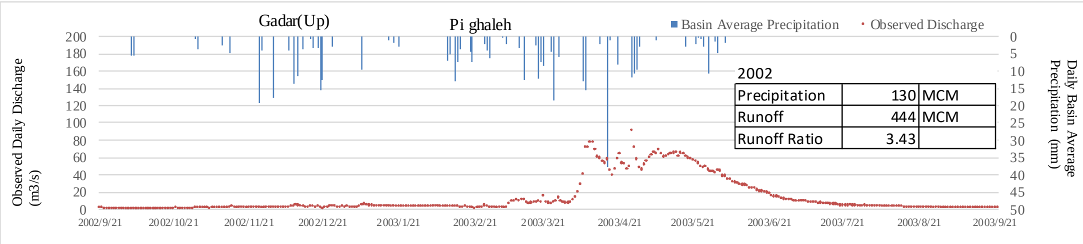


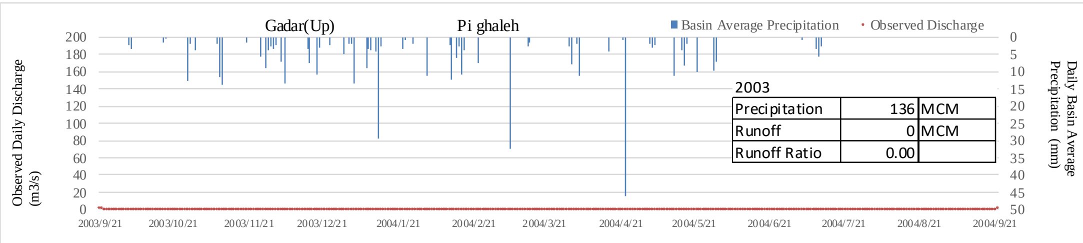


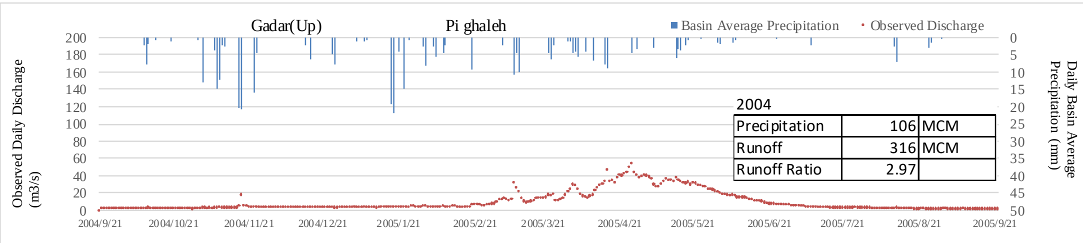
S-11 Pi ghaleh (Gadar chay) (1/2)

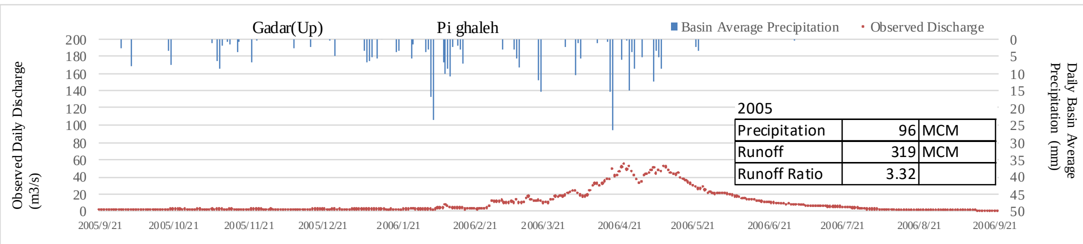


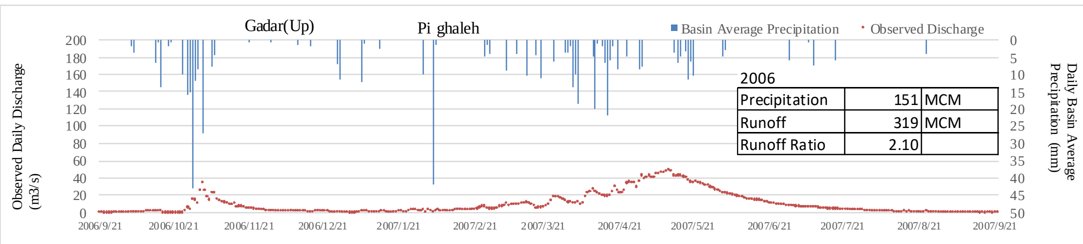




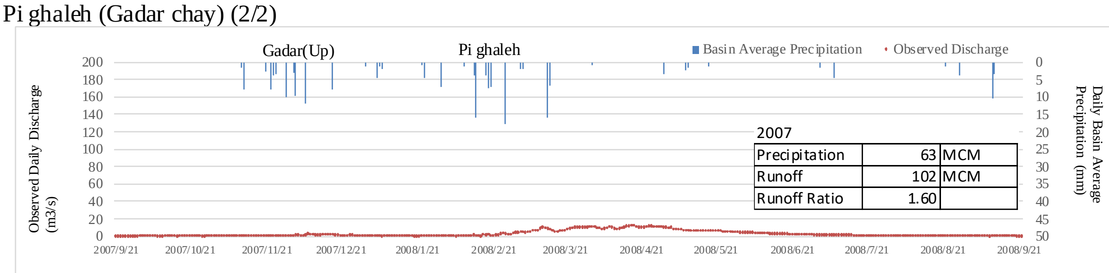


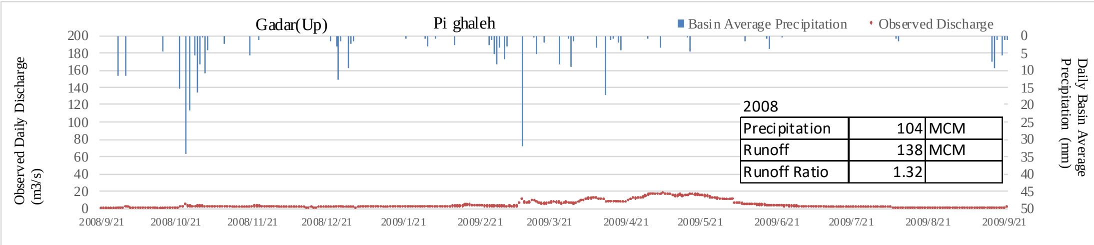


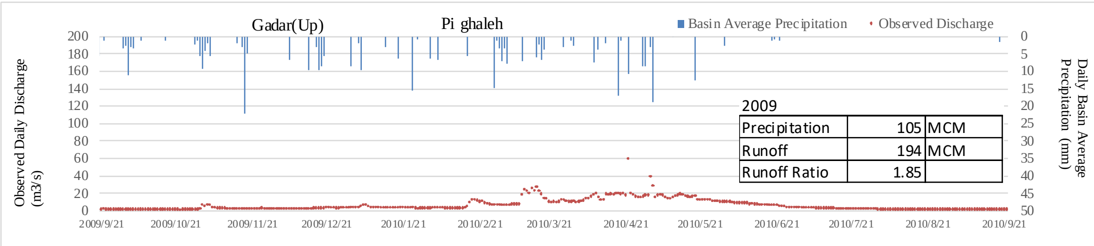


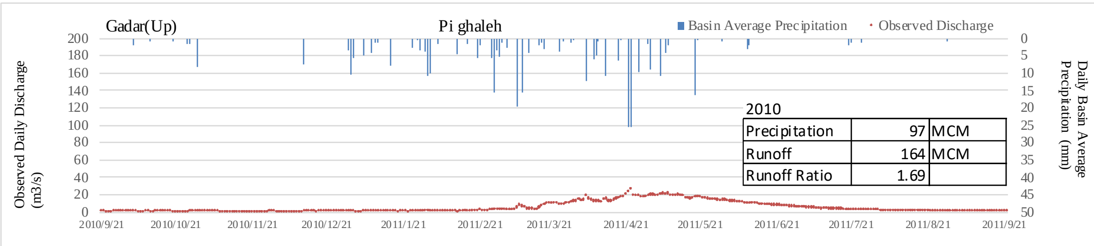


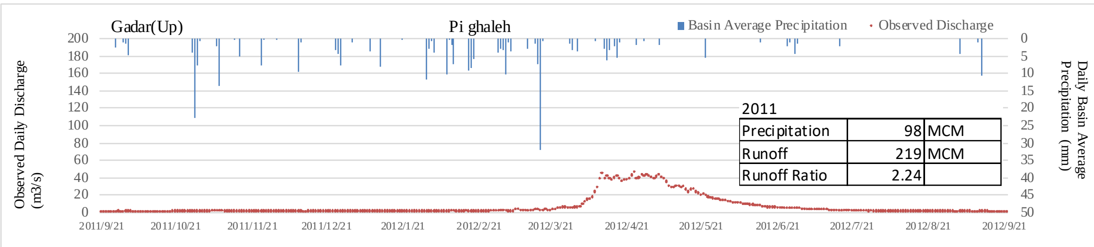
S-11 Pi ghaleh (Gadar chay) (2/2)

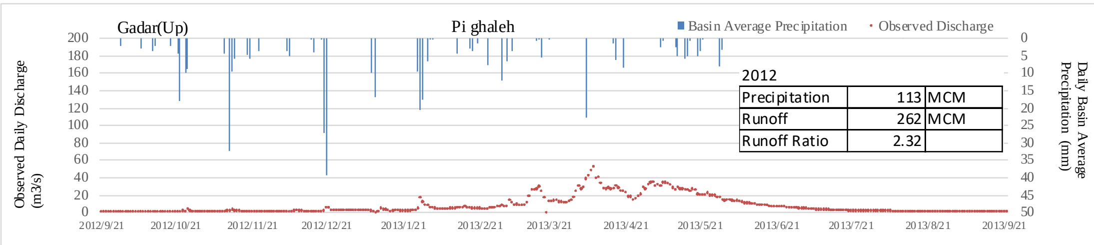


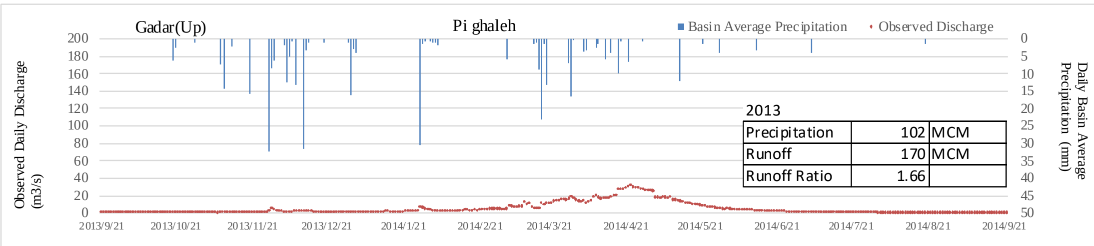




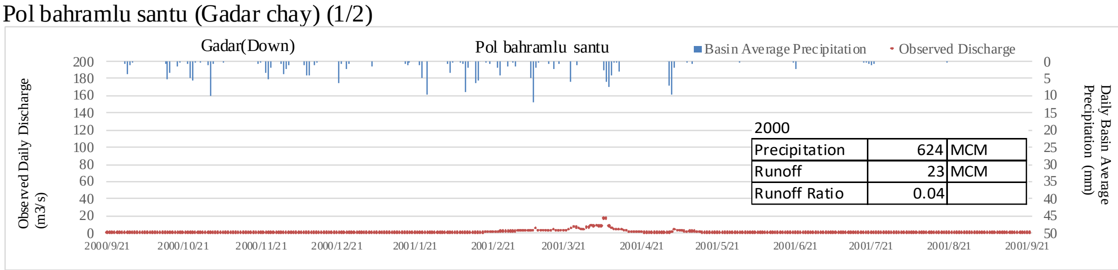


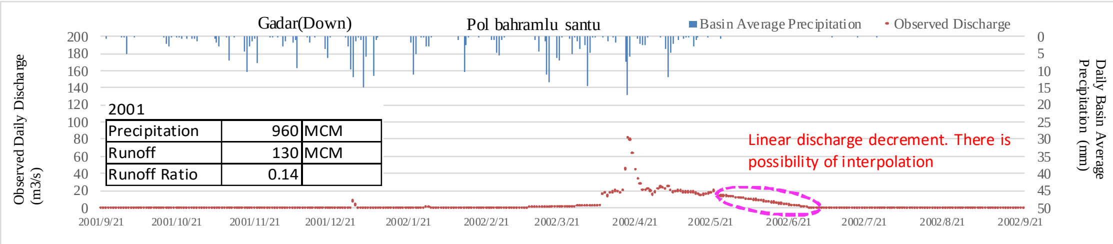


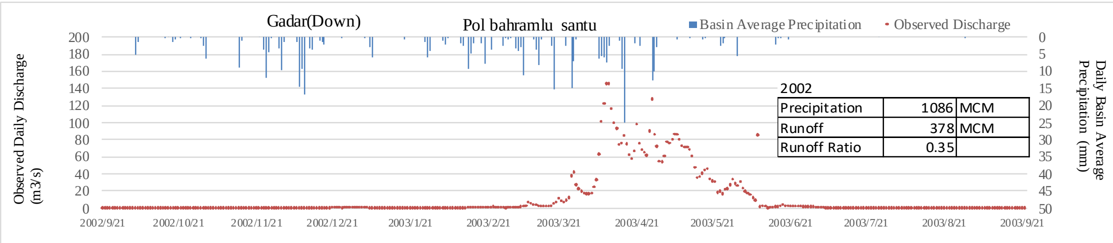


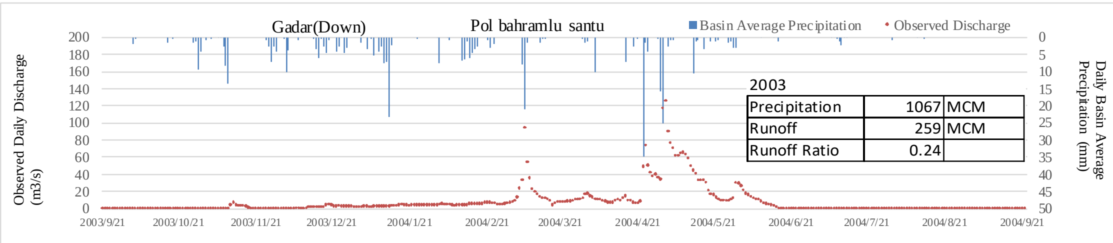


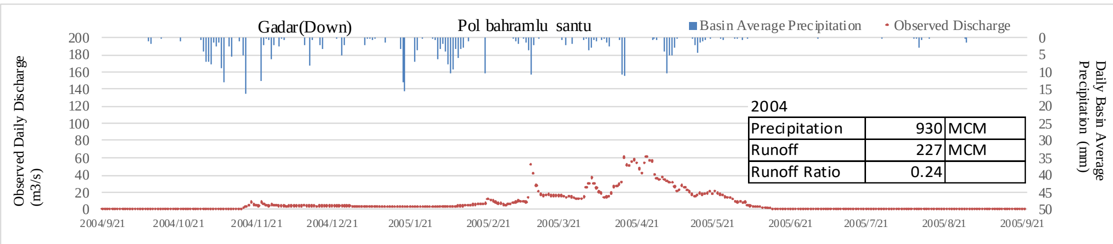
S-12 Pol bahramlu santu (Gadar chay) (1/2)

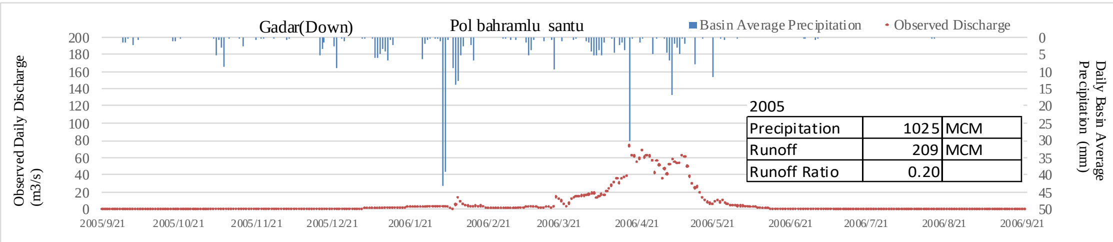


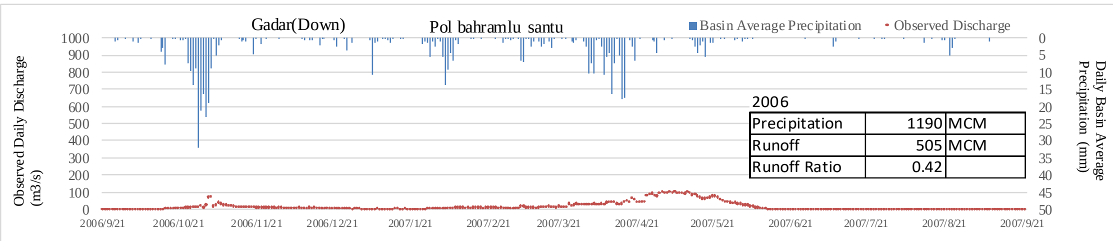




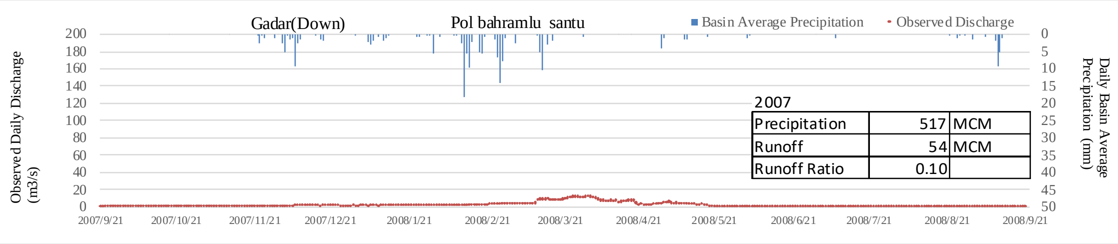


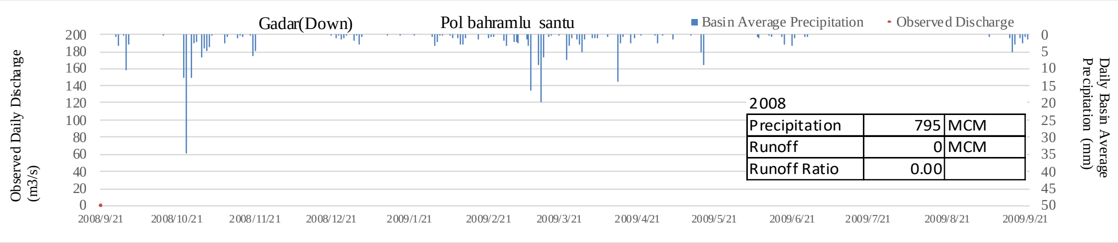


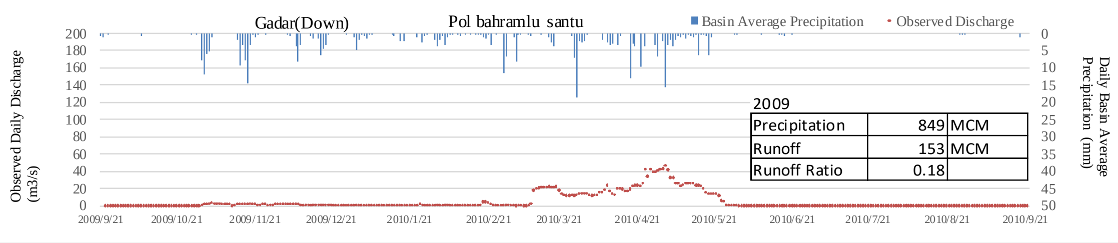


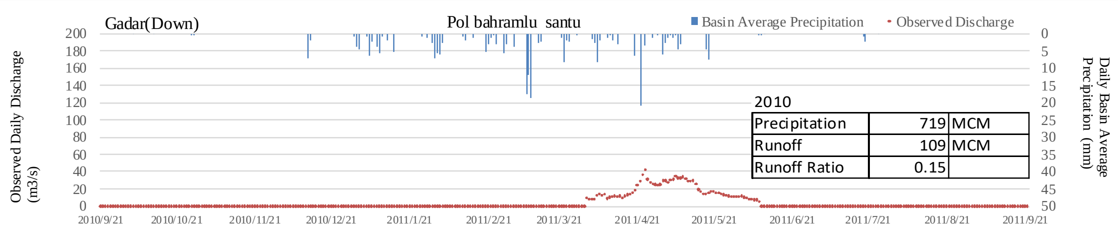


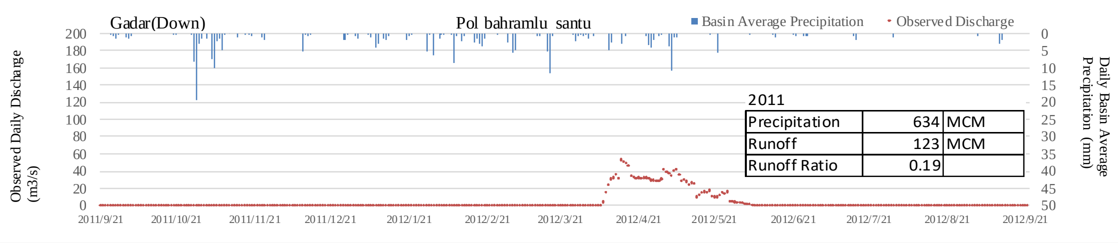
S-12 Pol bahramlu santu (Gadar chay) (2/2)

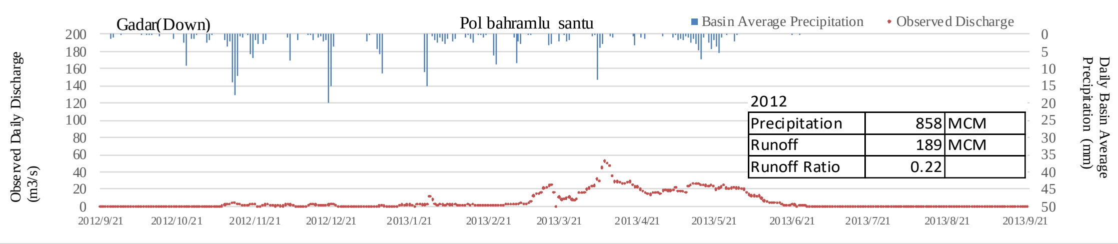


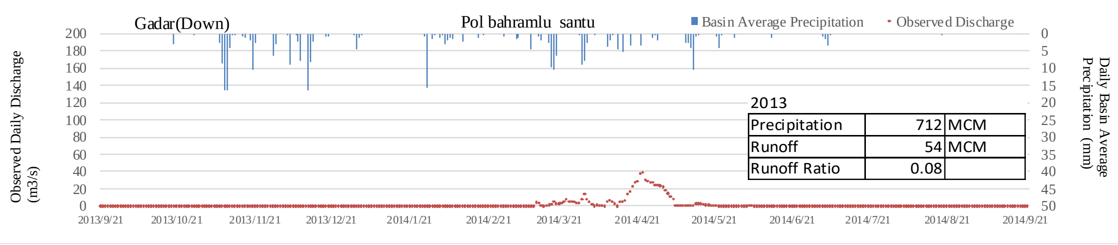




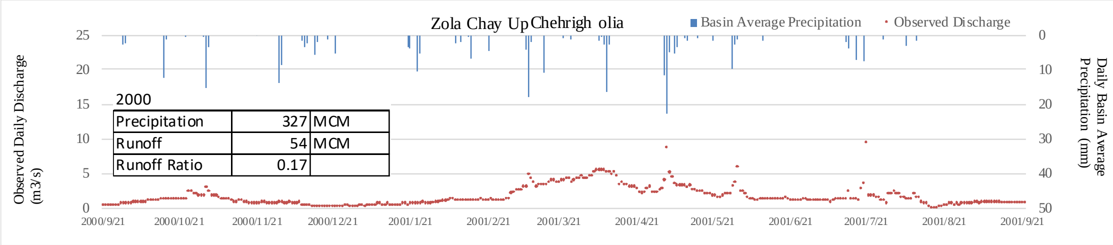


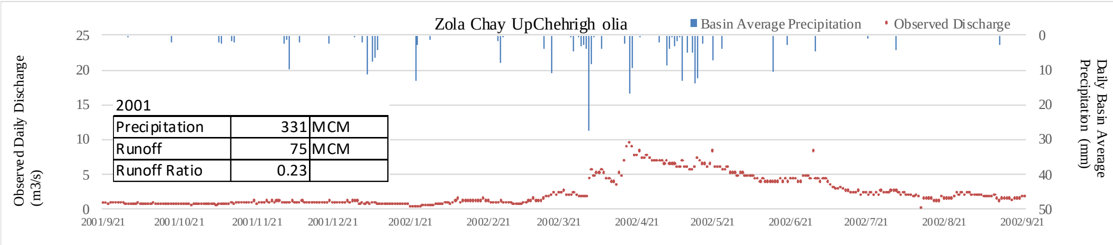


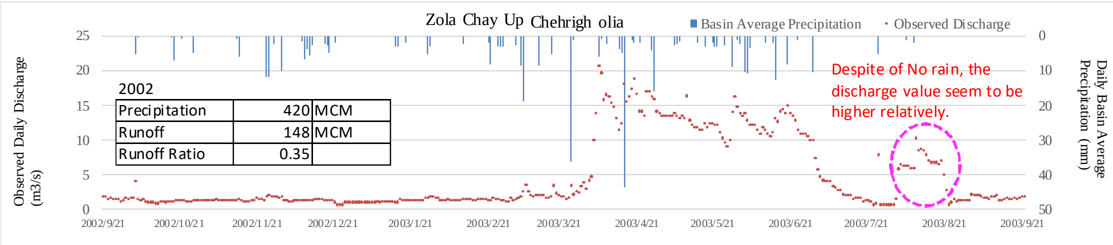


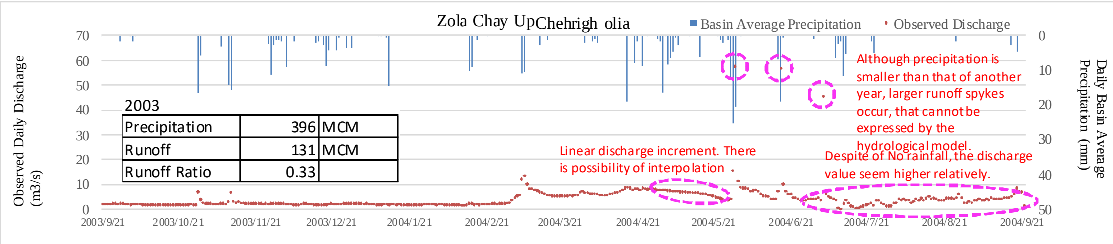


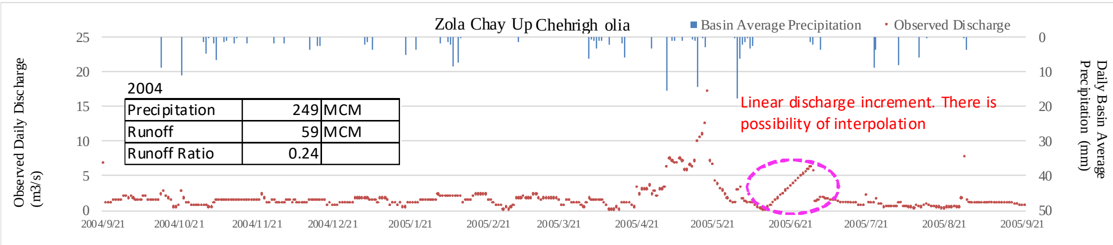
W-1 Yalghuz aghaj (Zola chay) (1/2)

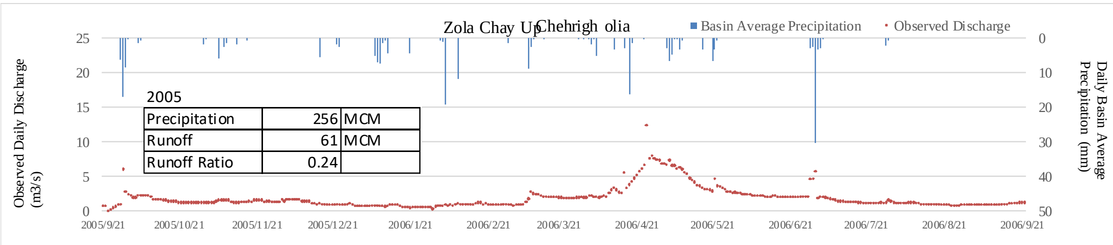


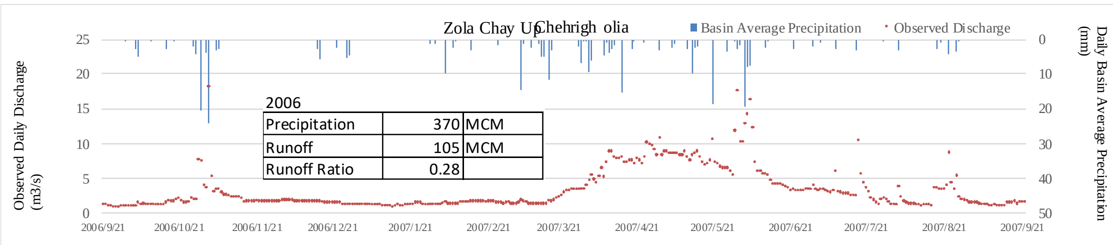




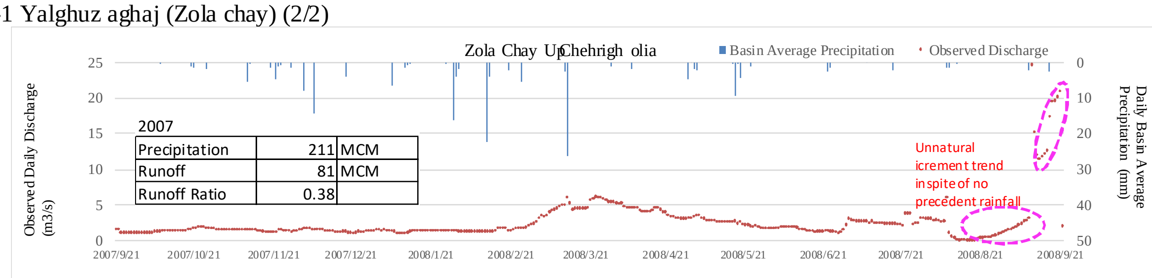


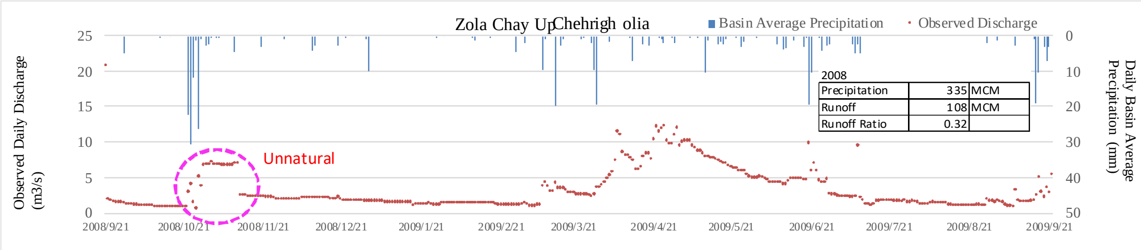


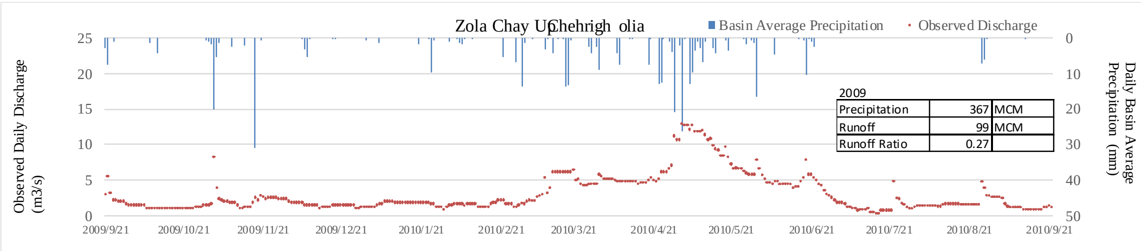


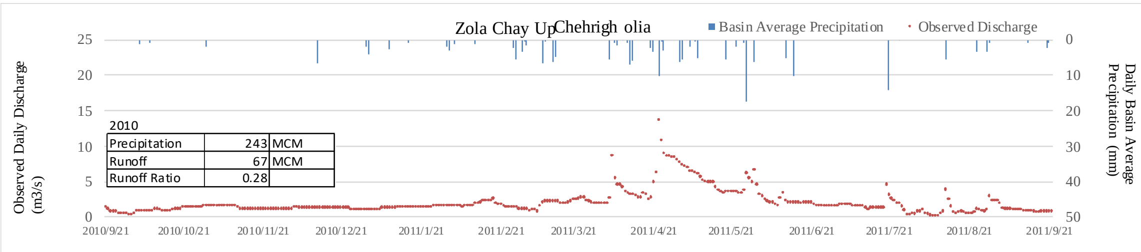


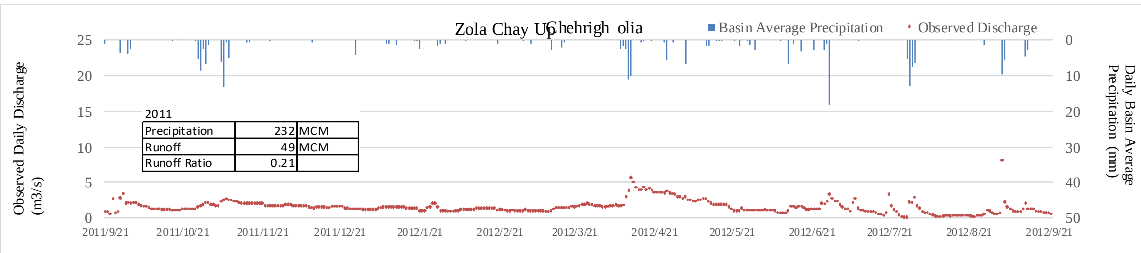
W-1 Yalghuz aghaj (Zola chay) (2/2)

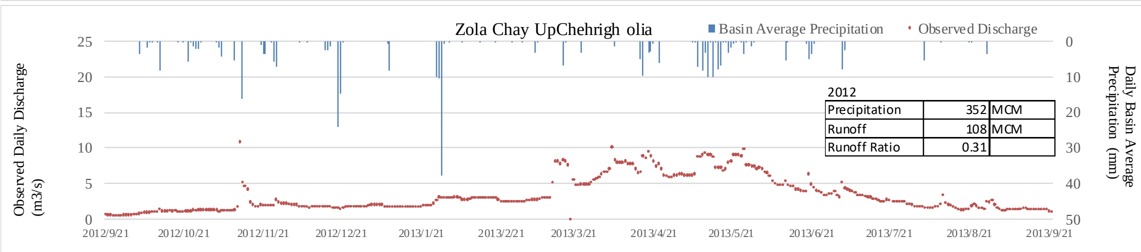


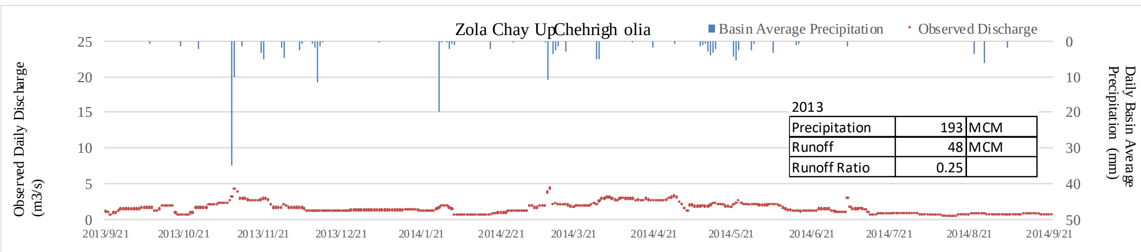




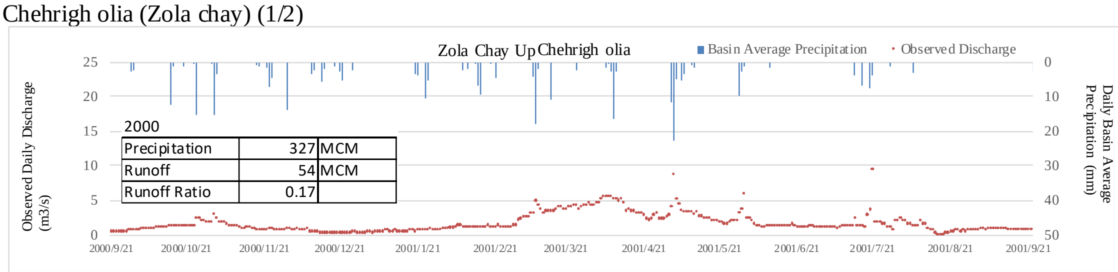


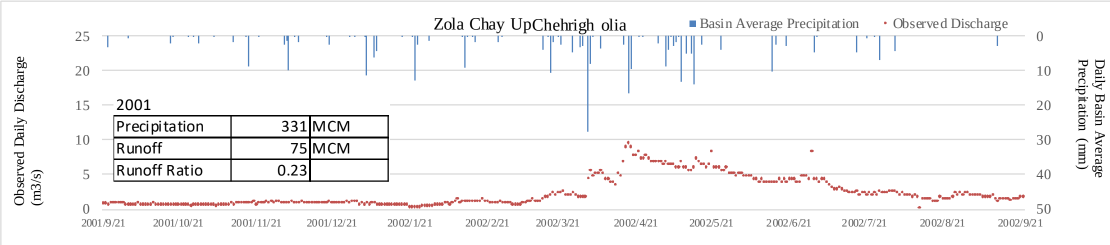


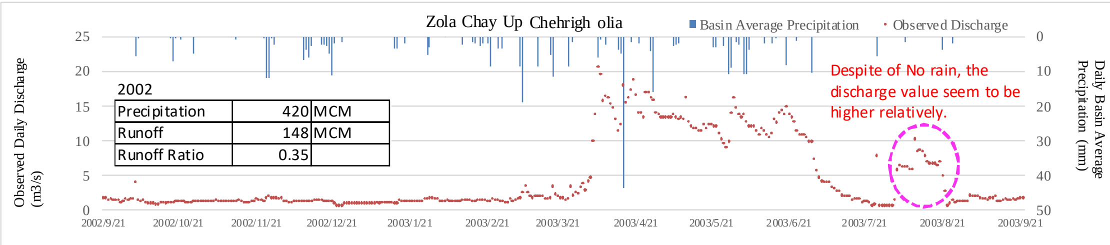


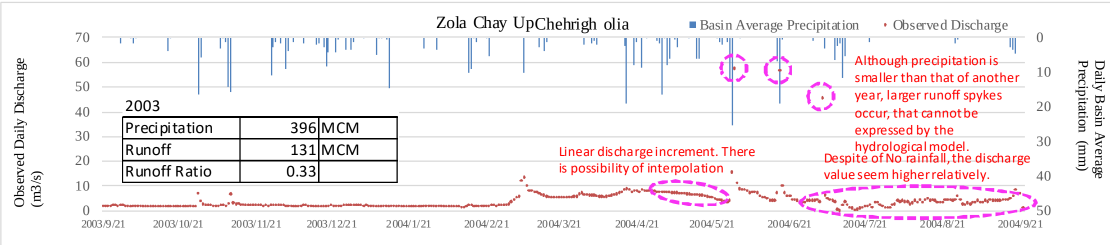


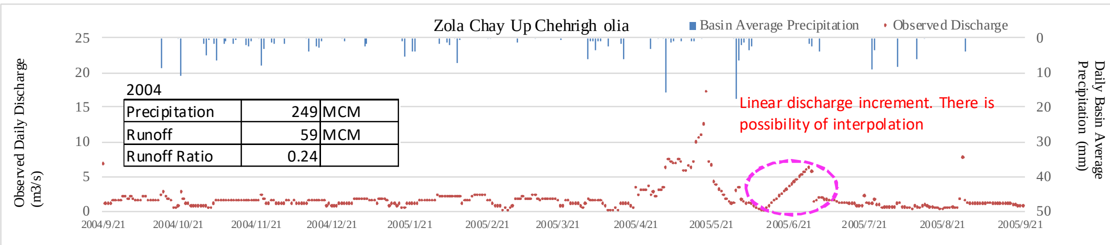
W-2 Chehrigh olia (Zola chay) (1/2)

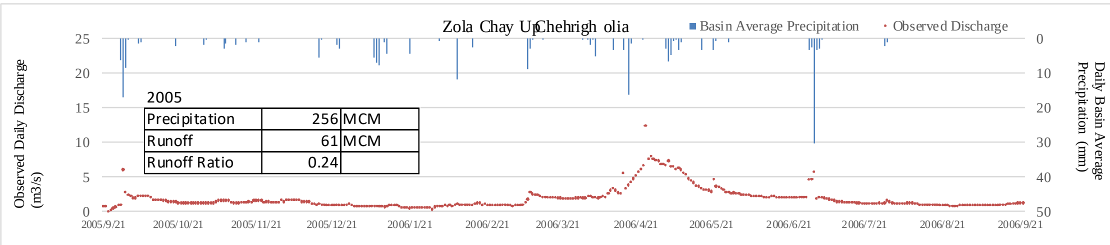


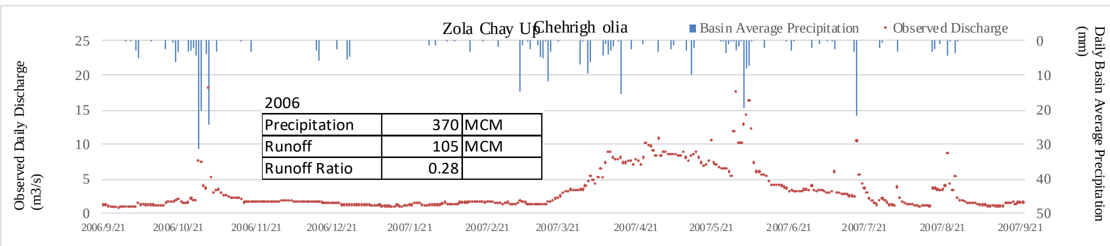




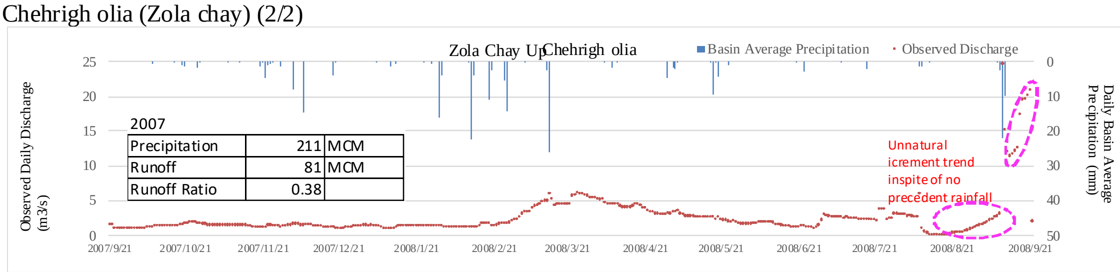


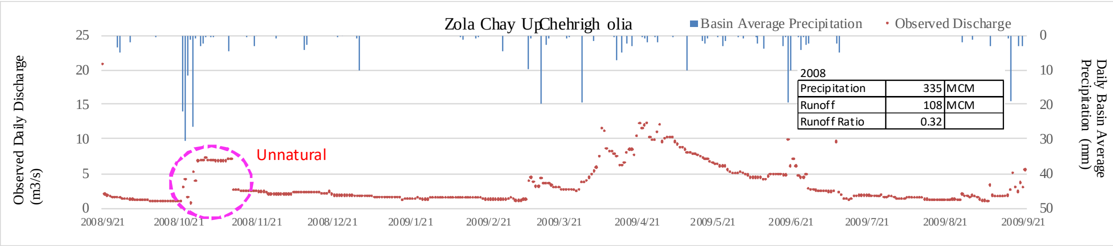


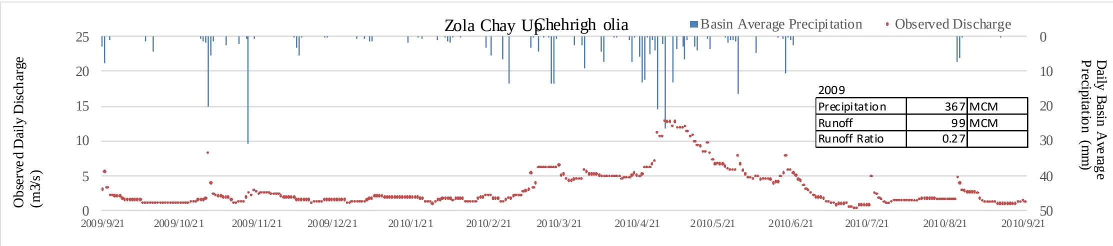


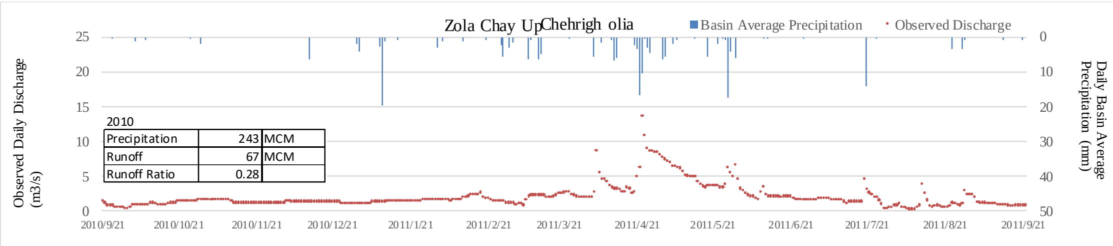


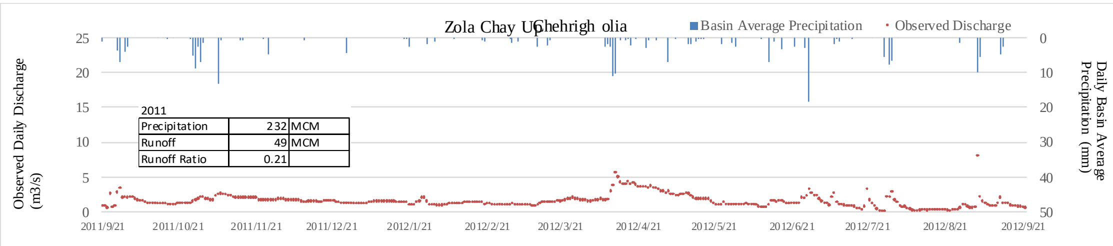
W-2 Chehrigh olia (Zola chay) (2/2)

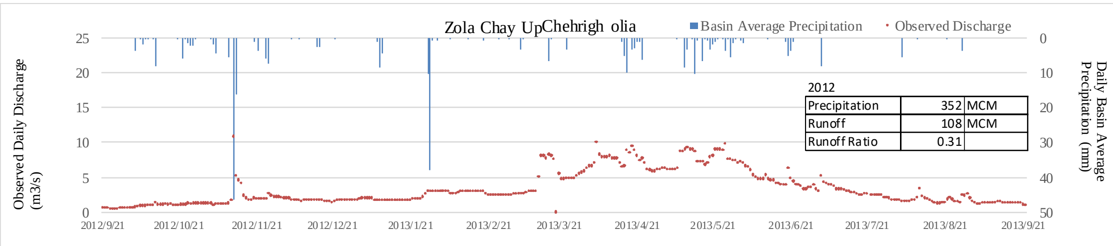


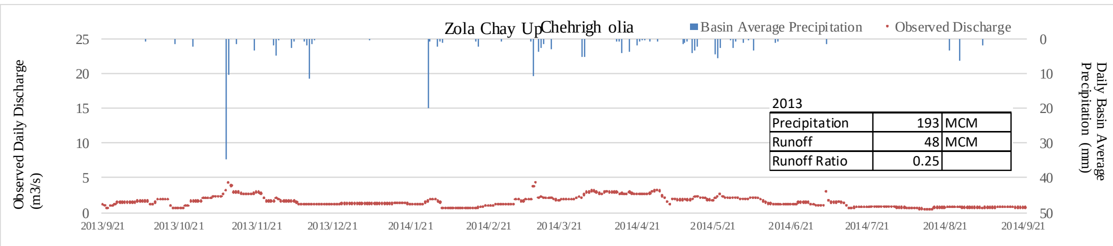




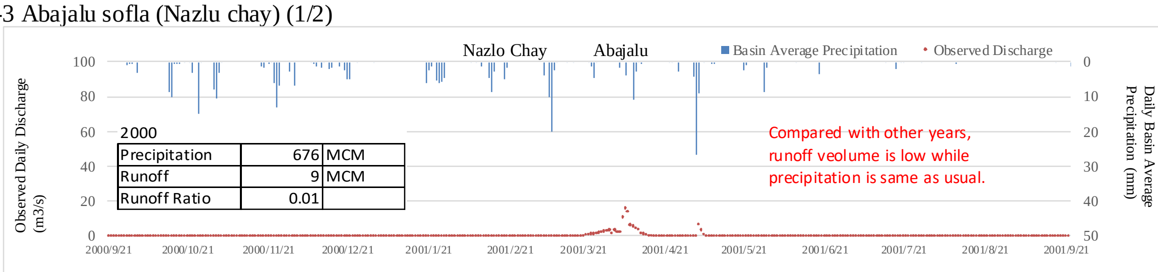


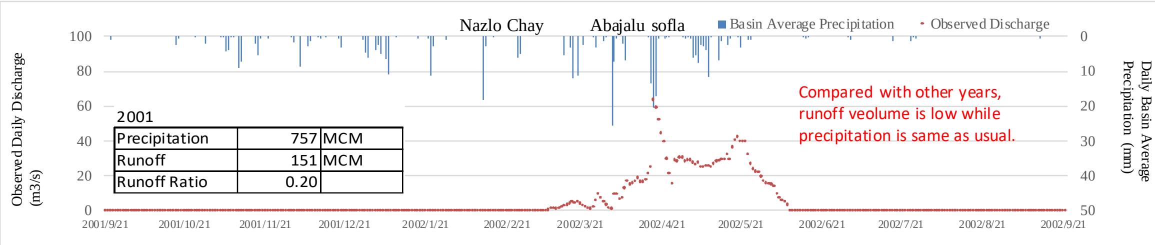


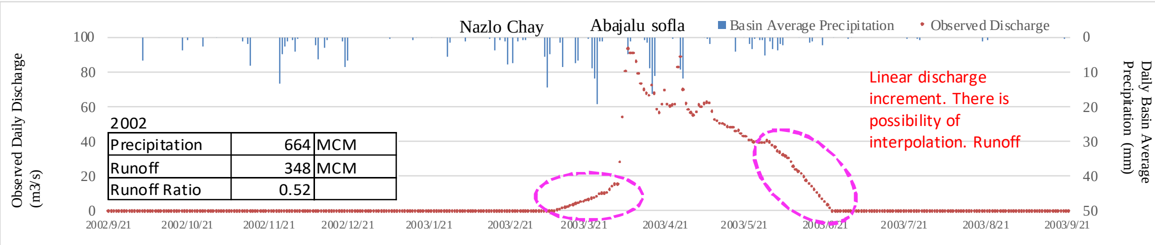


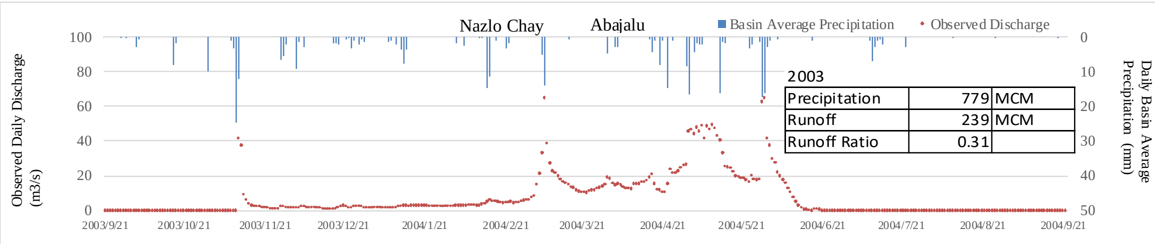


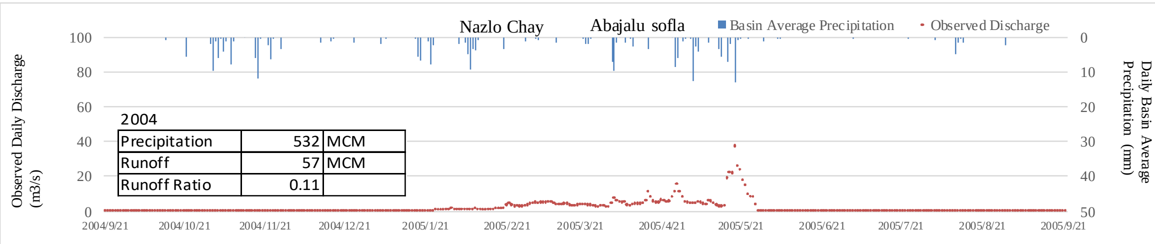
W-3 Abajalu sofla (Nazlu chay) (1/2)

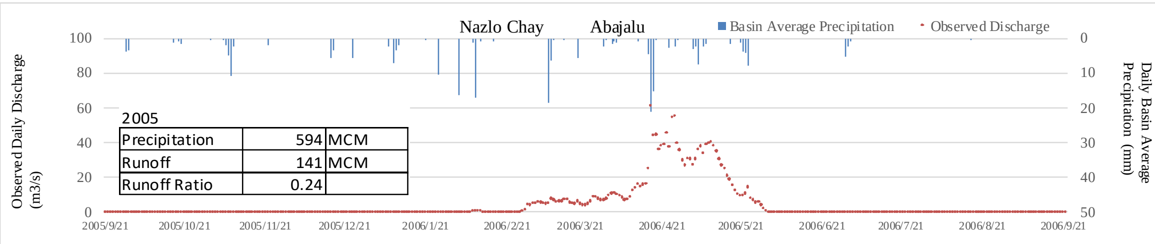


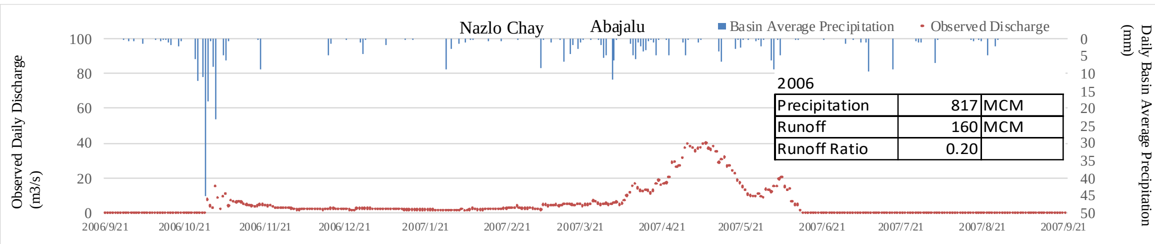




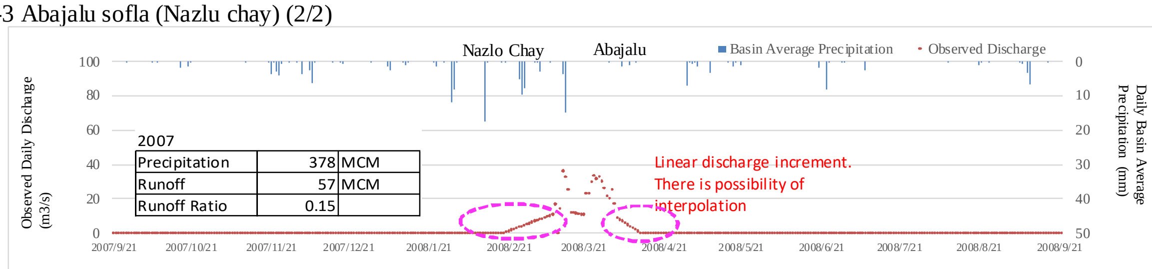


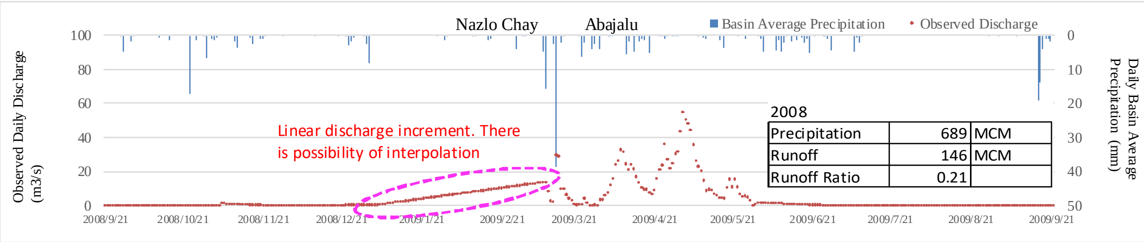


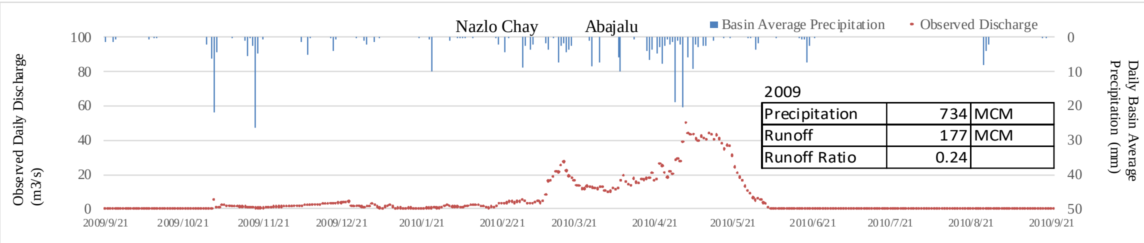


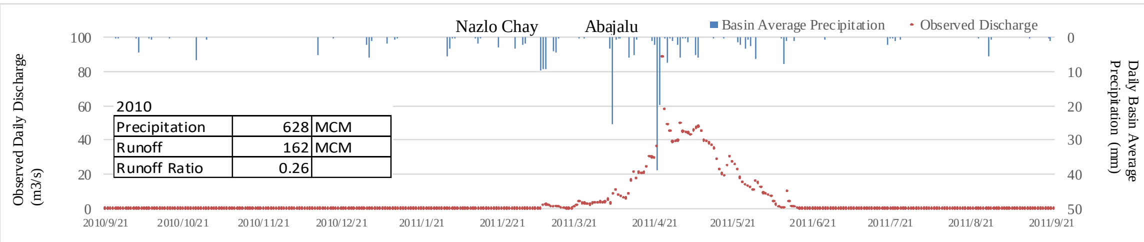


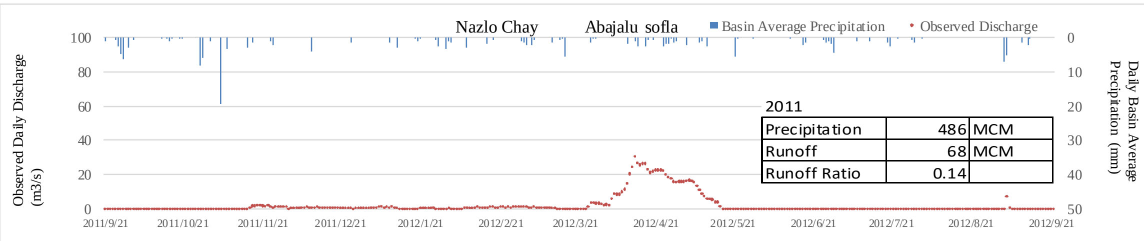
W-3 Abajalu sofla (Nazlu chay) (2/2)

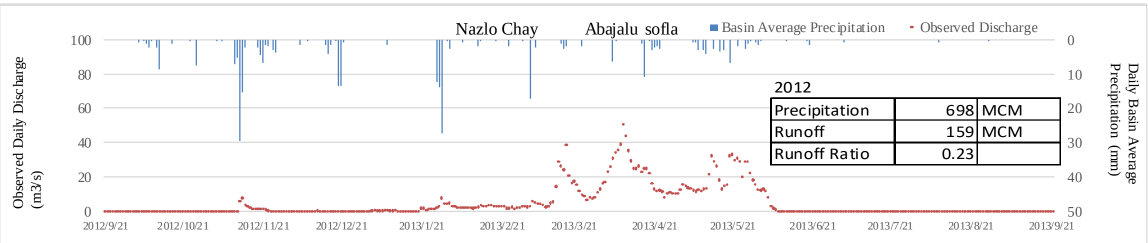


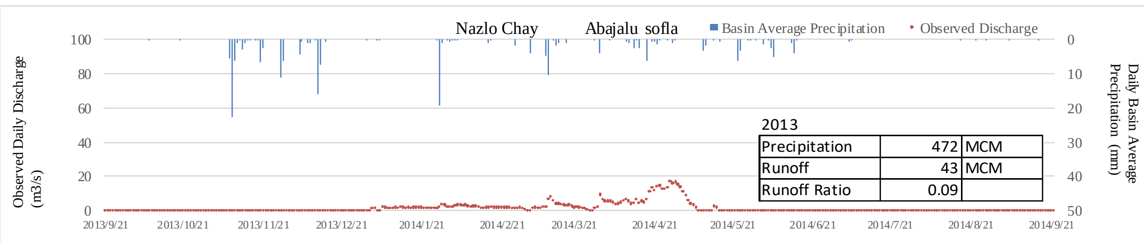




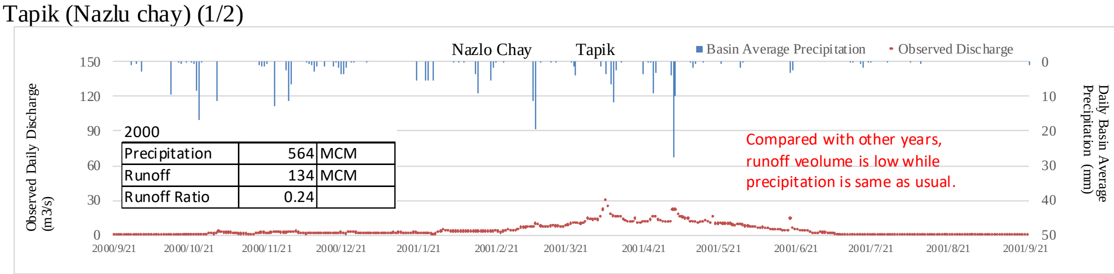


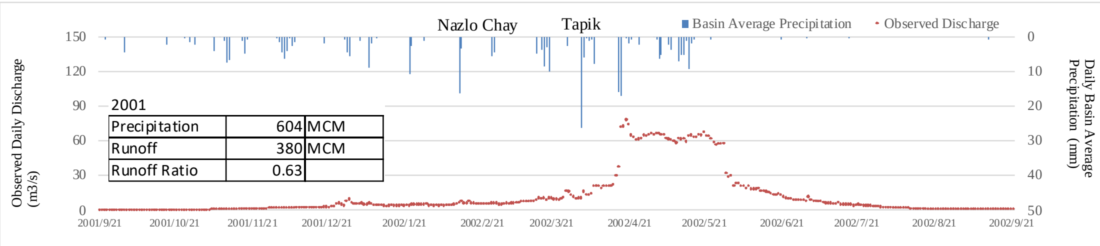


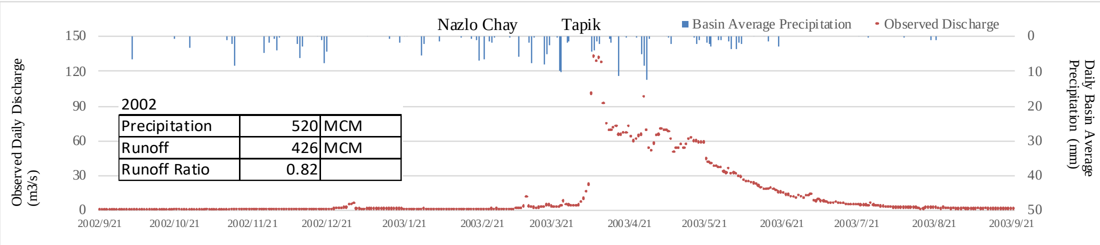


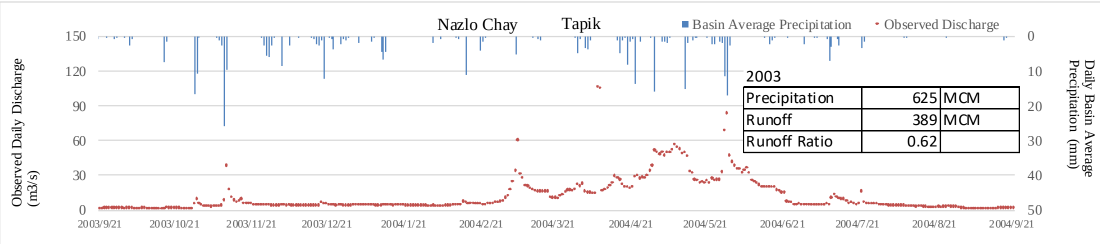


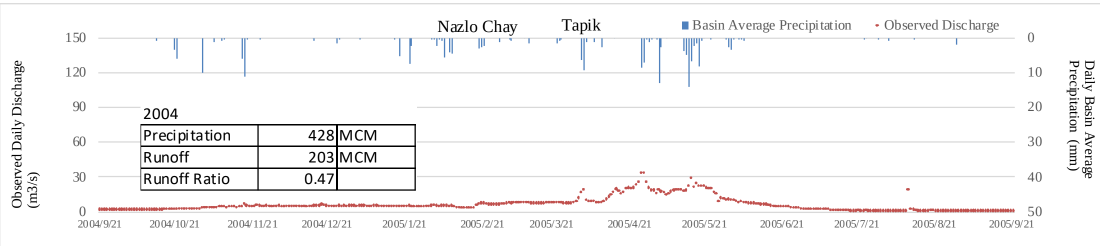
W-4 Tapik (Nazlu chay) (1/2)

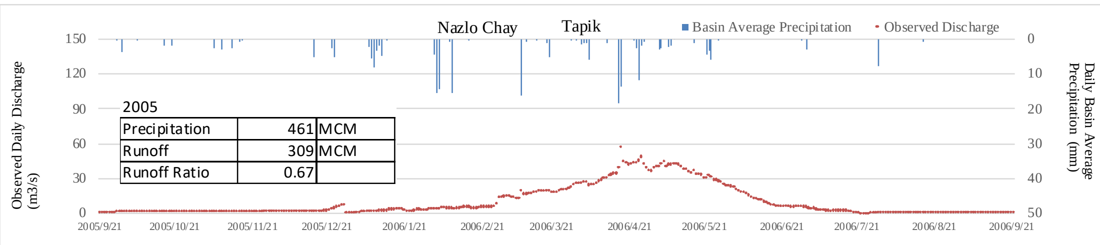


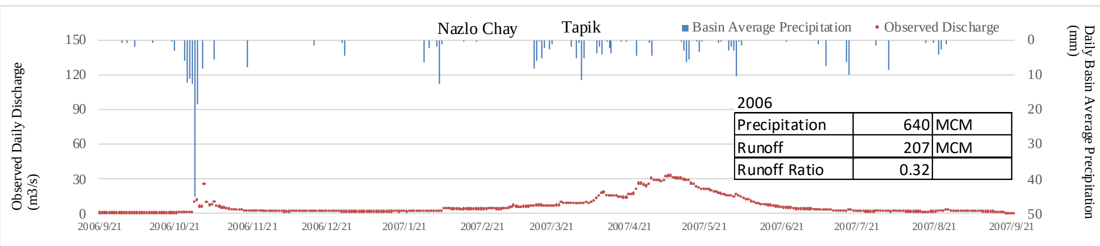




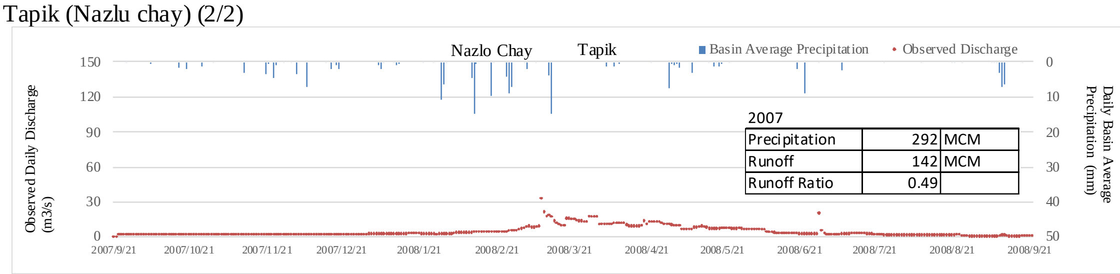


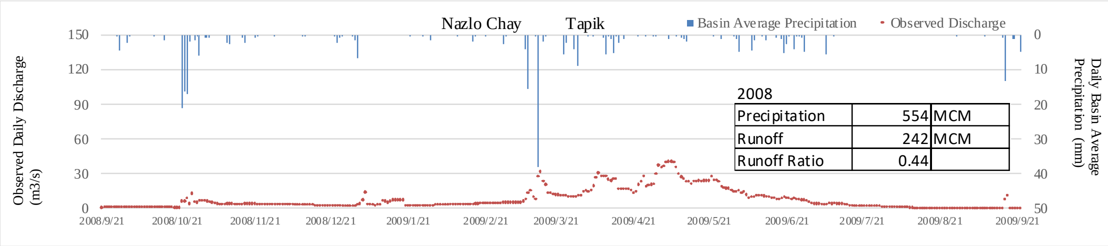


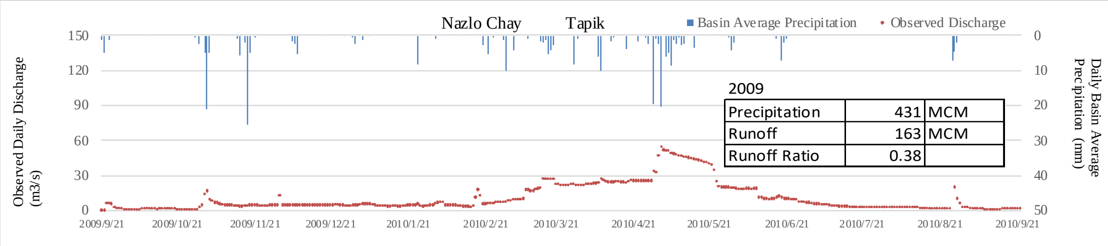


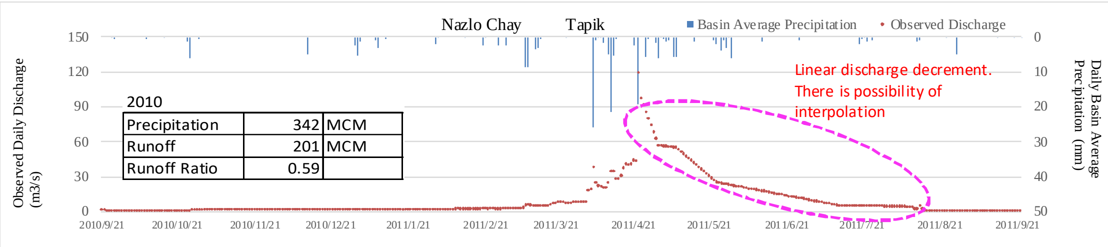


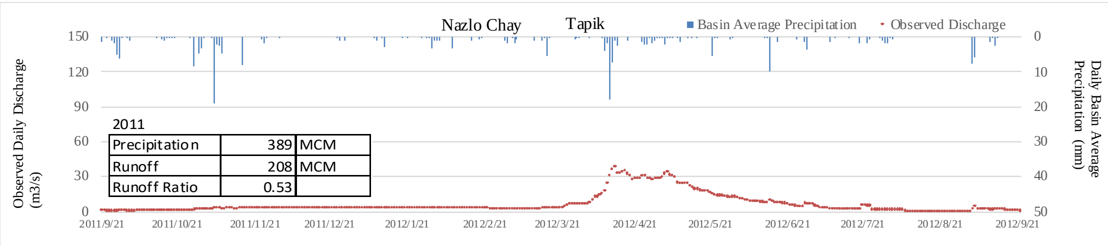
W-4 Tapik (Nazlu chay) (2/2)

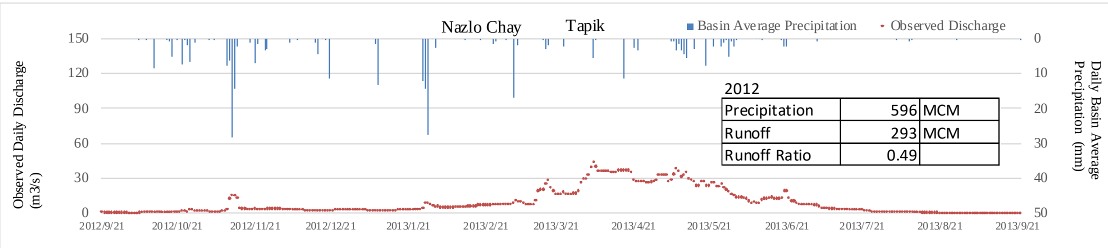


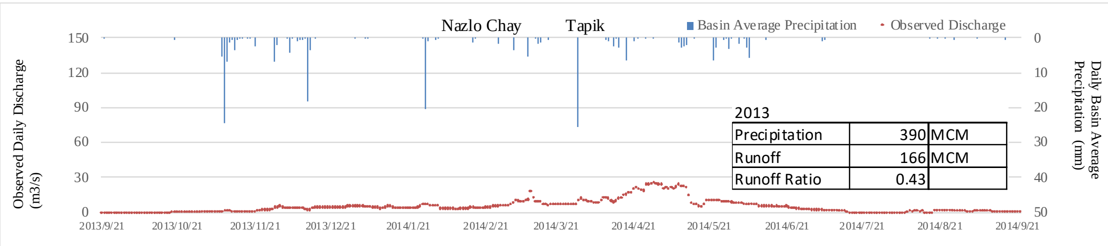




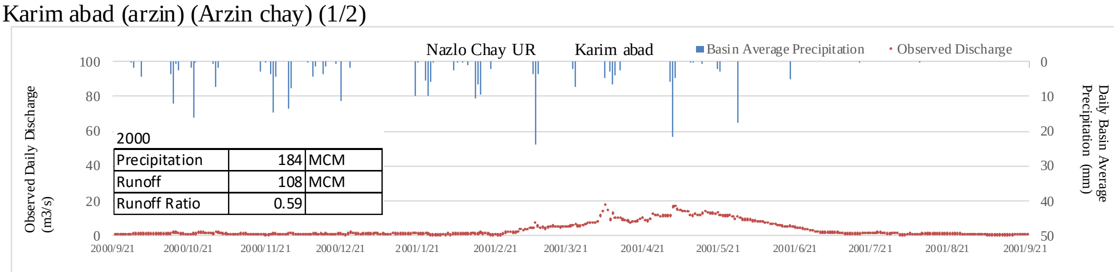


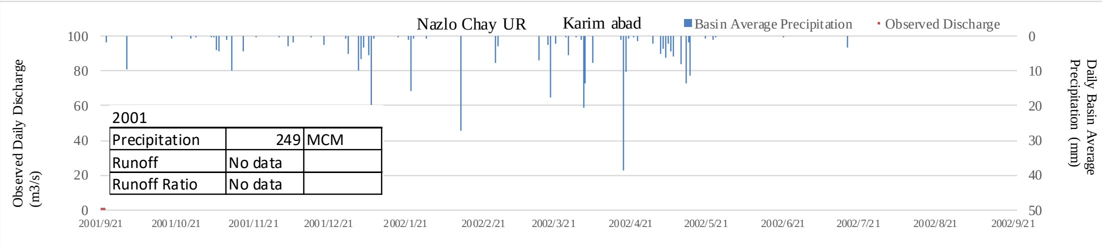


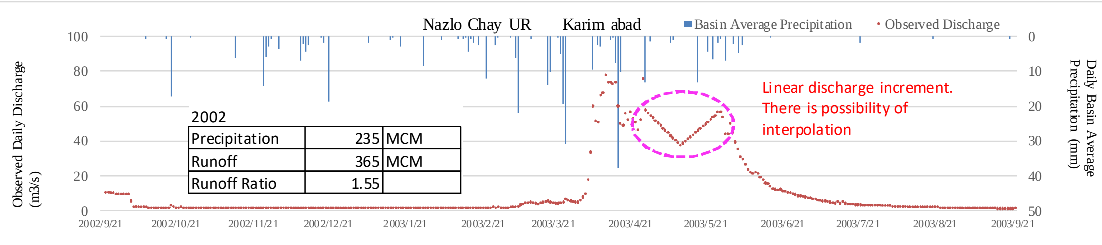


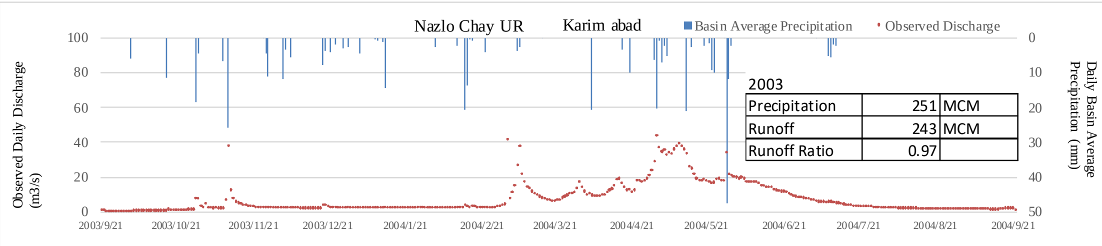


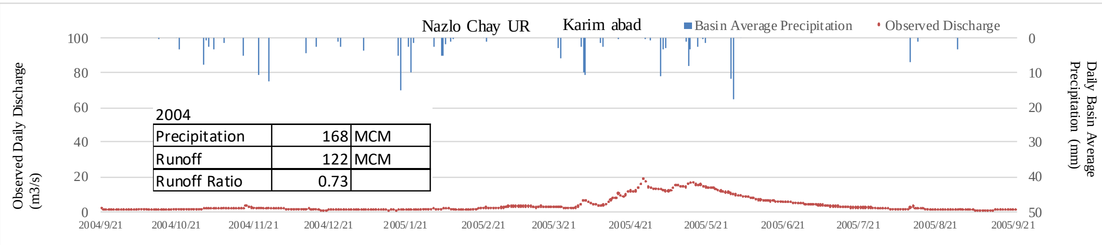
W-5 Karim abad (arzin) (Arzin chay) (1/2)

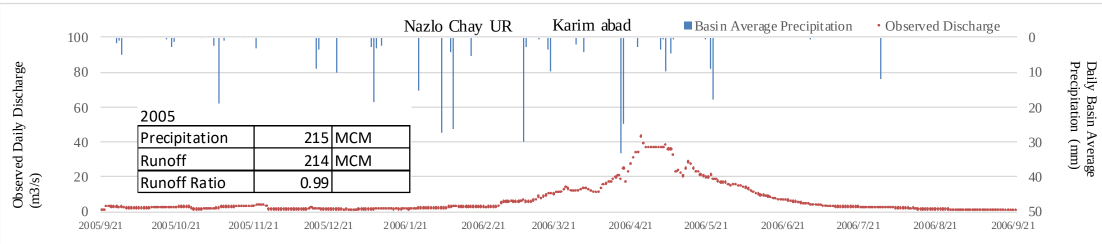


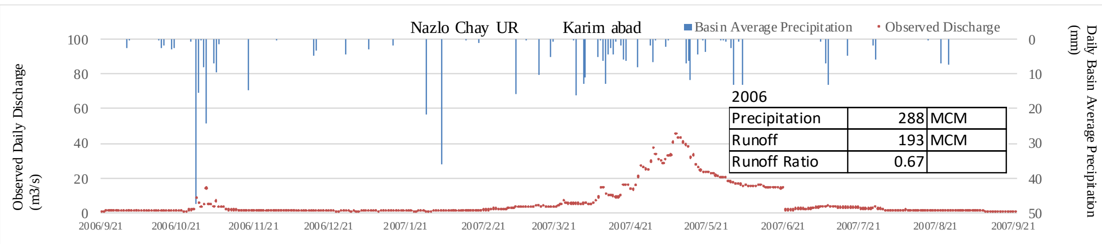




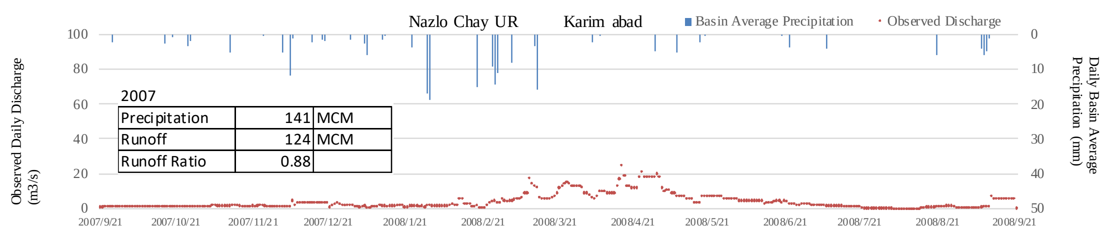


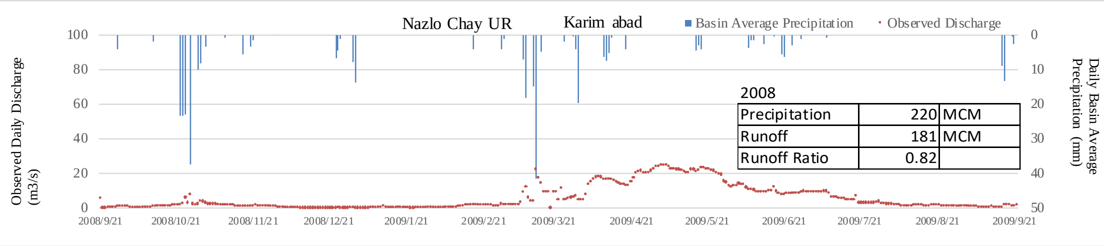


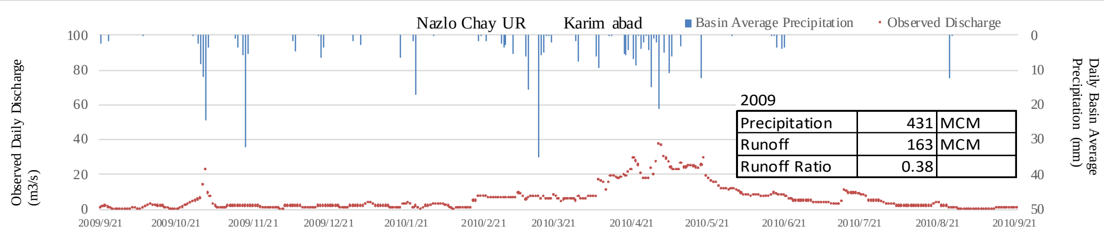


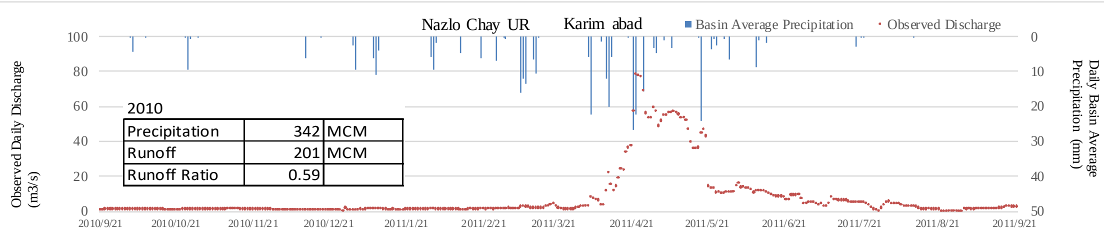


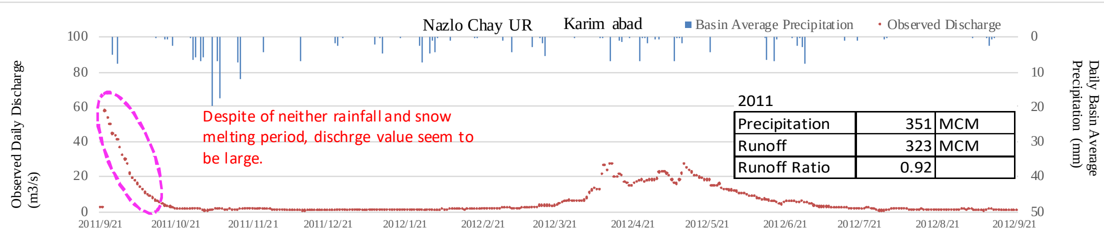
W-5 Karim abad (arzin) (Arzin chay) (2/2)

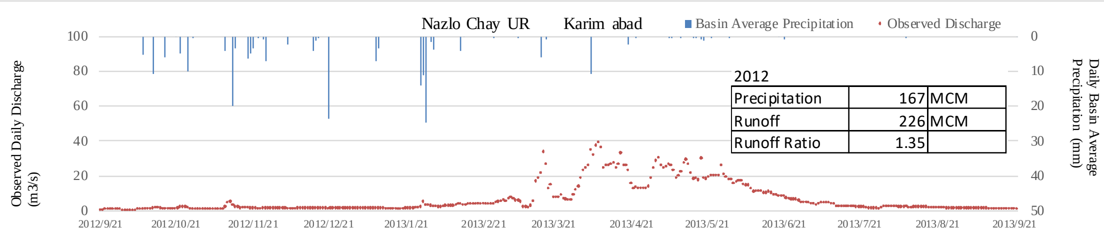


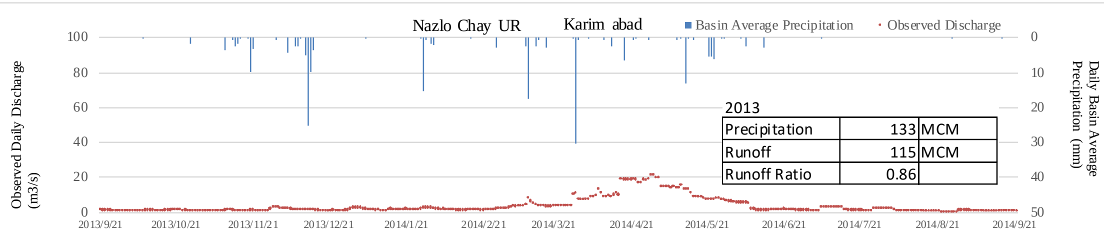




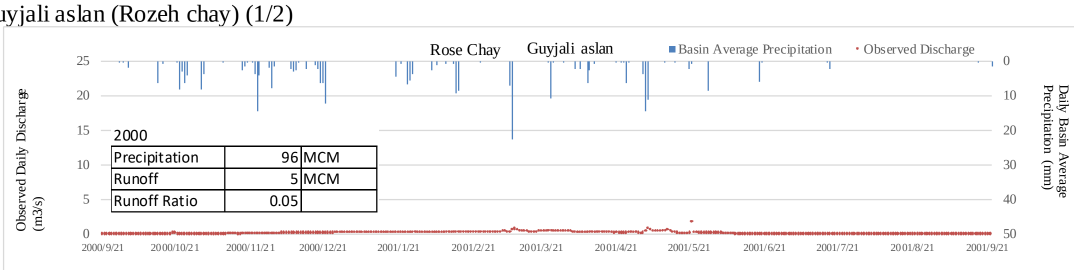


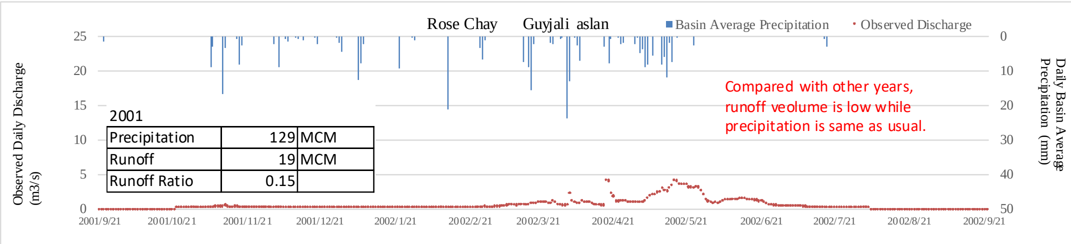


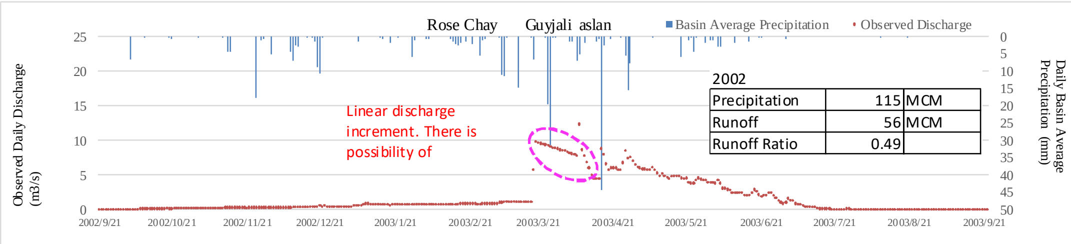


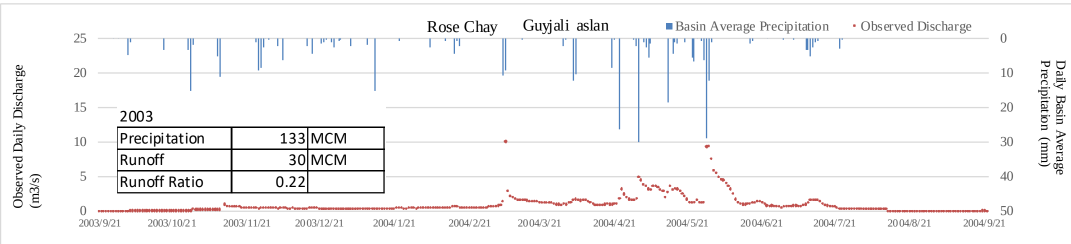


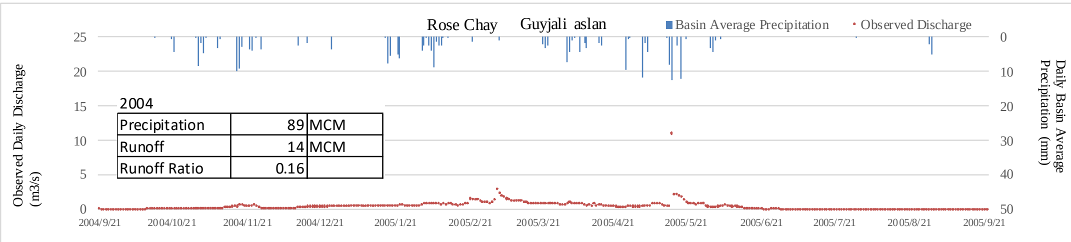
W-6 Guyjali aslan (Rozeh chay) (1/2)

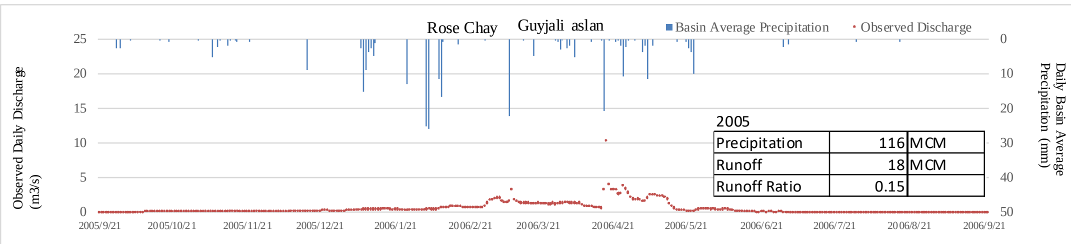


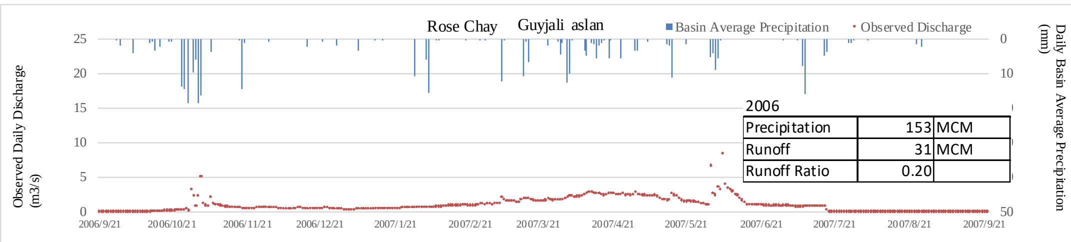




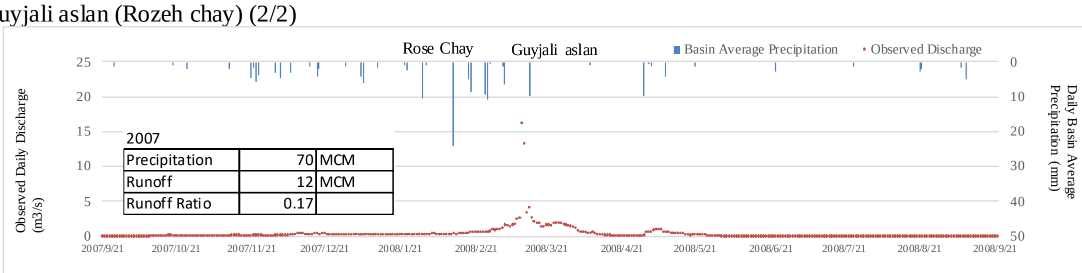


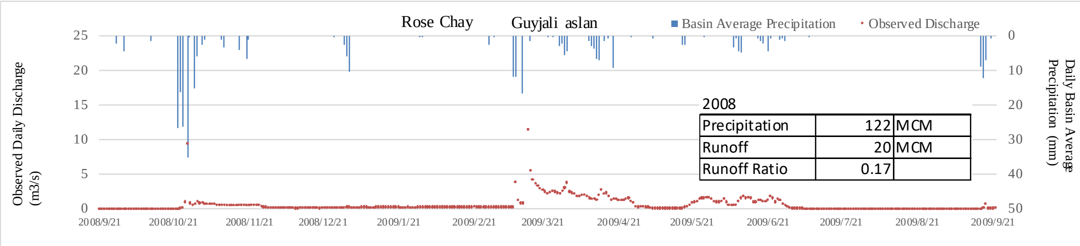


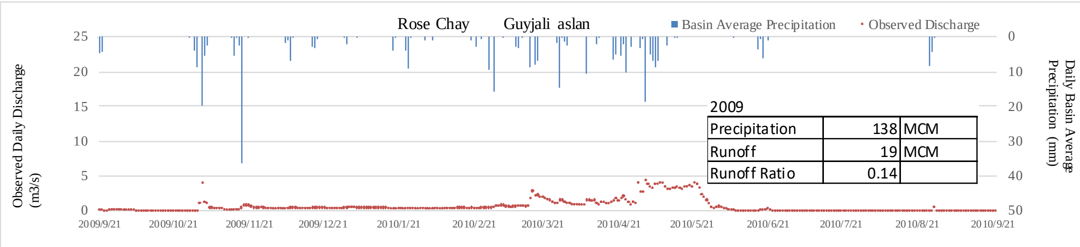


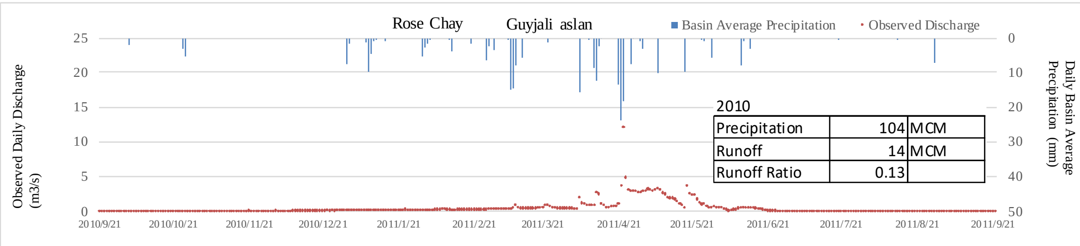


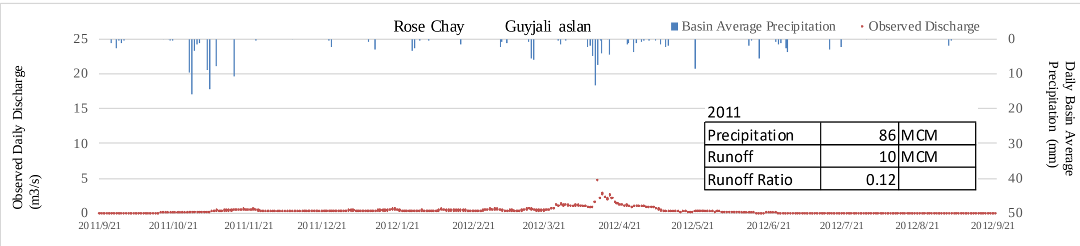
W-6 Guyjali aslan (Rozeh chay) (2/2)

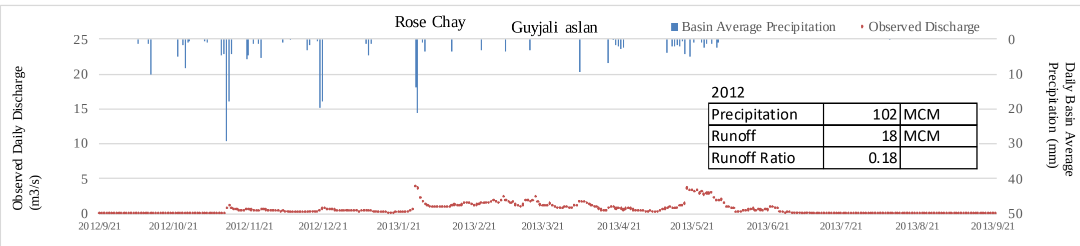


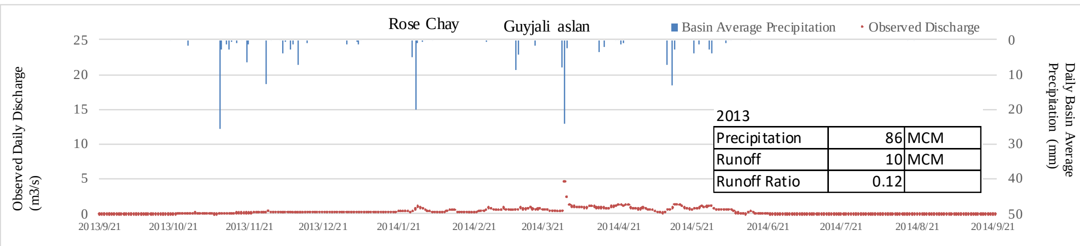




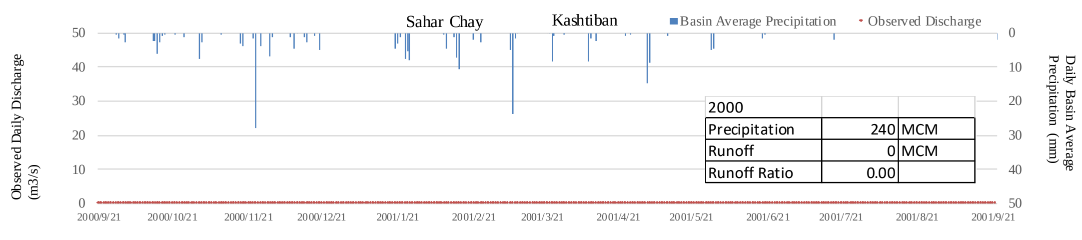


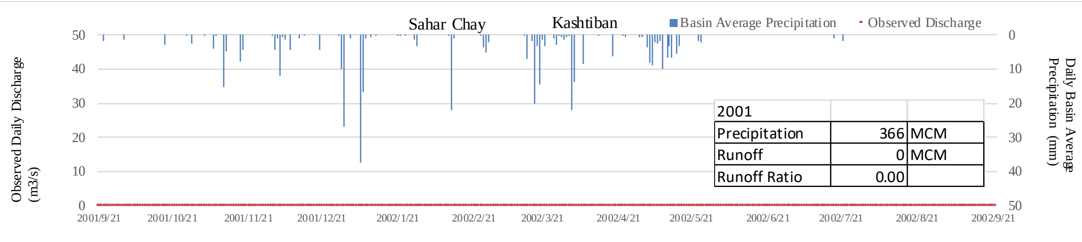


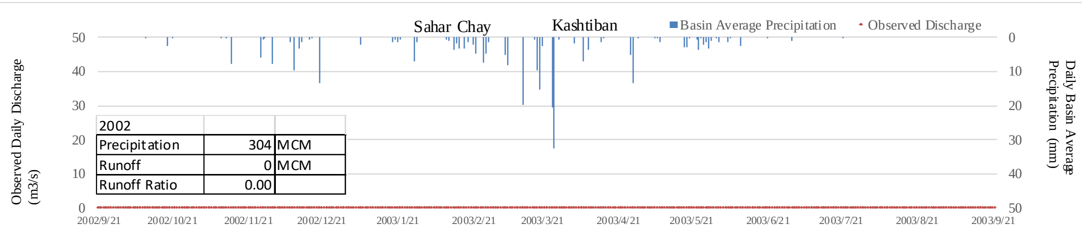


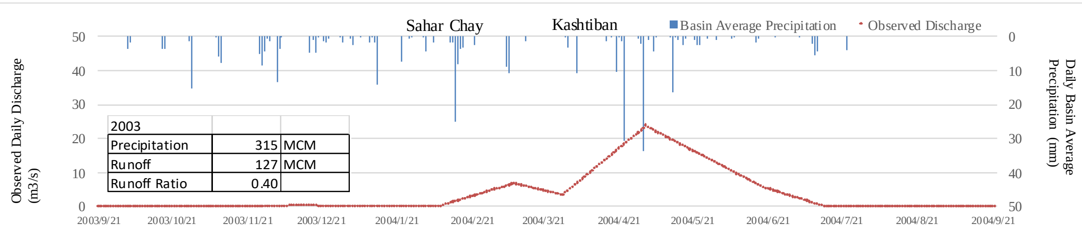


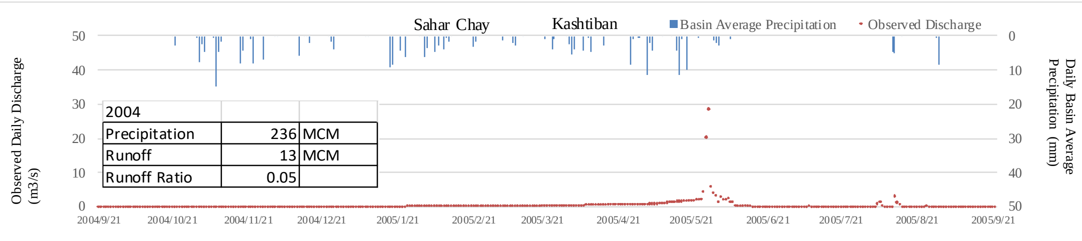
W-7 Kashtiban (Shahr chay) (1/2)

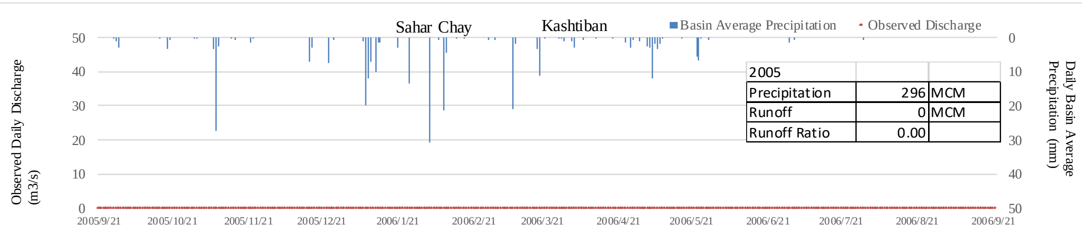


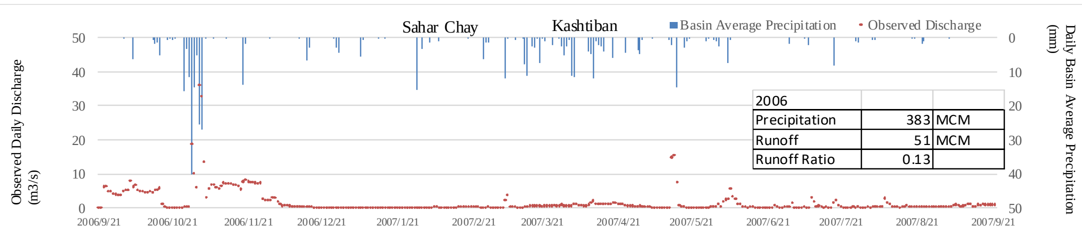




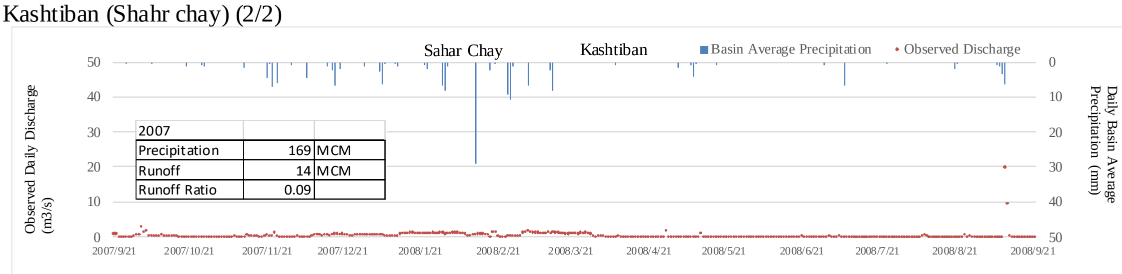


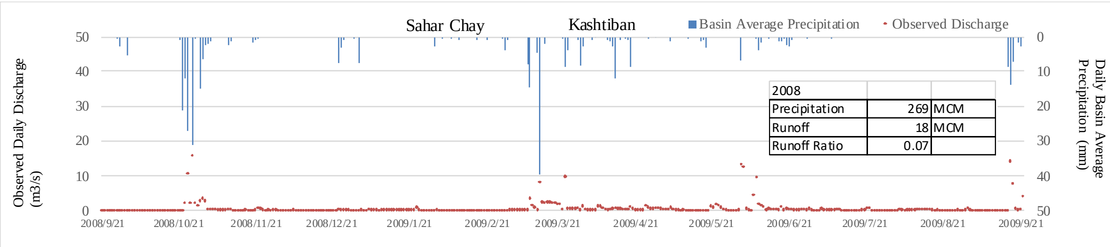


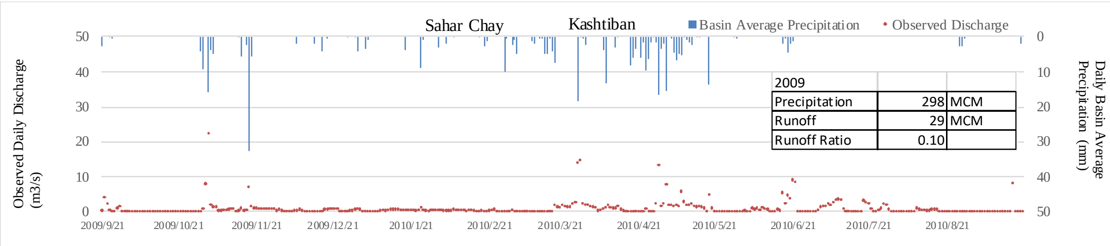


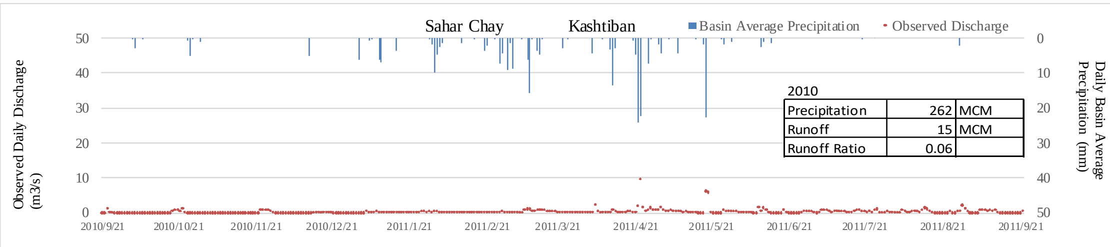


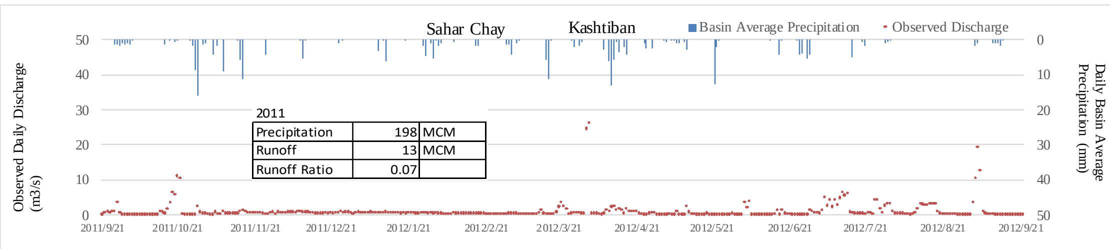
W-7 Kashtiban (Shahr chay) (2/2)

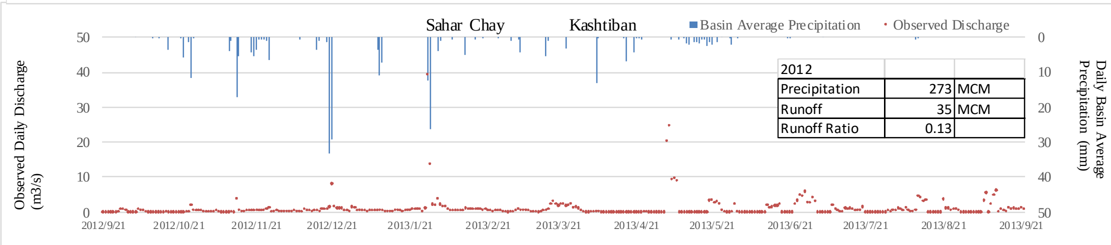


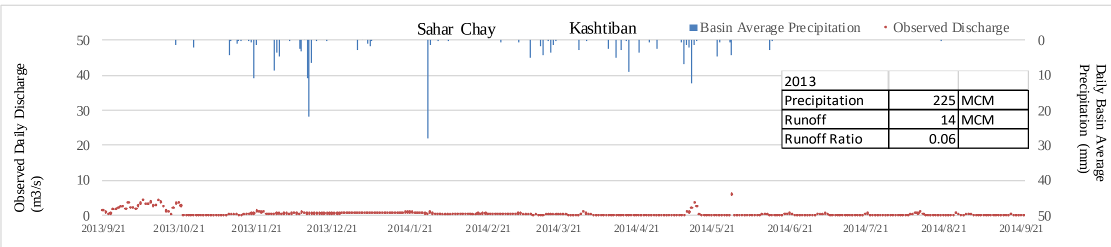




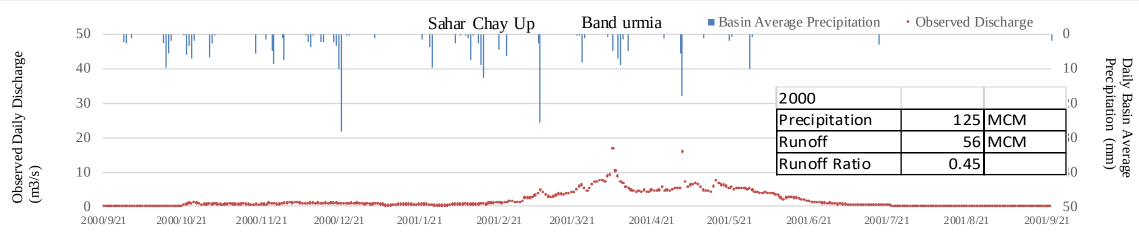


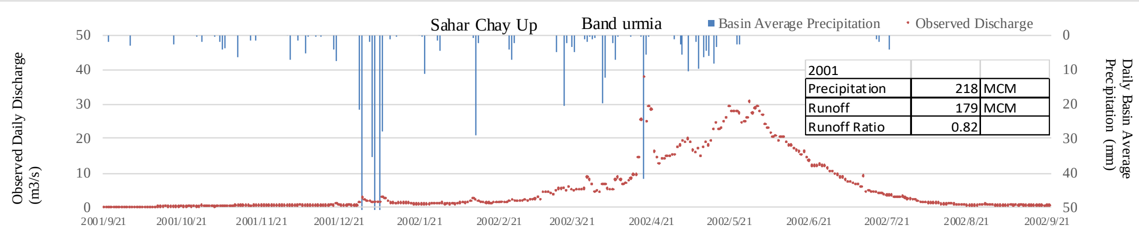


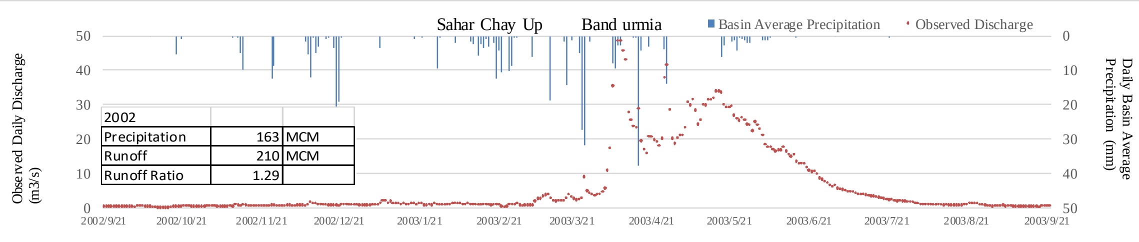


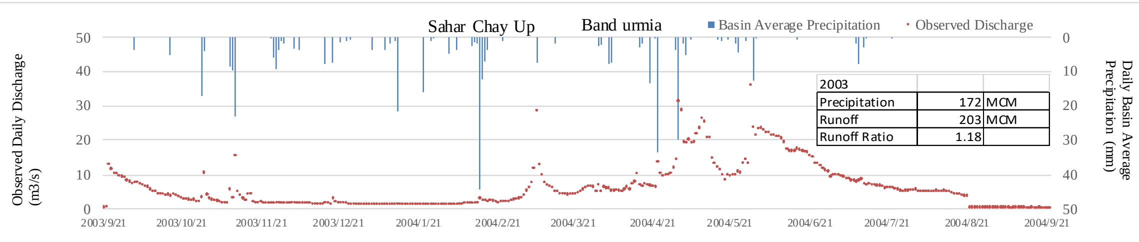


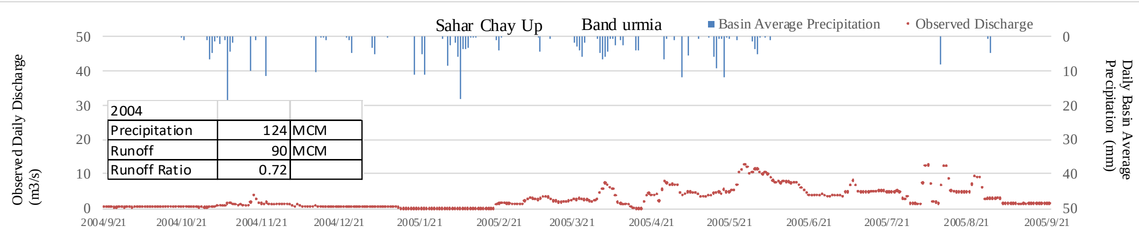
W-8 Band urmia (Shahr chay) (1/2)

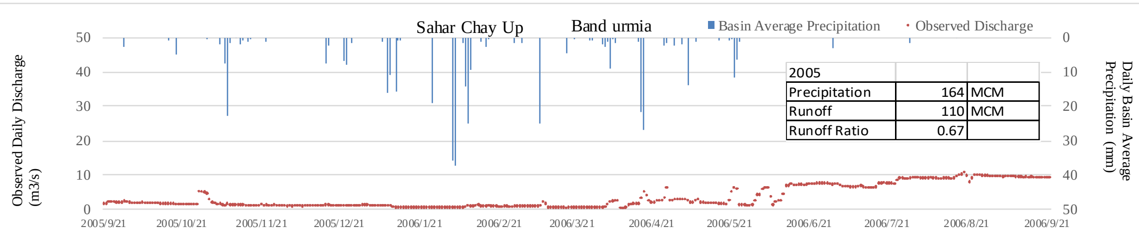


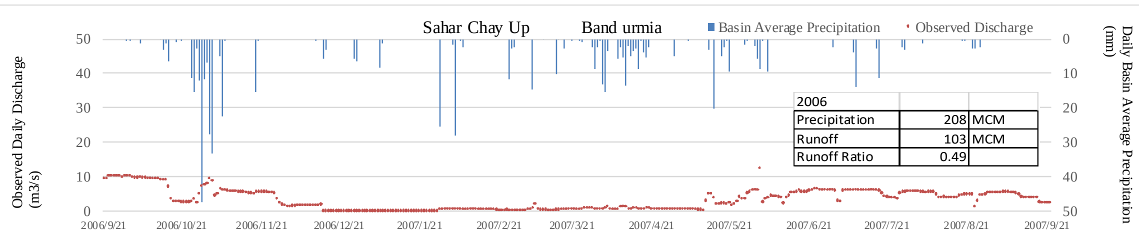




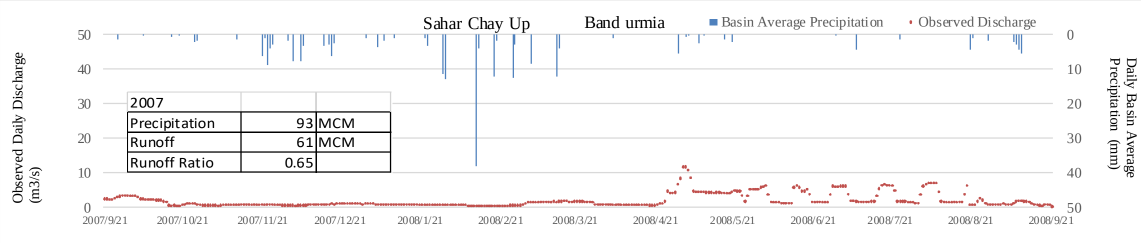


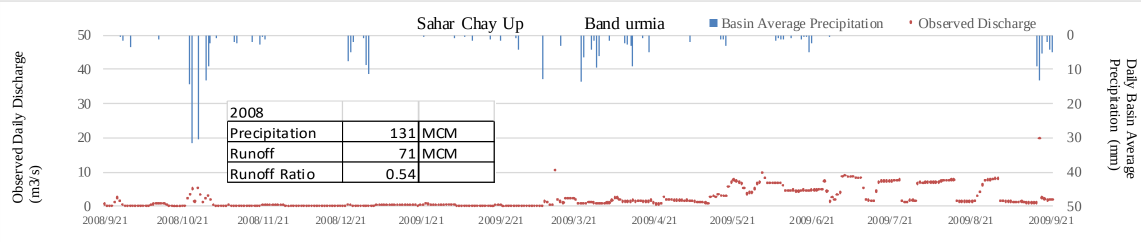


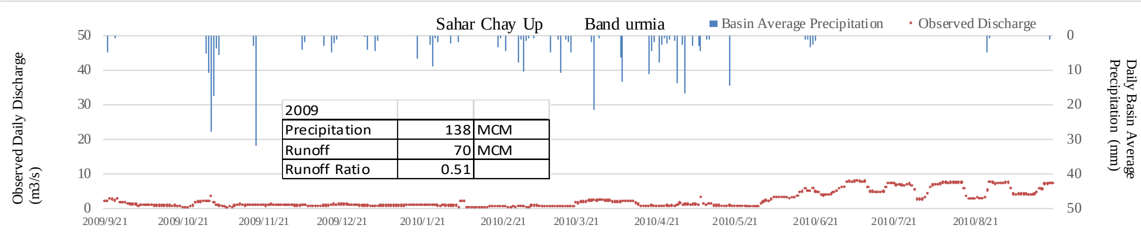


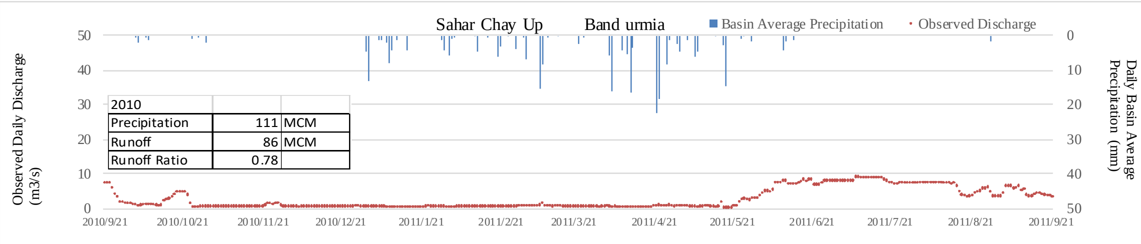


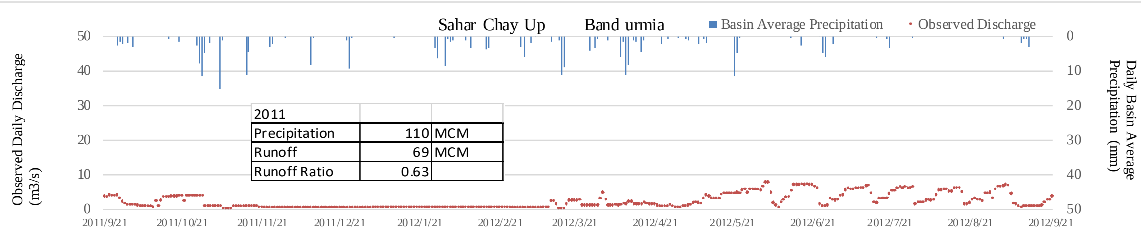
W-8 Band urmia (Shahr chay) (2/2)

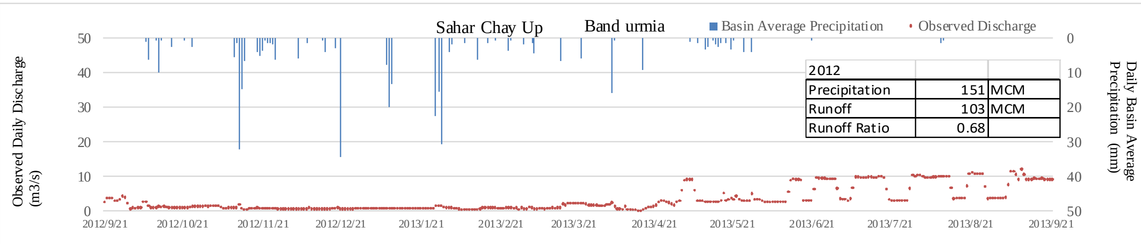


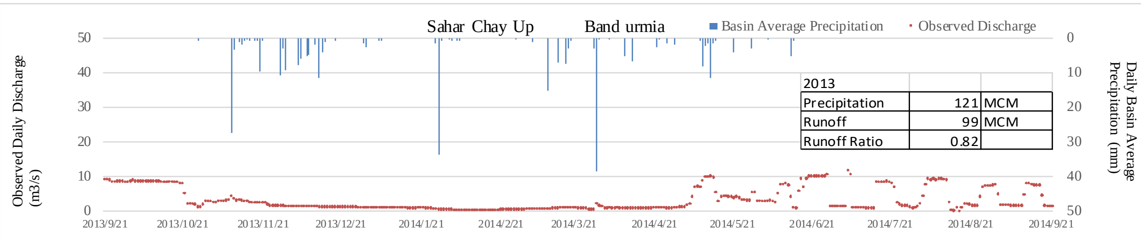




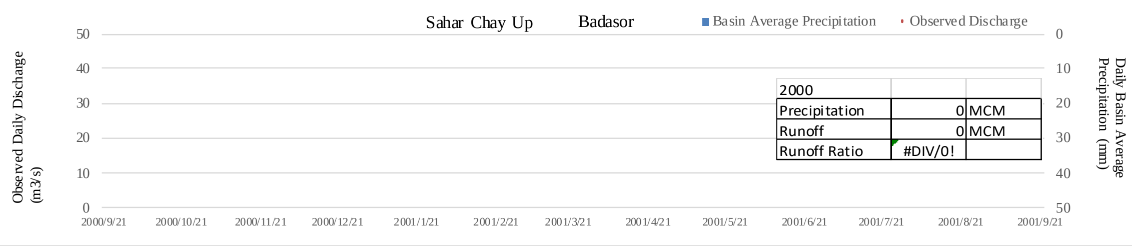


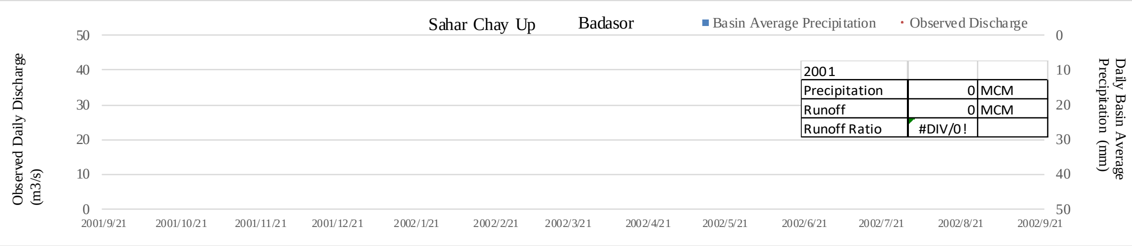


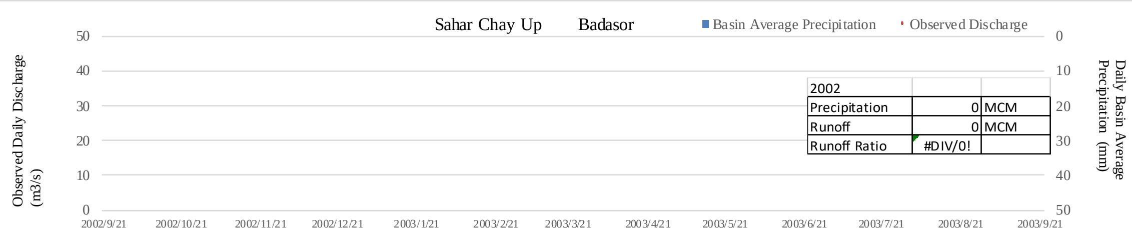


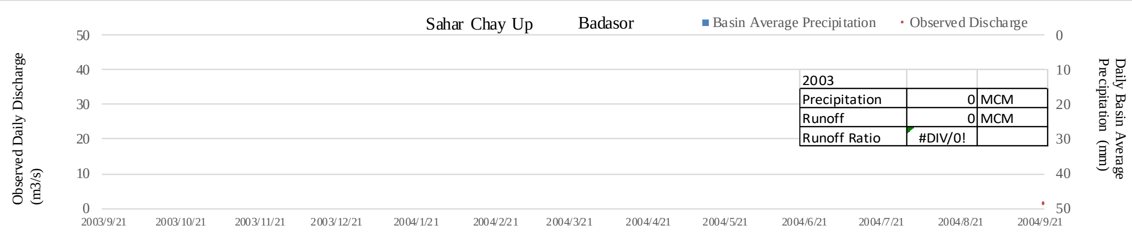


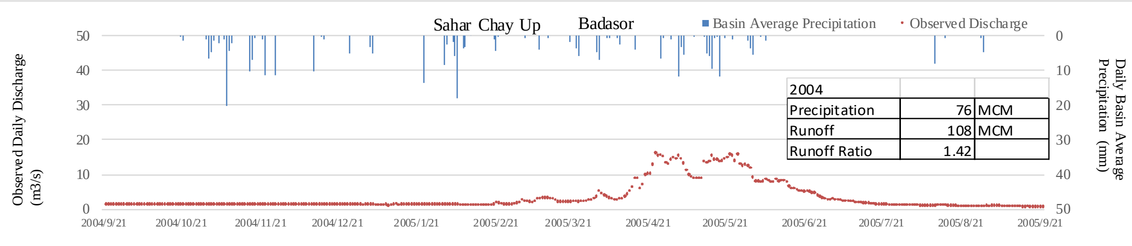
W-9 Badasor (Shahr chay) (1/2)

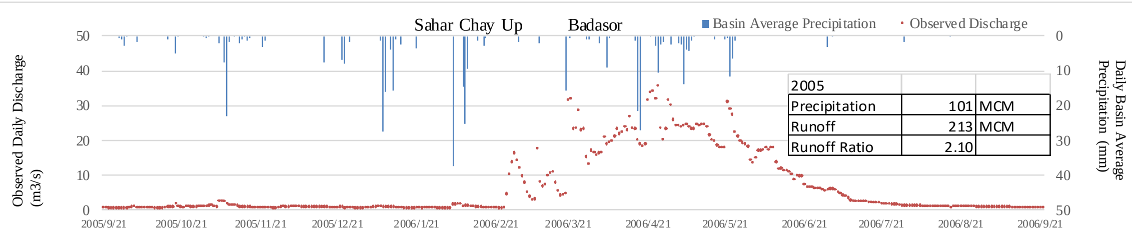


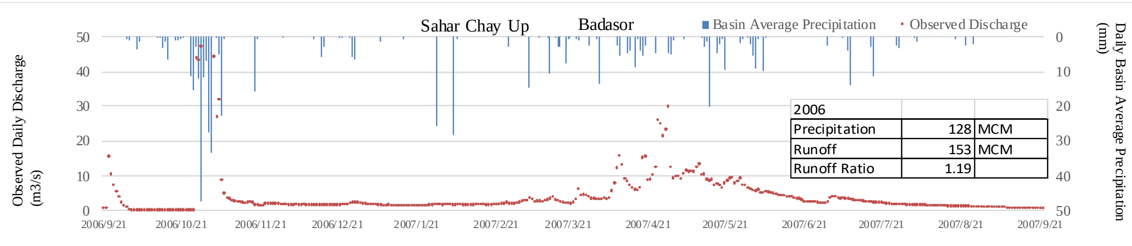




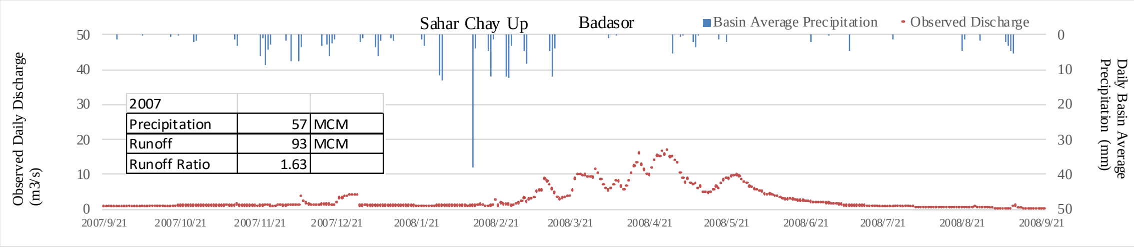


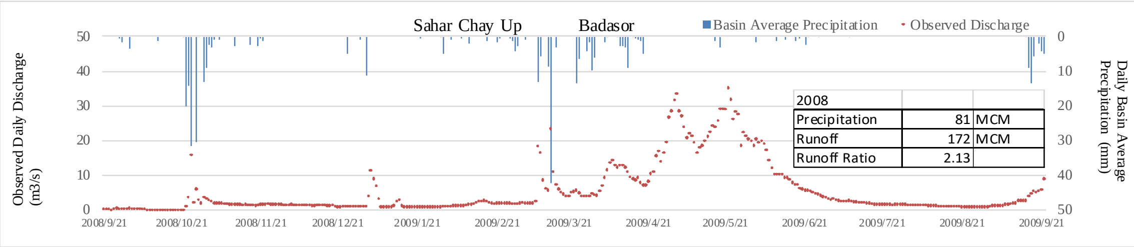


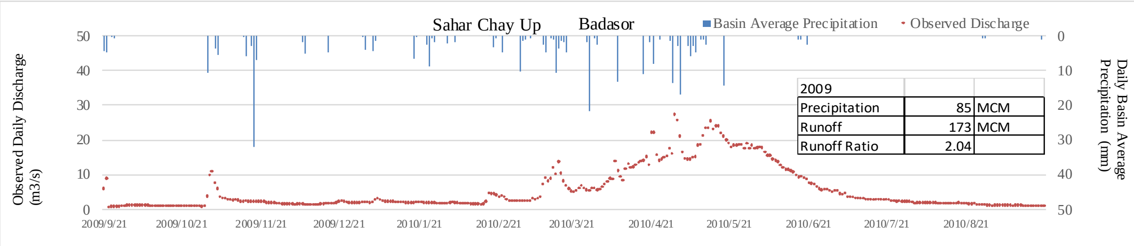


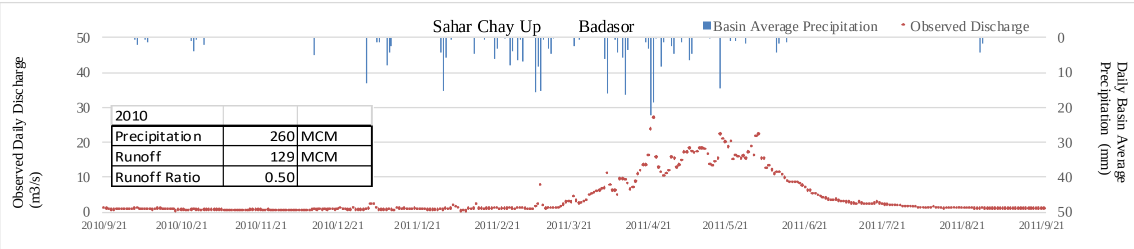


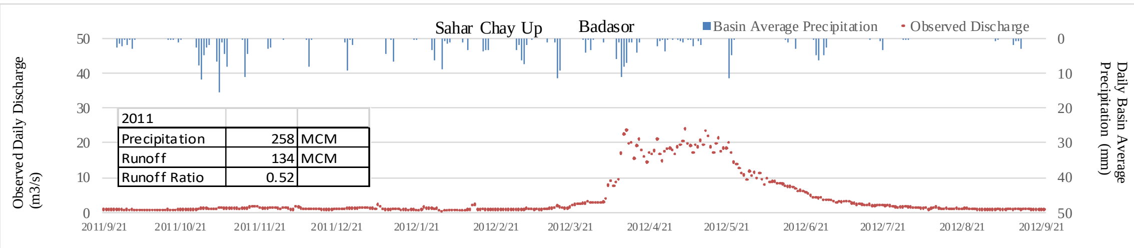
W-9 Badasor (Shahr chay) (2/2)

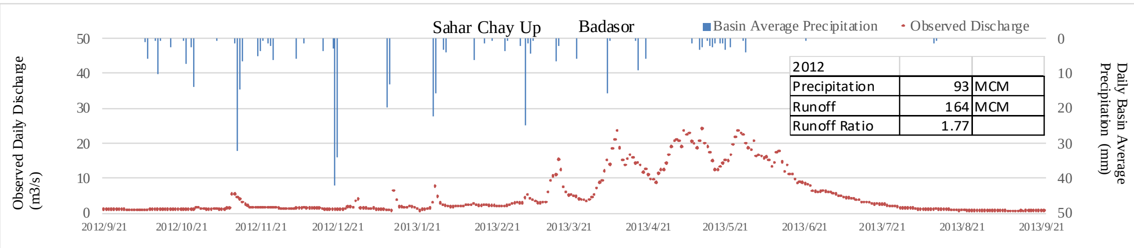


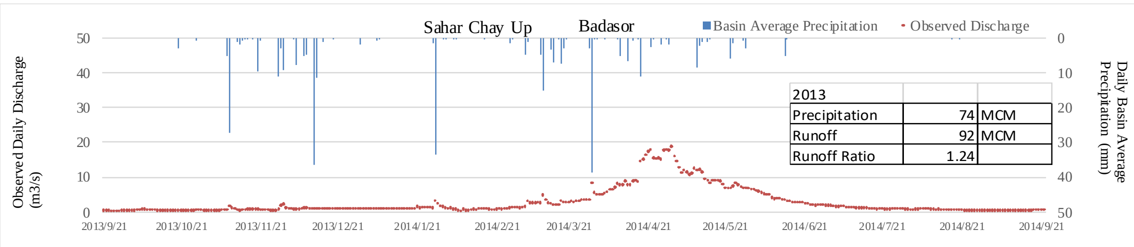




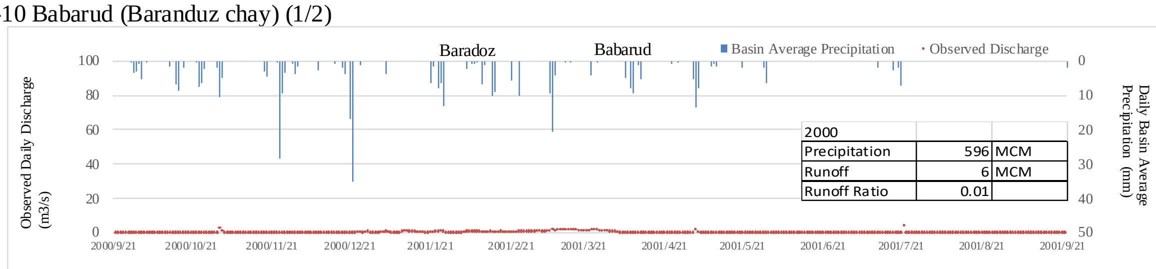


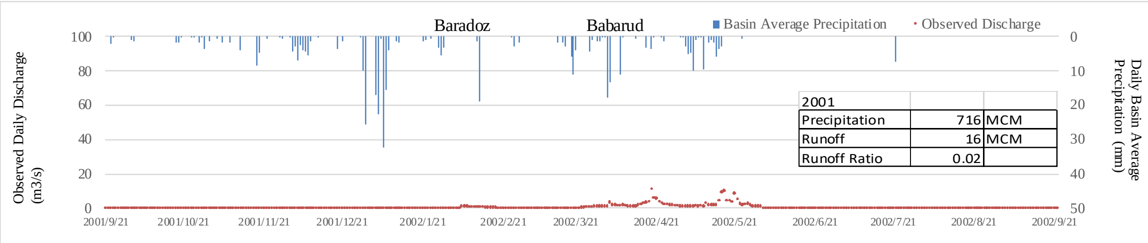


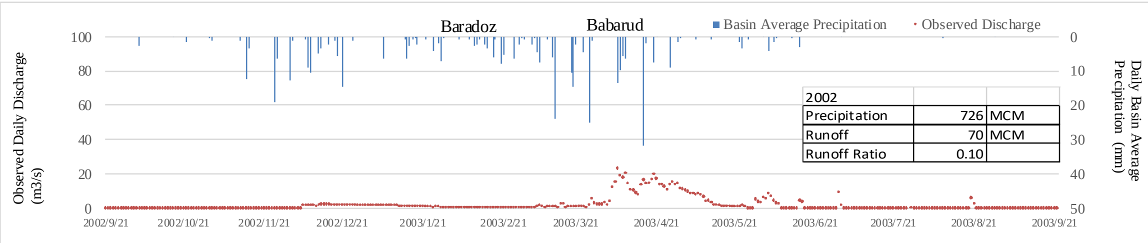


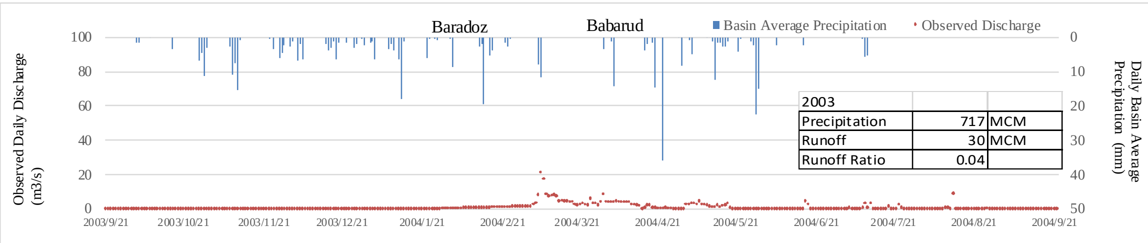


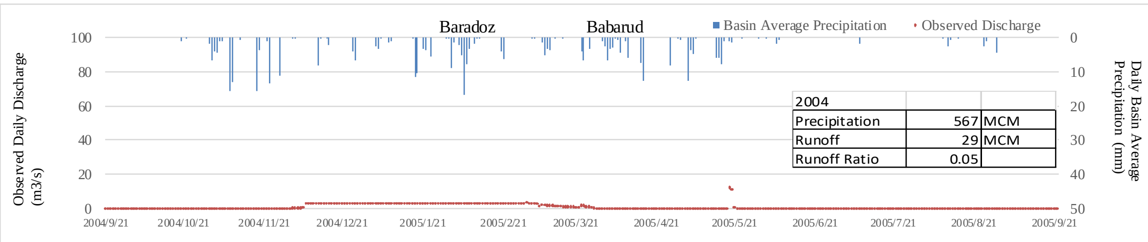
W-10 Babarud (Baranduz chay) (1/2)

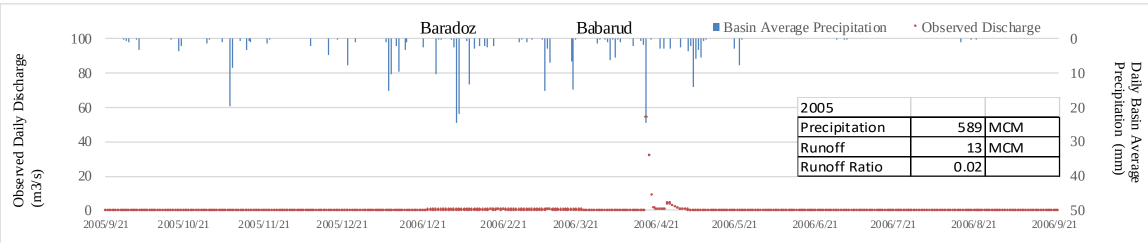


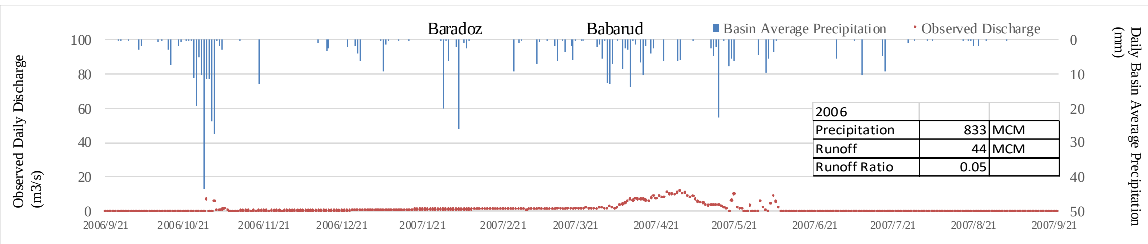




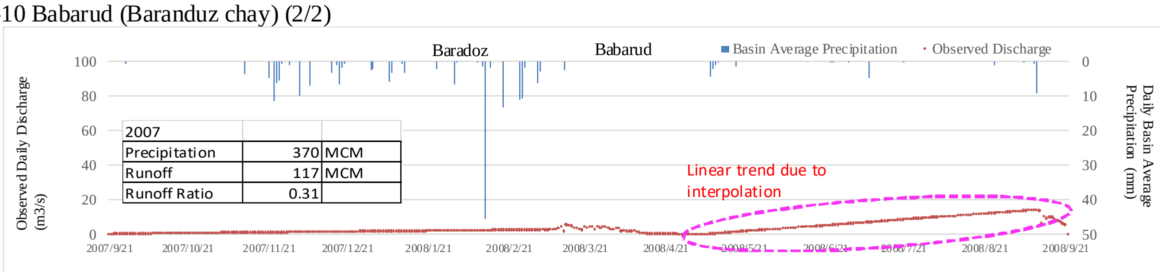


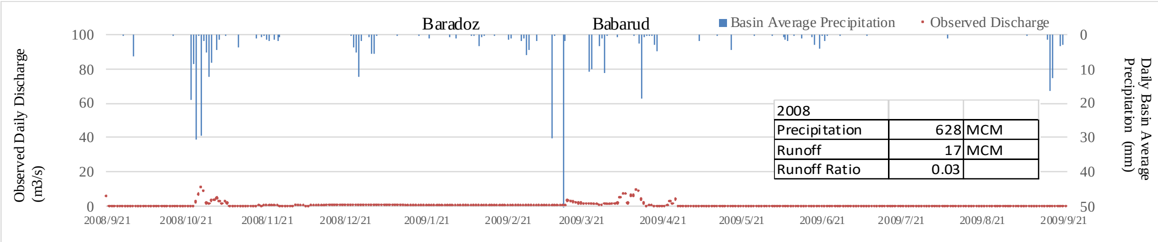


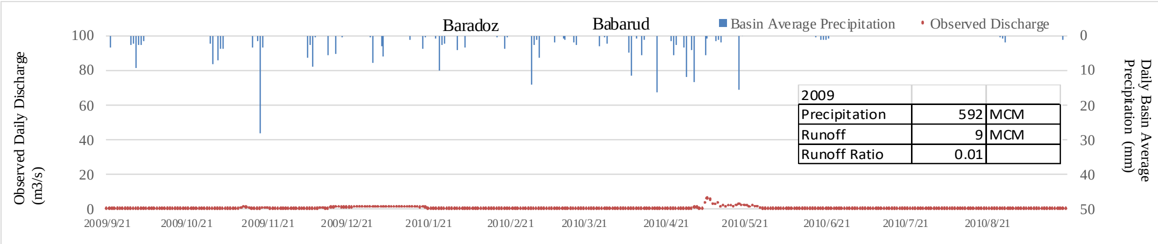


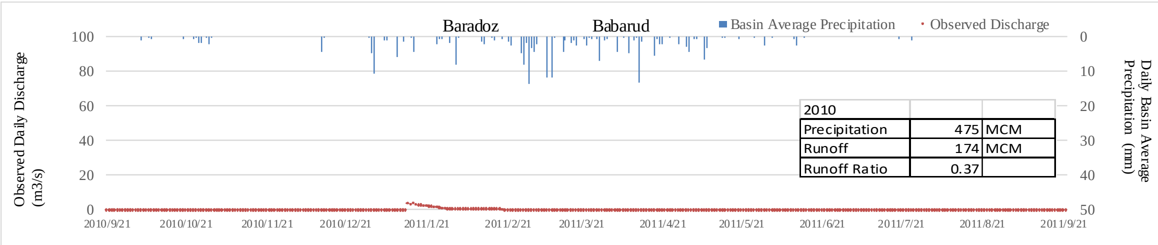


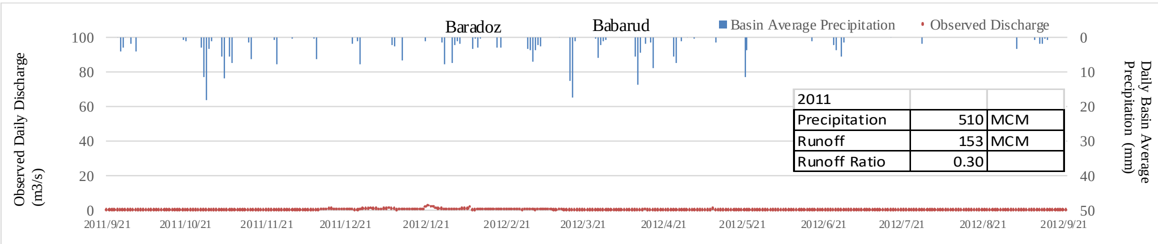
W-10 Babarud (Baranduz chay) (2/2)

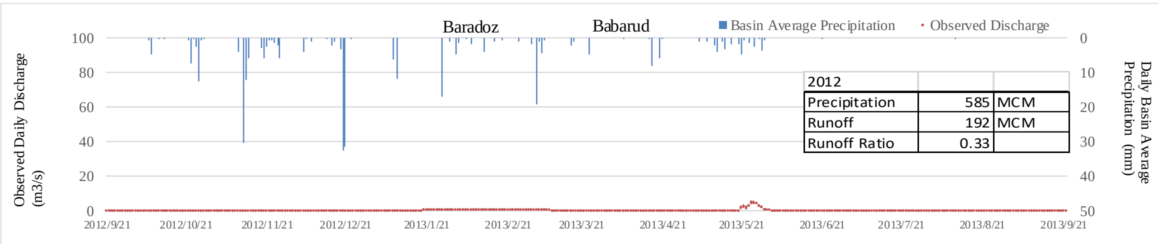


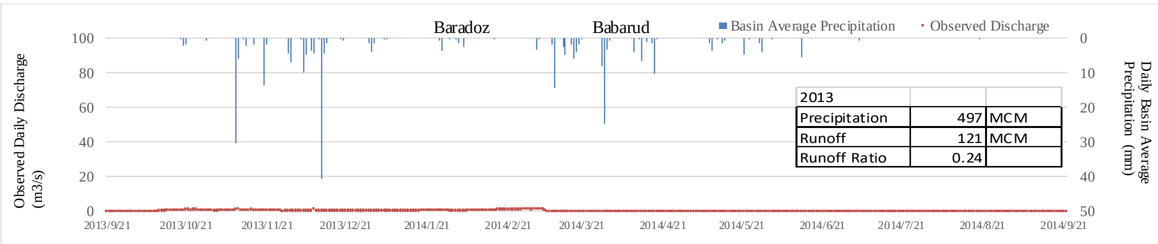




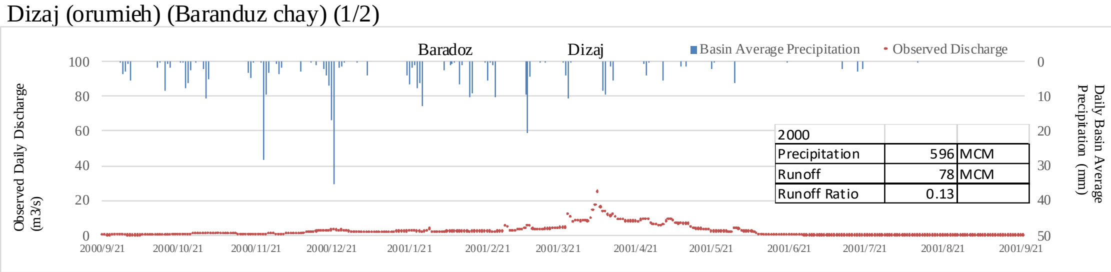


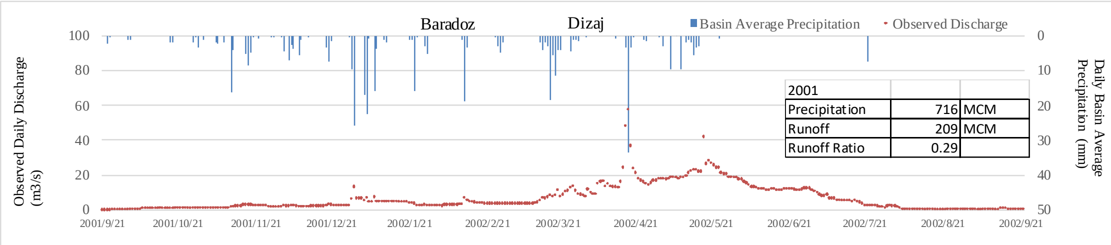


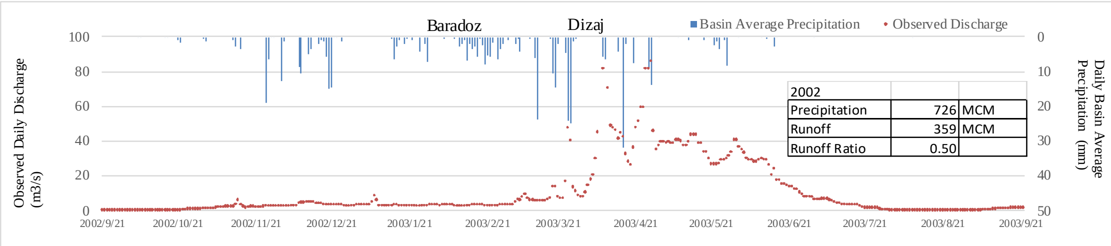


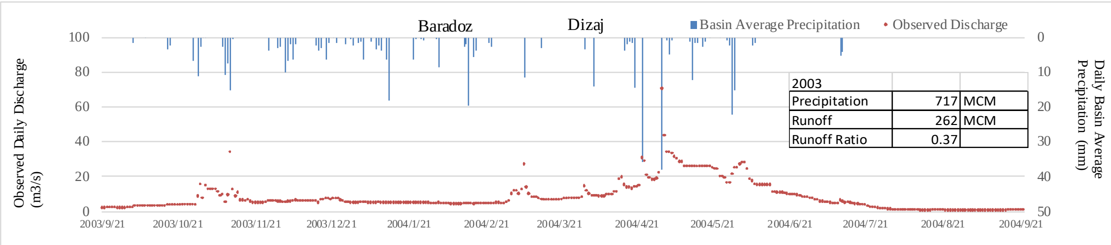


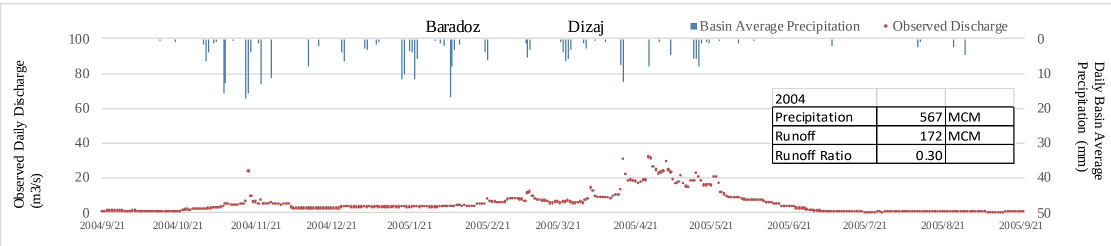
W-11 Dizaj (orumieh) (Baranduz chay) (1/2)

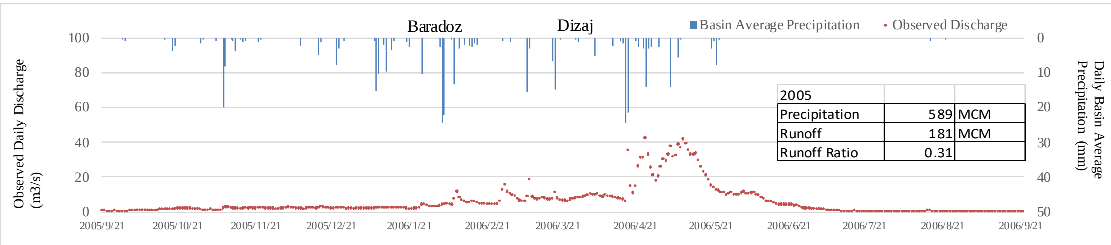


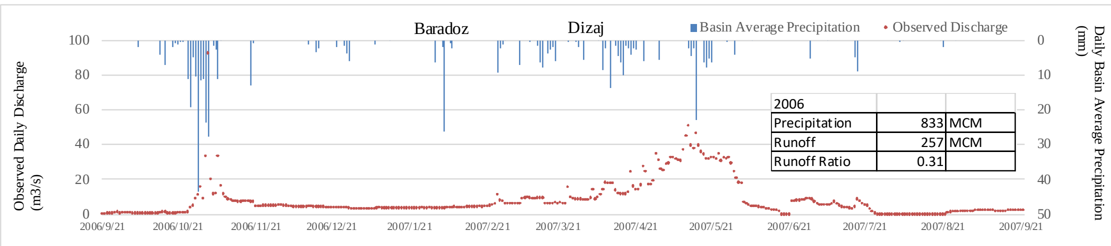




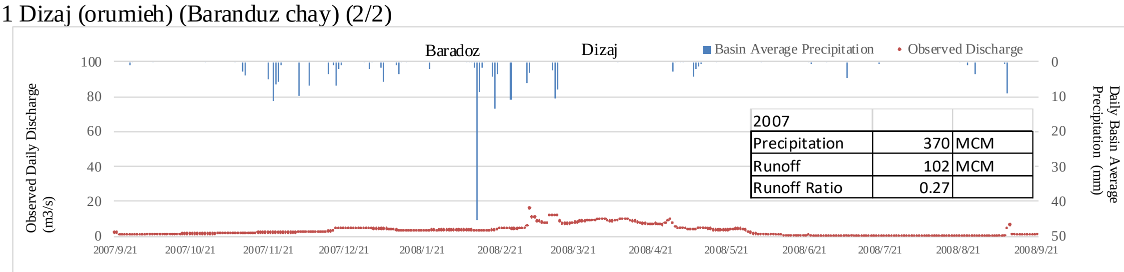


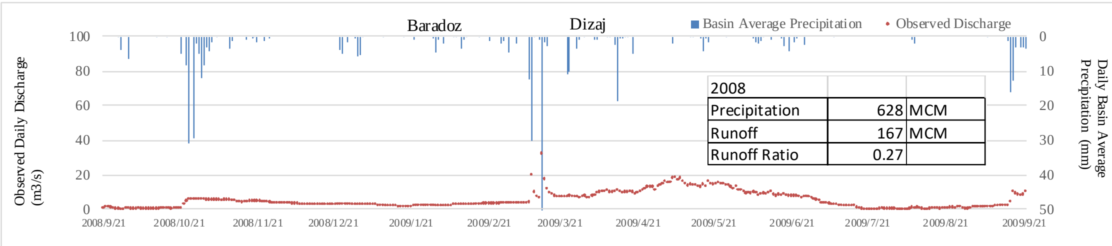


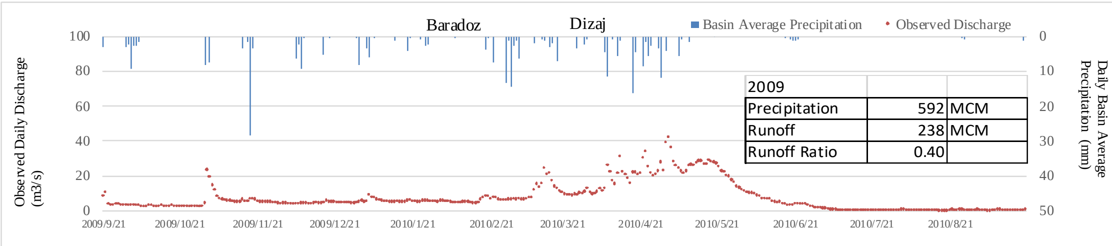


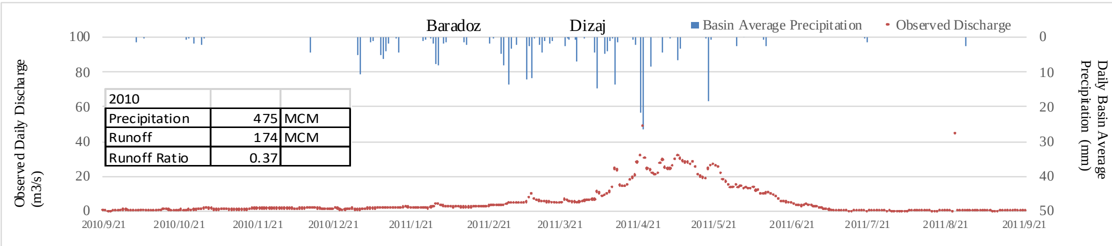


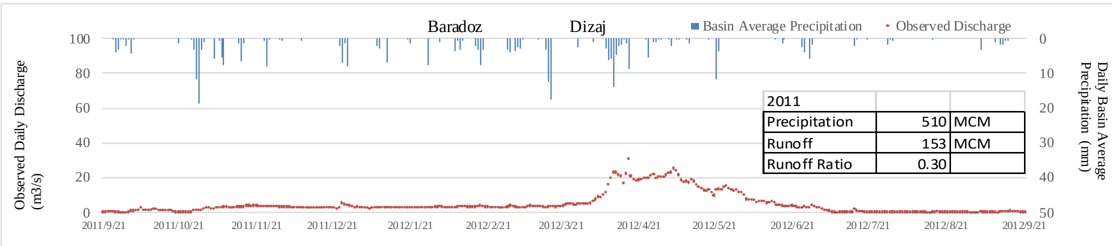
W-11 Dizaj (orumieh) (Baranduz chay) (2/2)

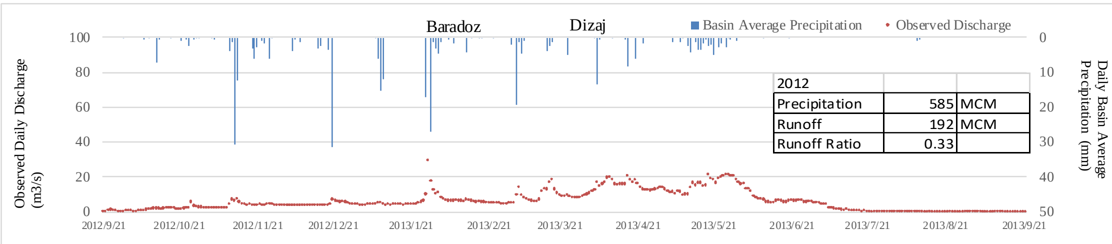


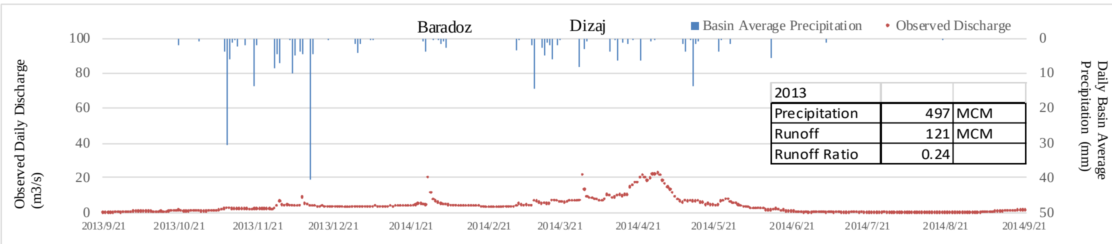




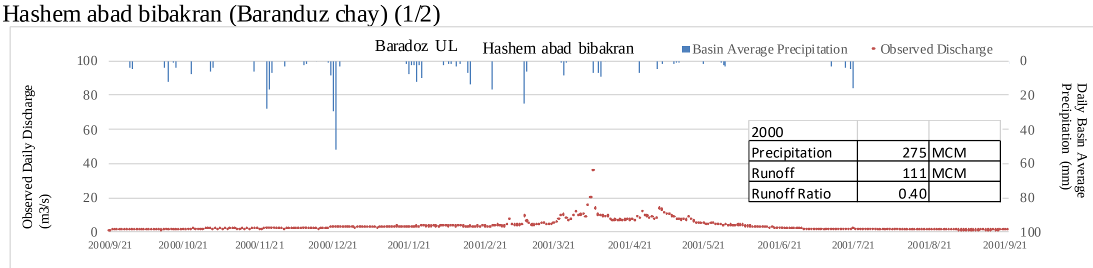


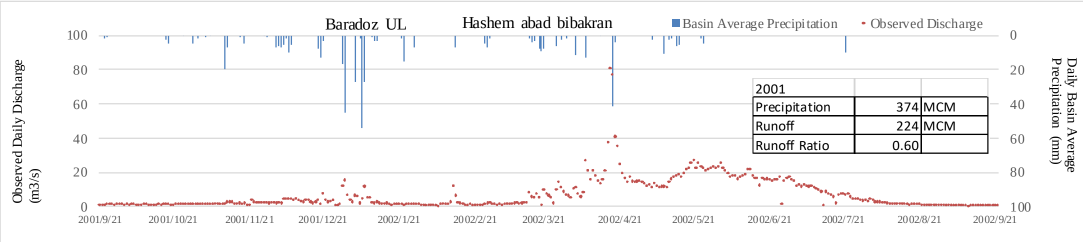


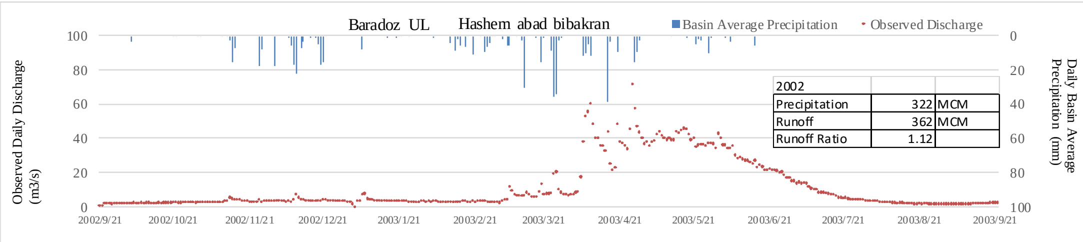


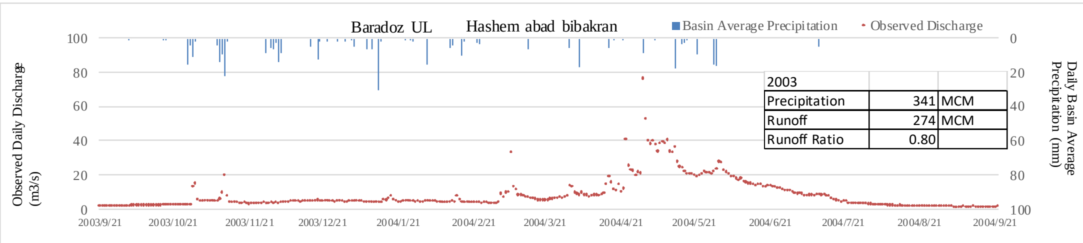


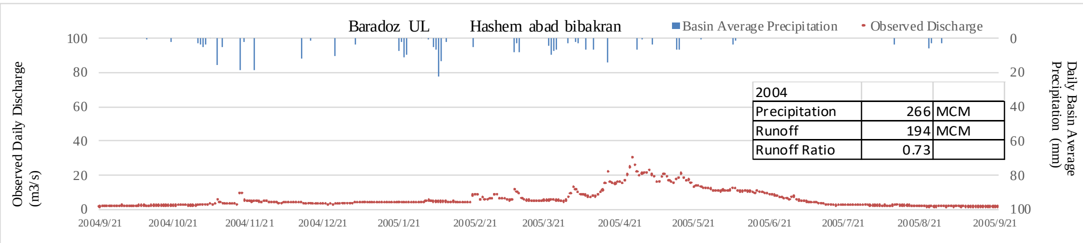
W-12 Hashem abad bibakran (Baranduz chay) (1/2)

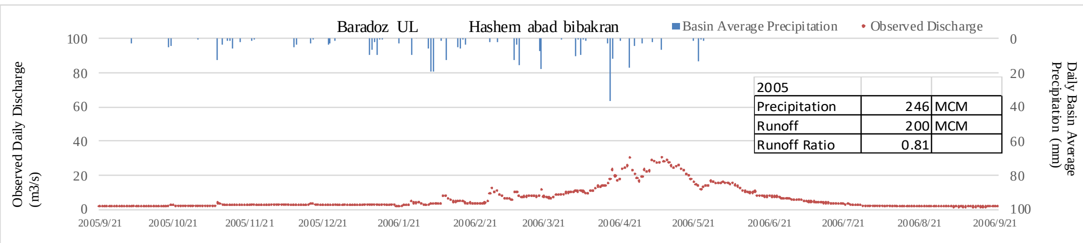


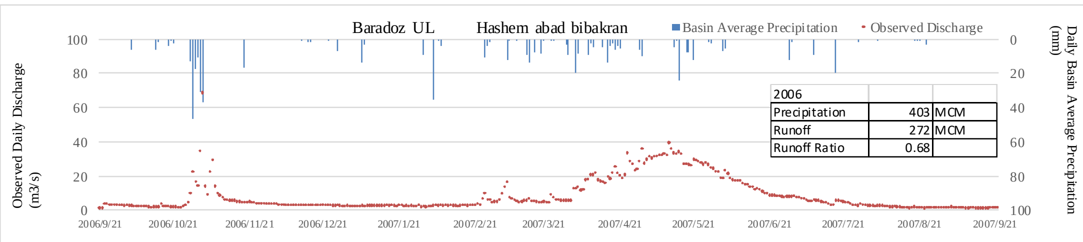




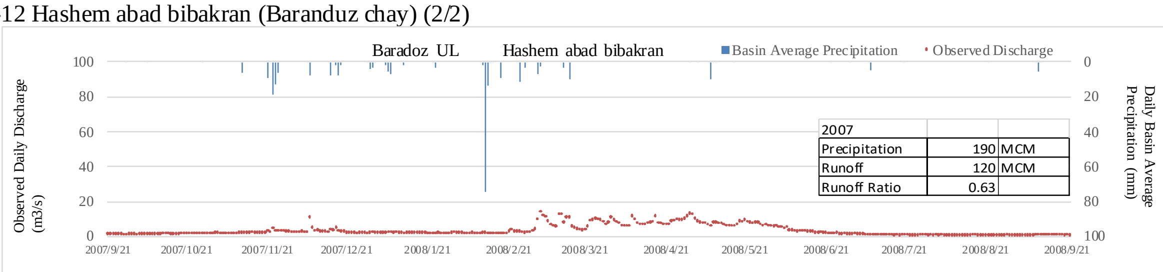


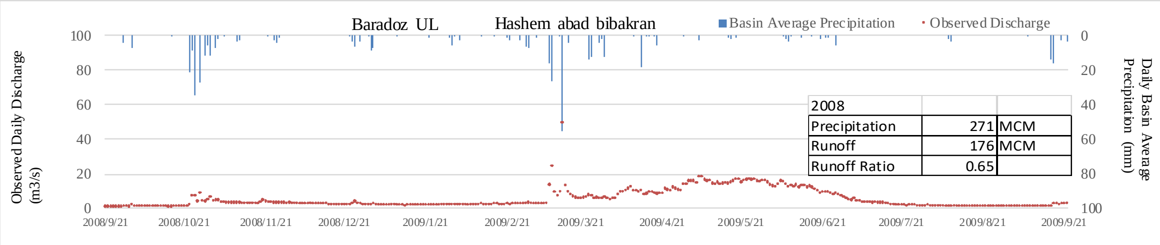


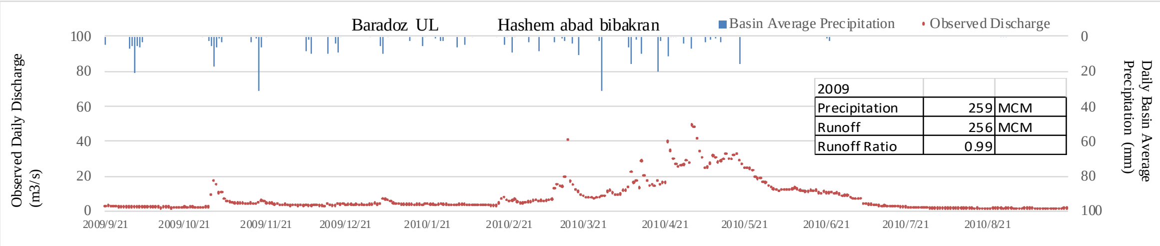


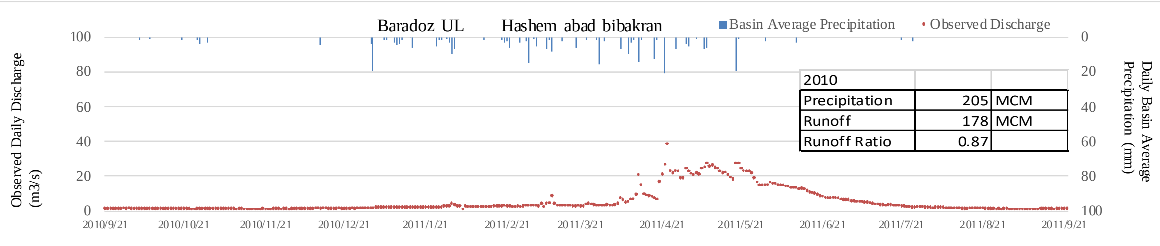


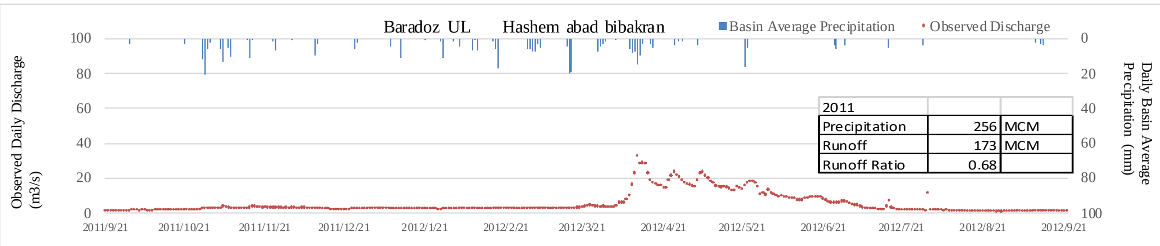
W-12 Hashem abad bibakran (Baranduz chay) (2/2)

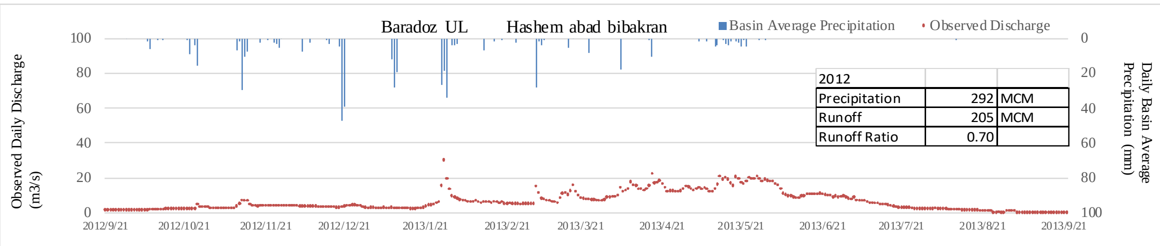


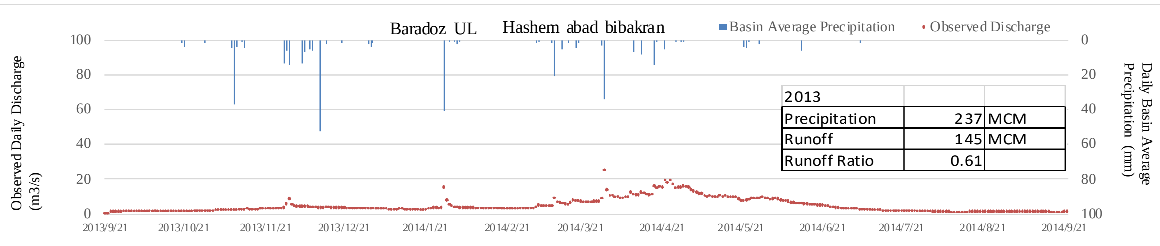




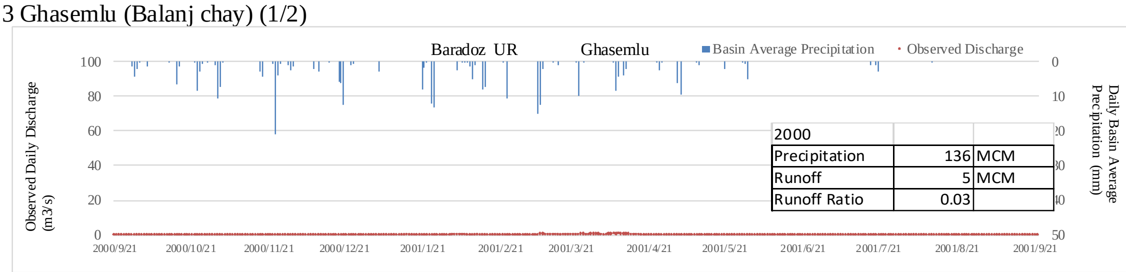


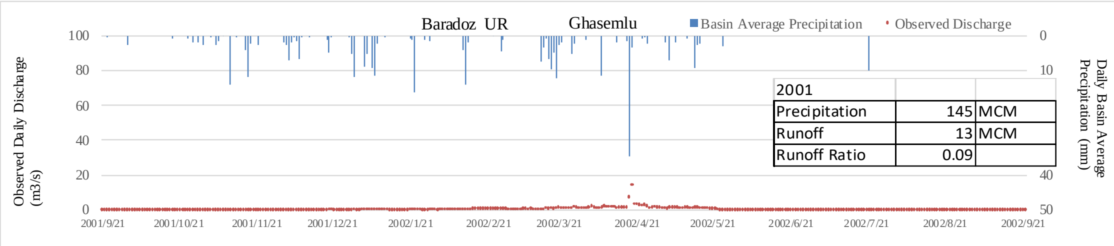


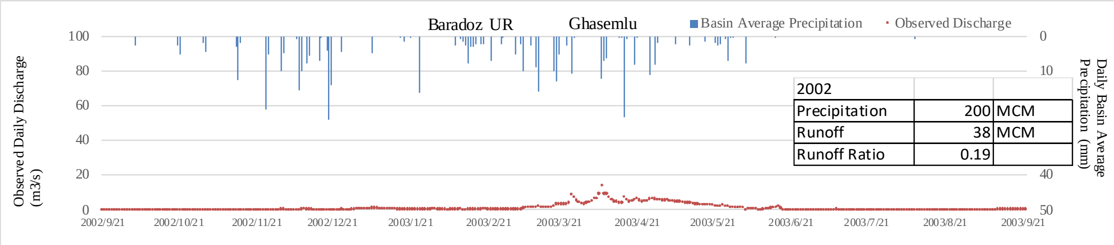


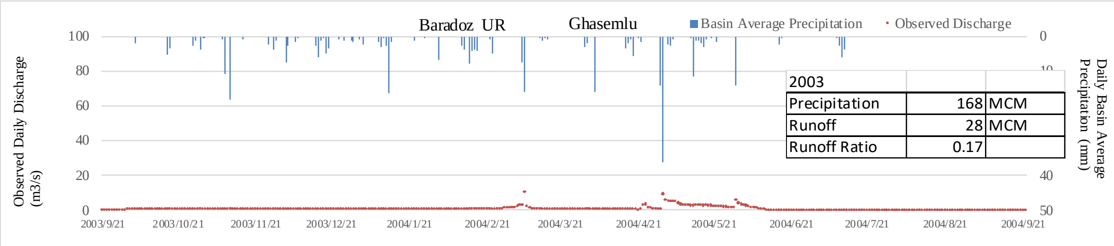


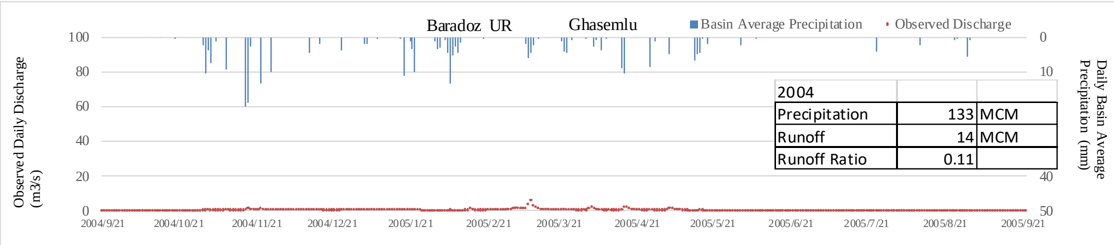
W-13 Ghasemlu (Balanj chay) (1/2)

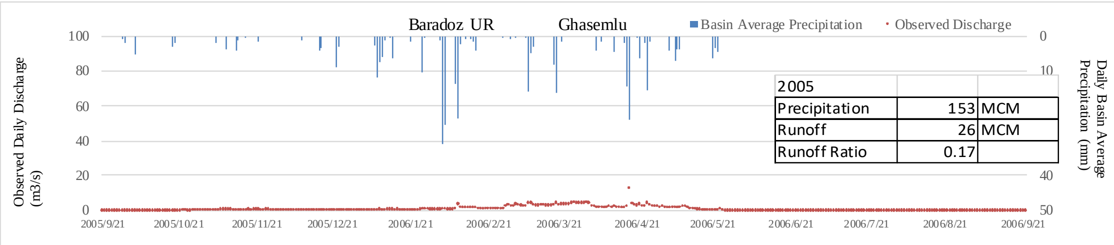


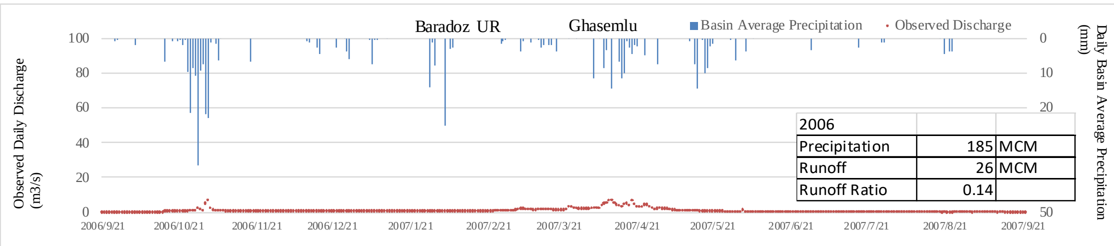




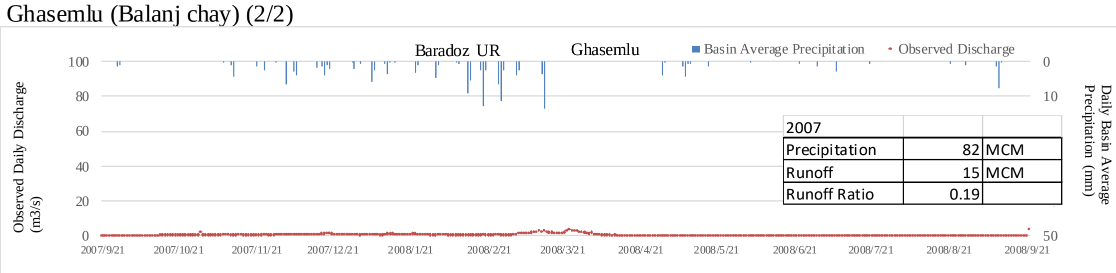


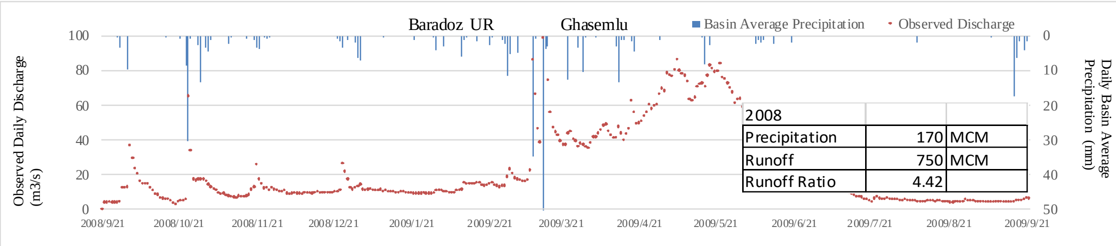


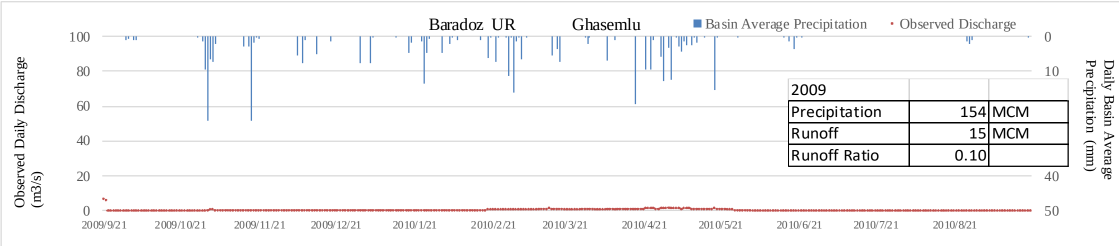


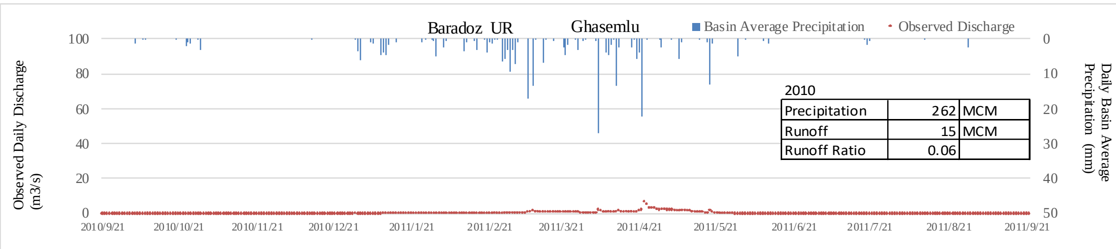


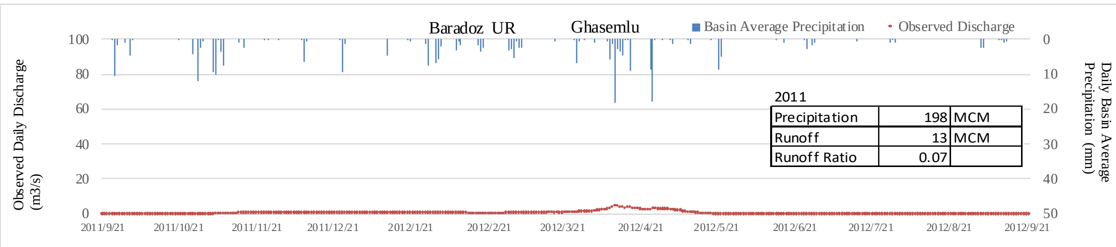
W-13 Ghasemlu (Balanj chay) (2/2)

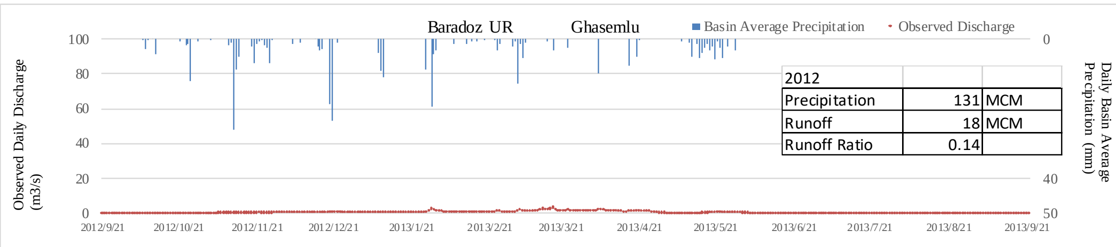


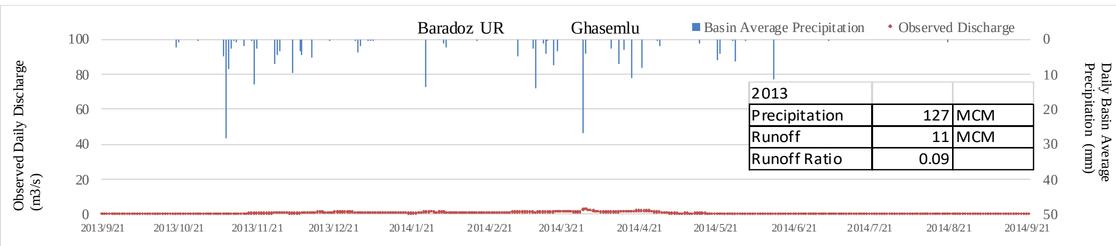




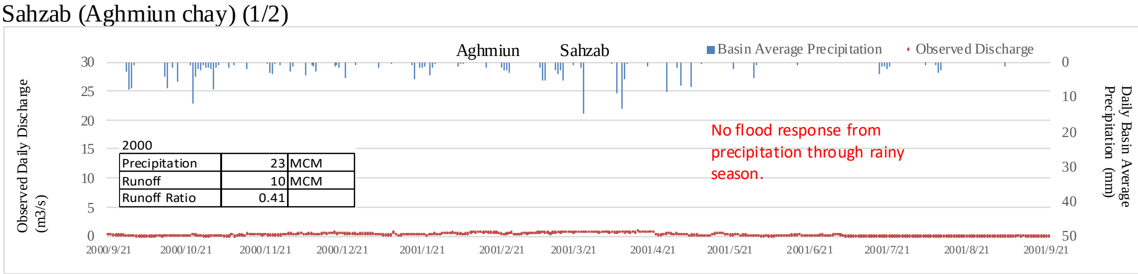


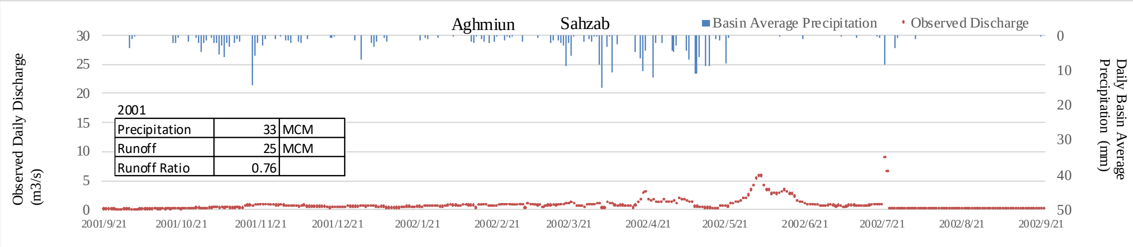


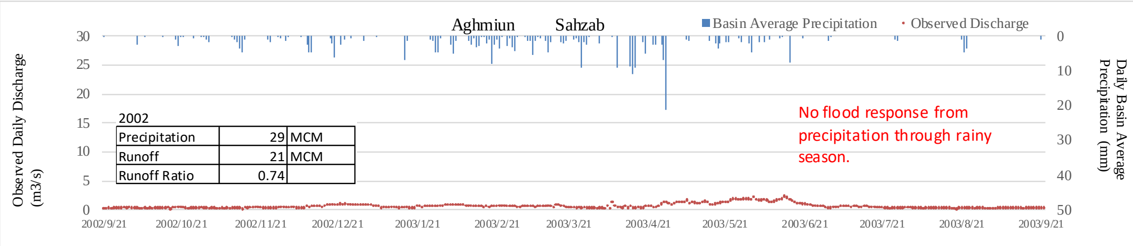


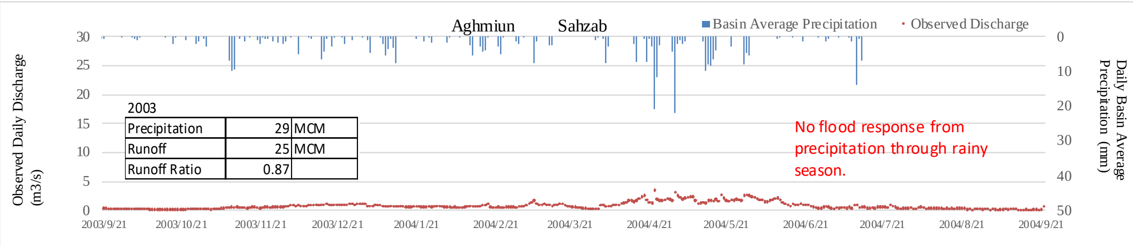


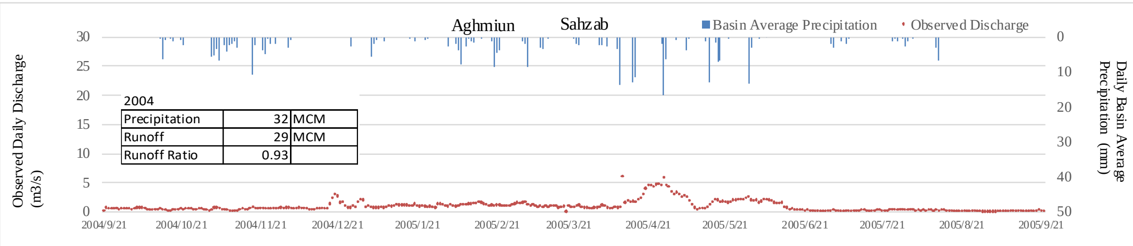
E-1 Sahzab (Aghmiun chay) (1/2)

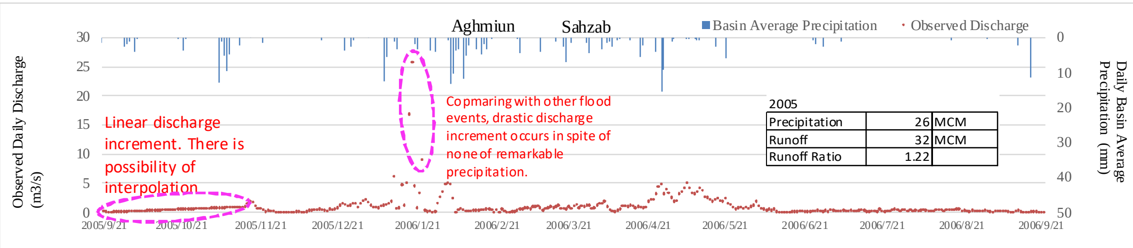


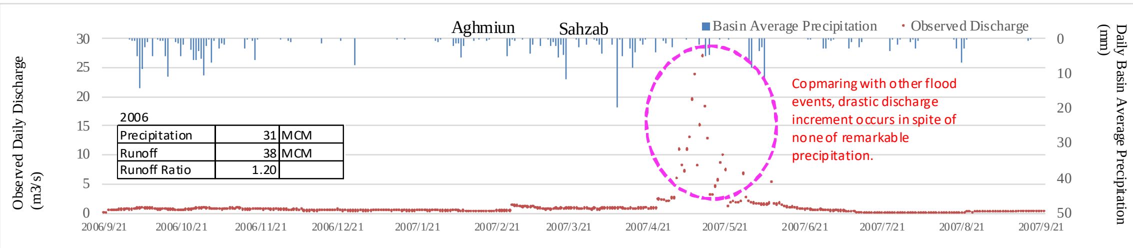




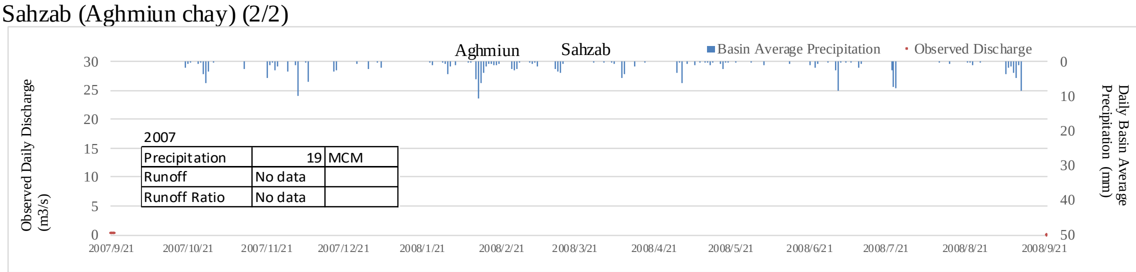


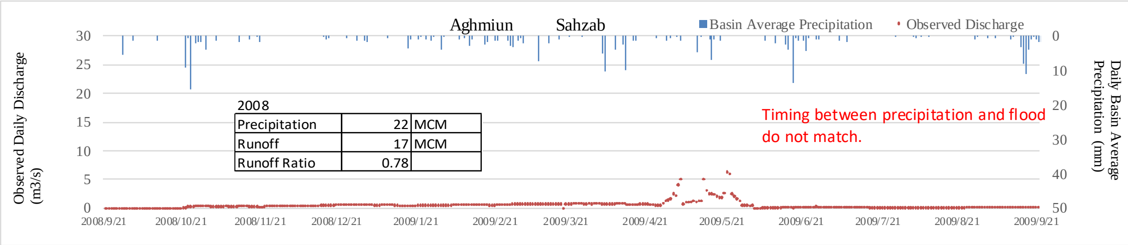


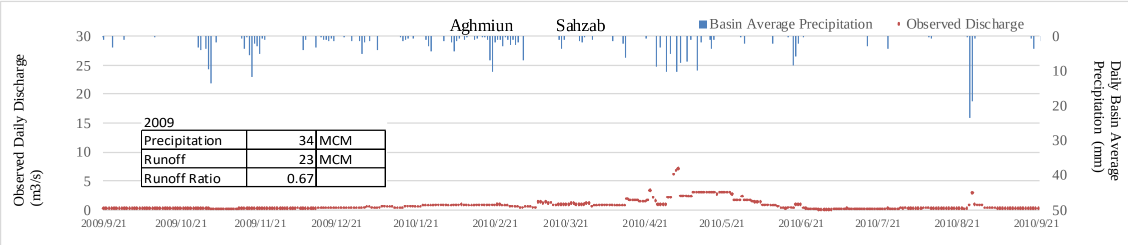


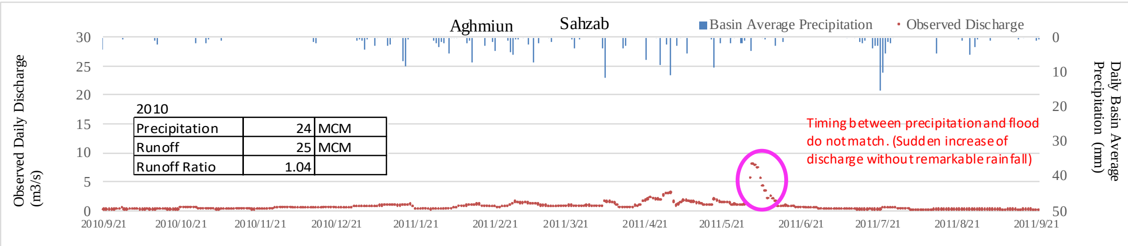


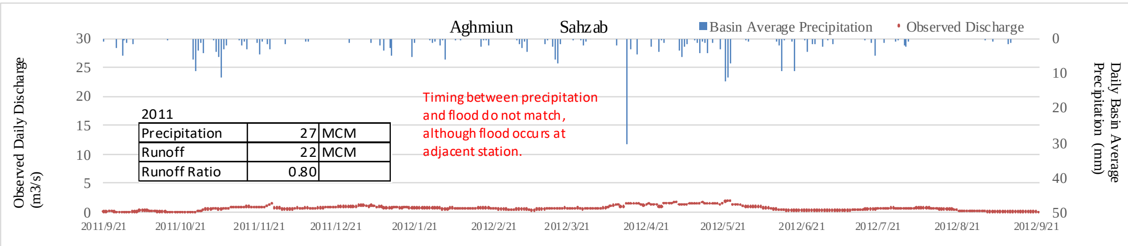
E-1 Sahzab (Aghmiun chay) (2/2)

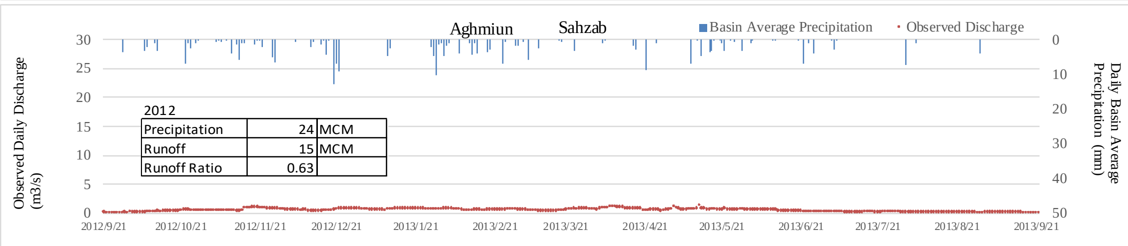


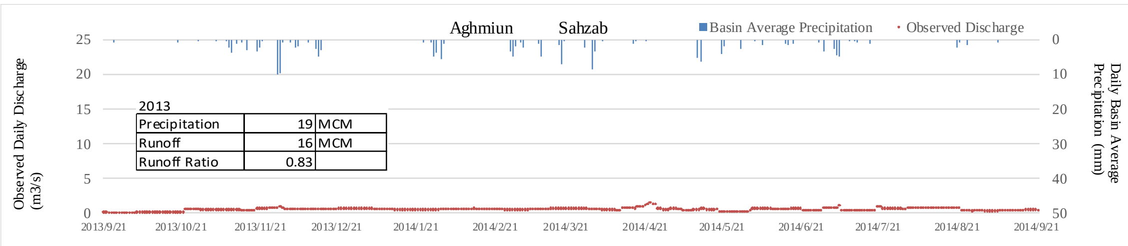




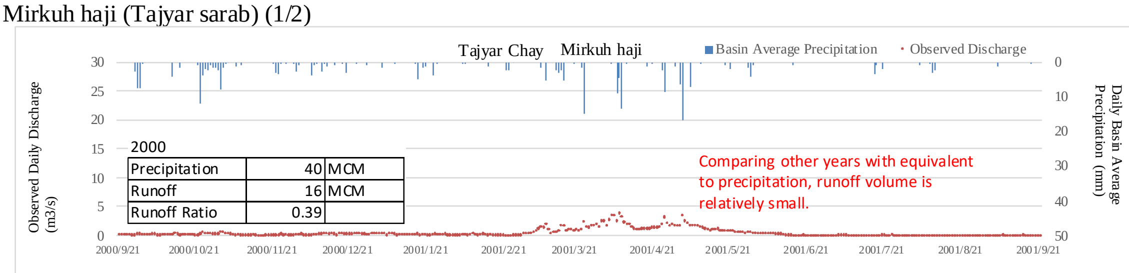


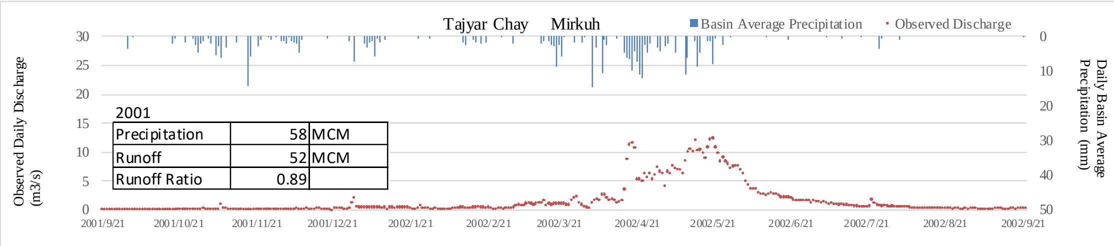


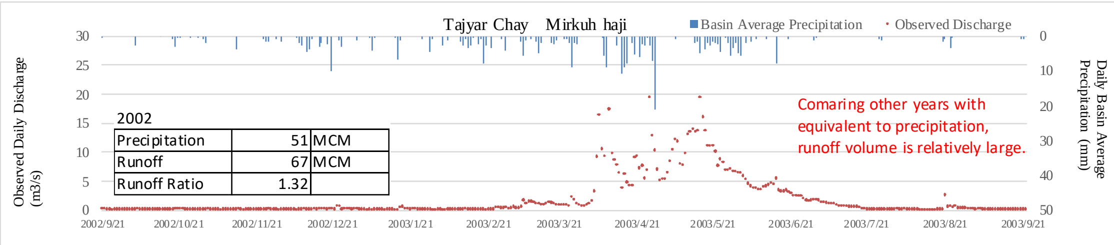


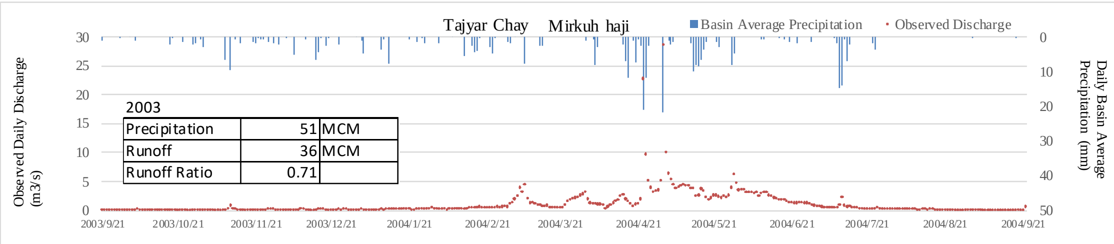


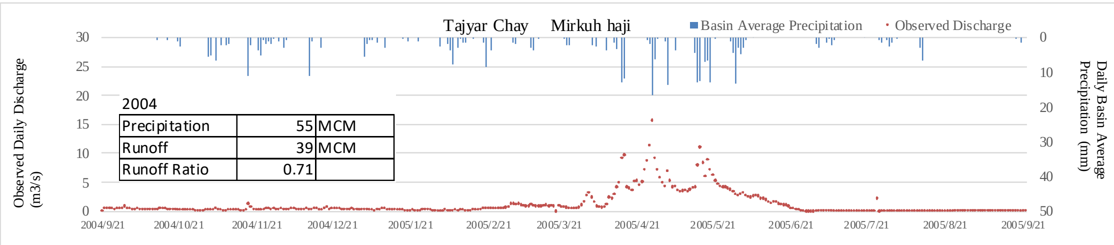
E-2 Mirkuh haji (Tajyar sarab) (1/2)

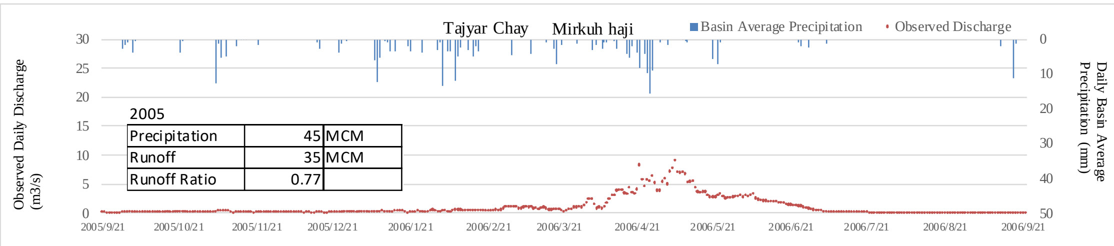


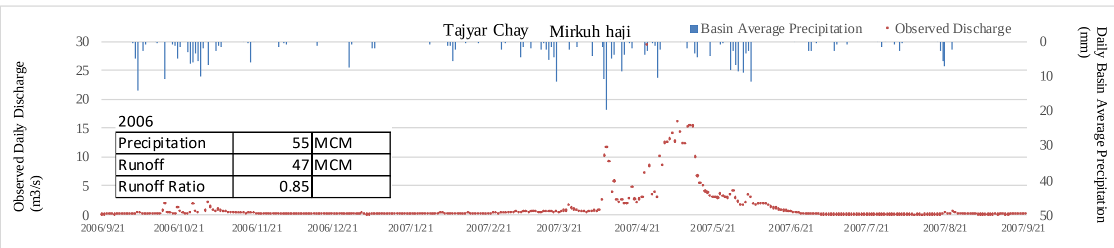




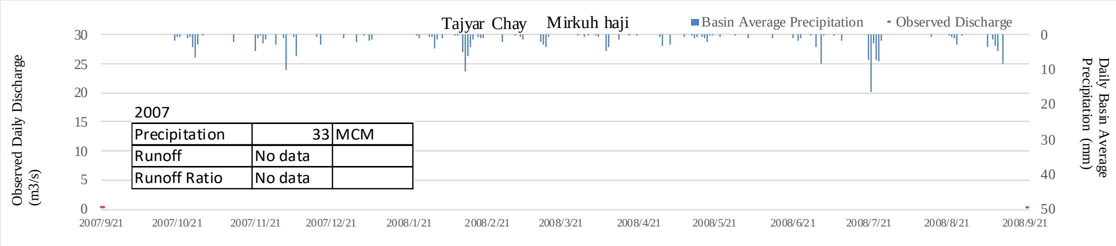


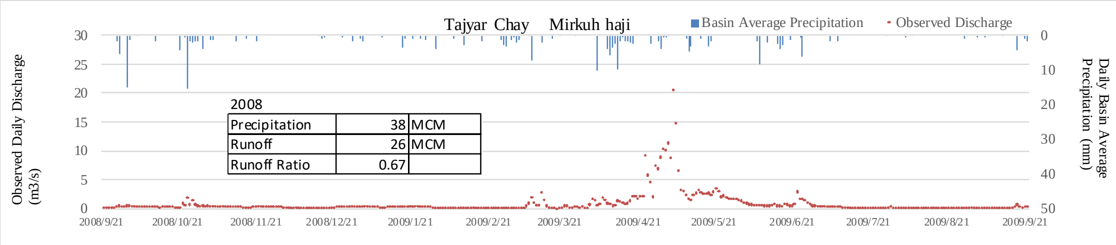


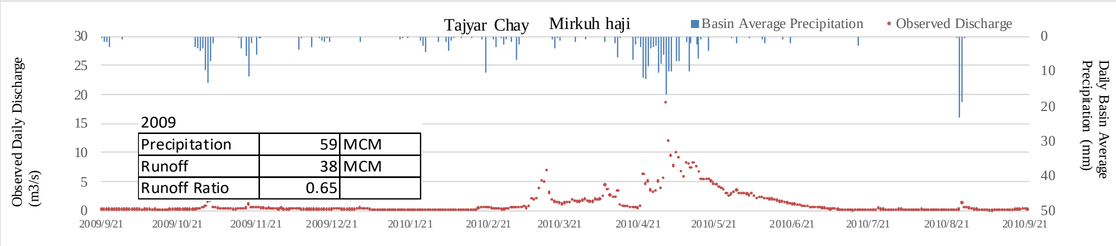


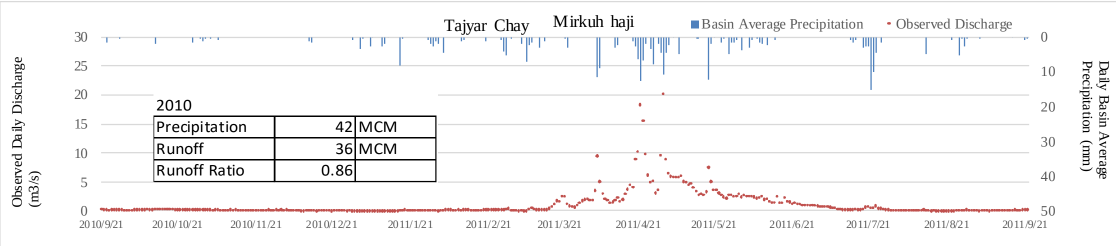


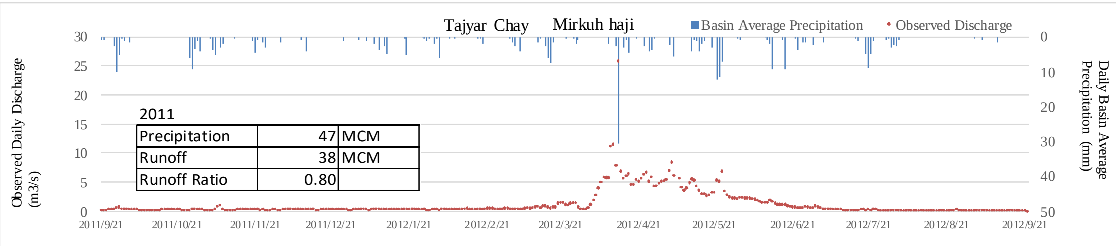
E-2 Mirkuh haji (Tajyar sarab) (2/2)

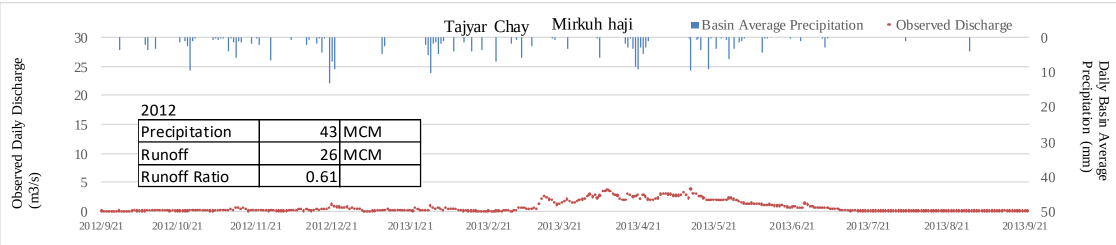


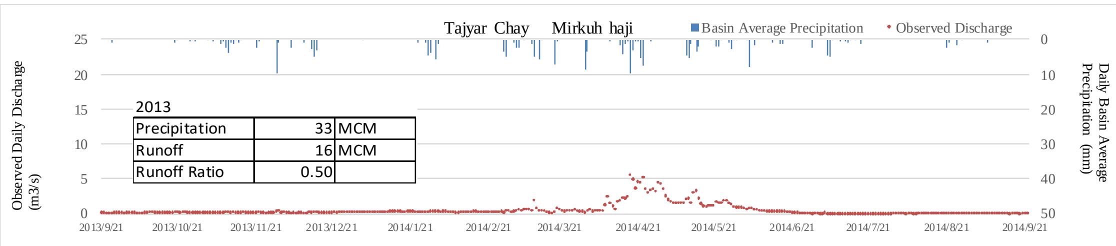




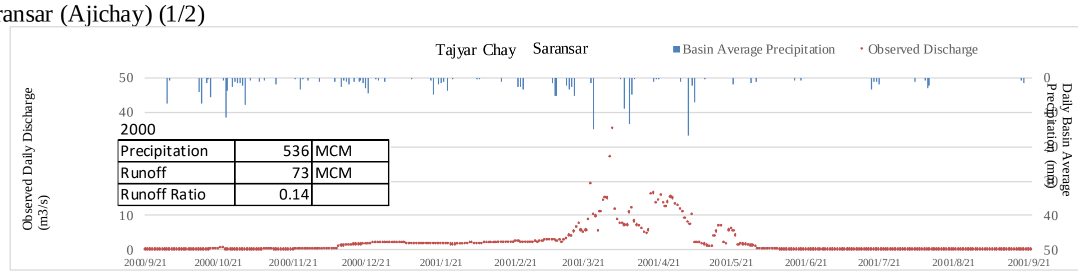


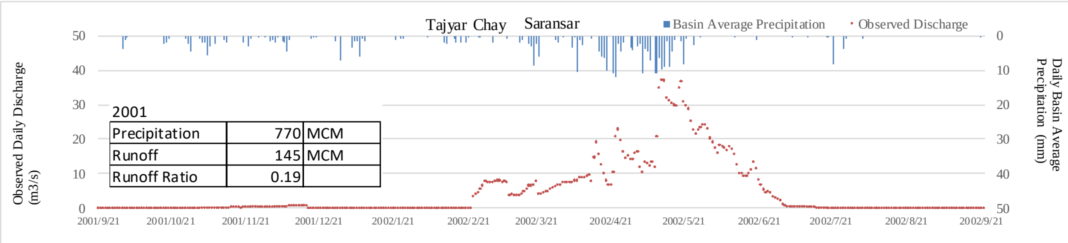


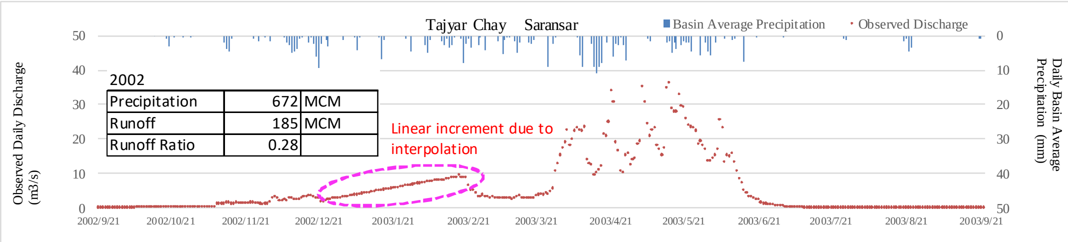


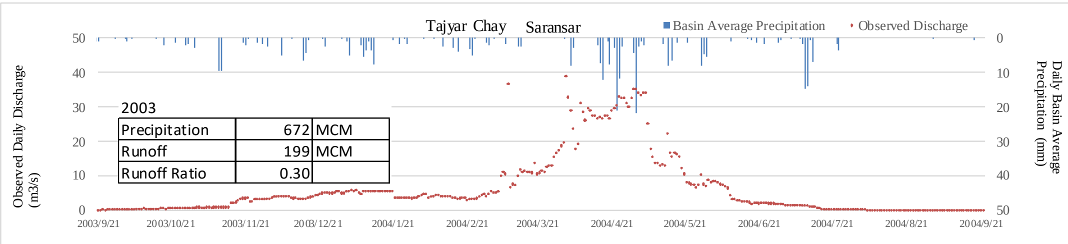


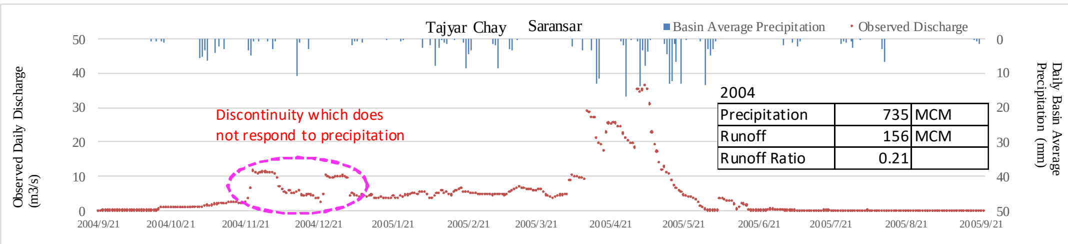
E-3 Saransar (Ajichay) (1/2)

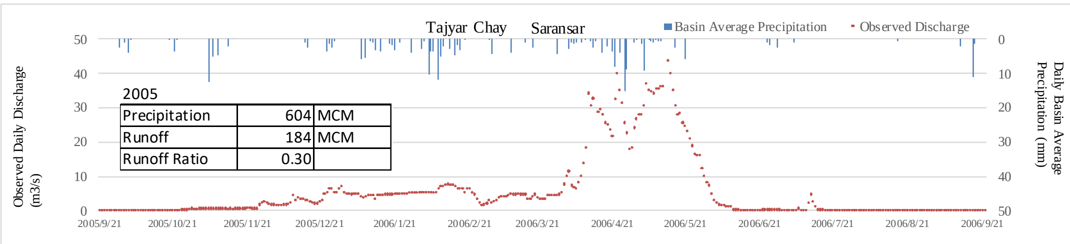


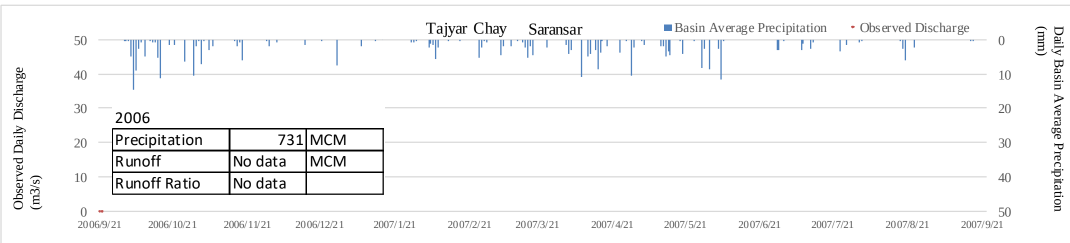




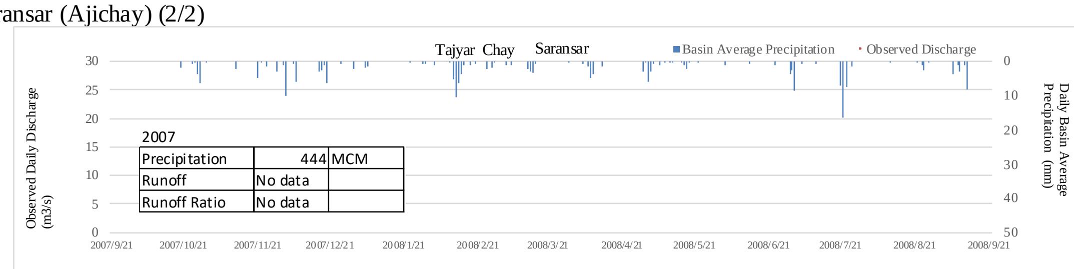


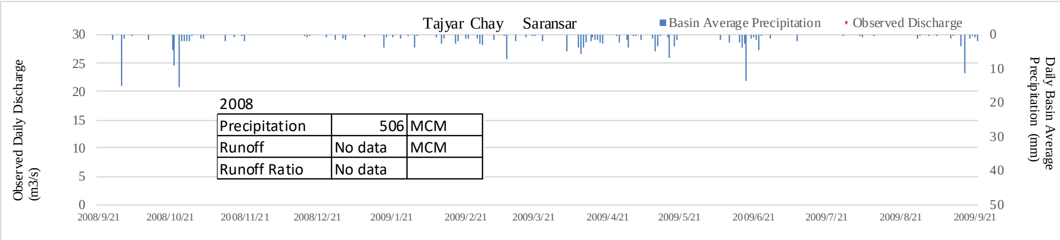


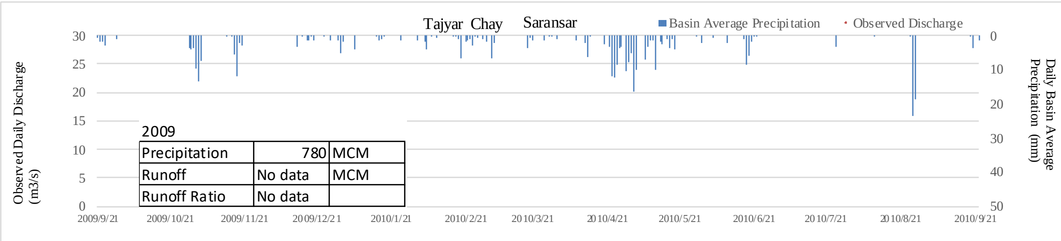


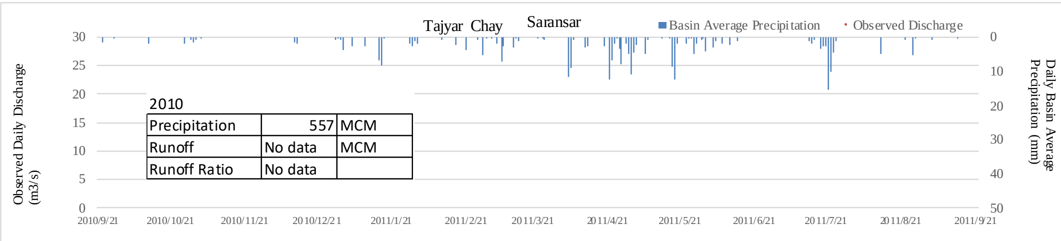


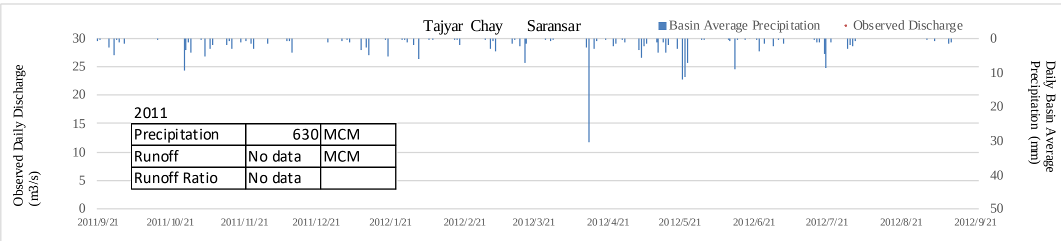
E-3 Saransar (Ajichay) (2/2)

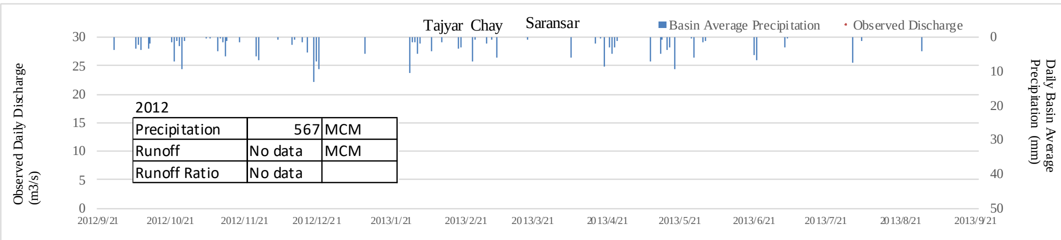


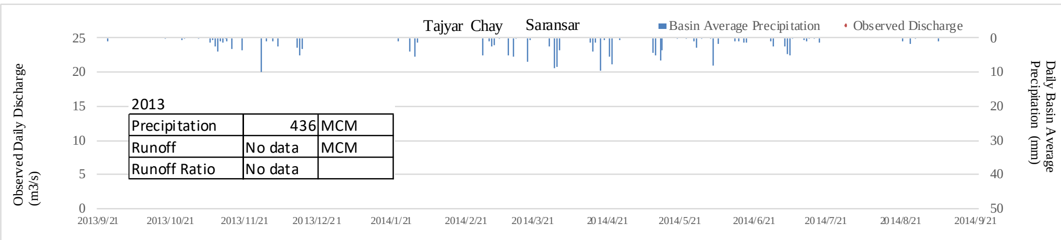




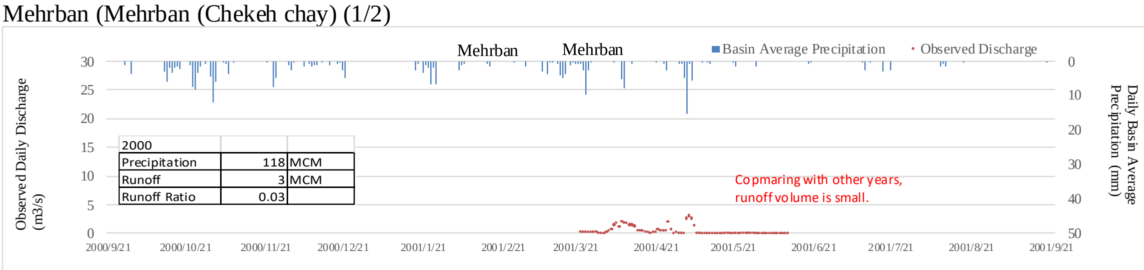


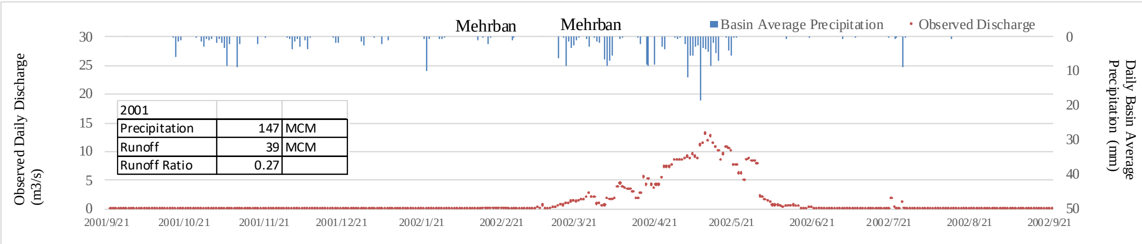


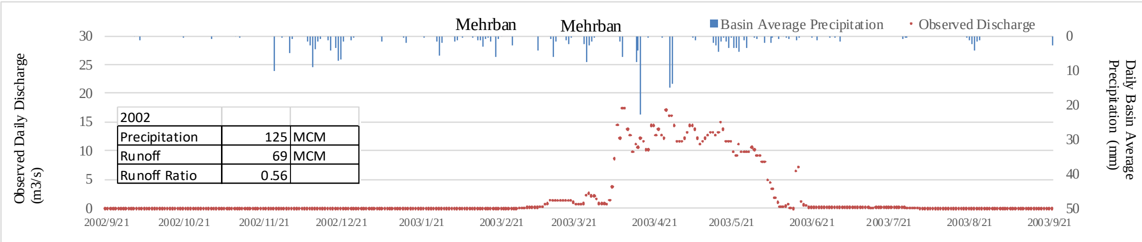


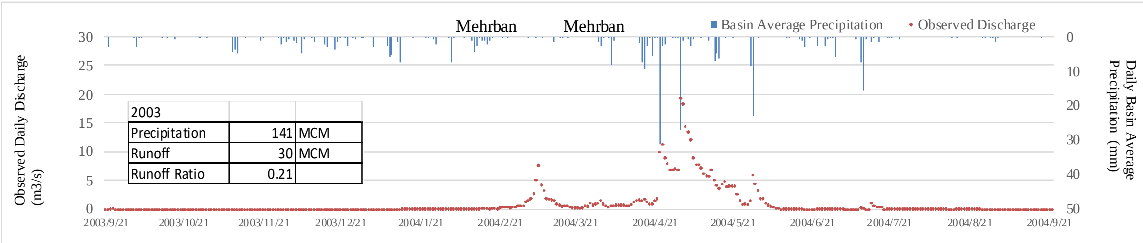


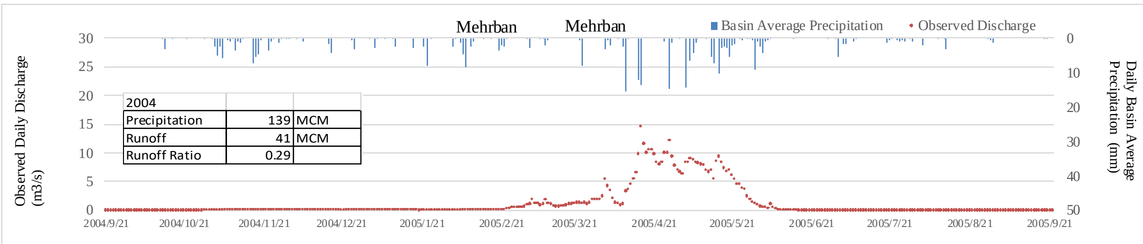
E-4 Mehrban (Mehrban (Chekeh chay) (1/2)

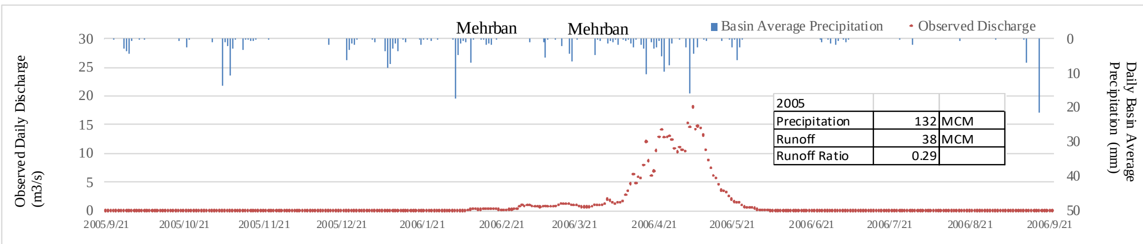


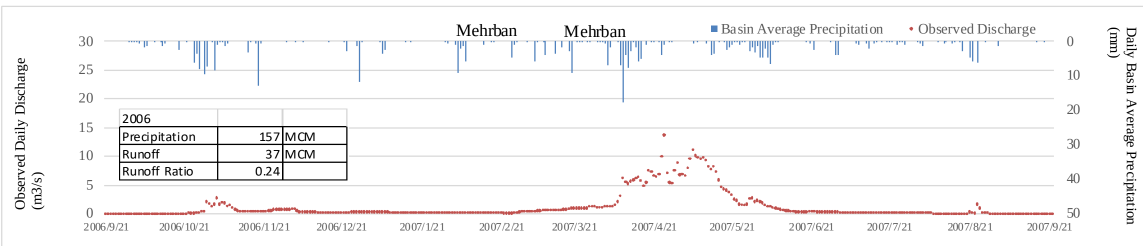




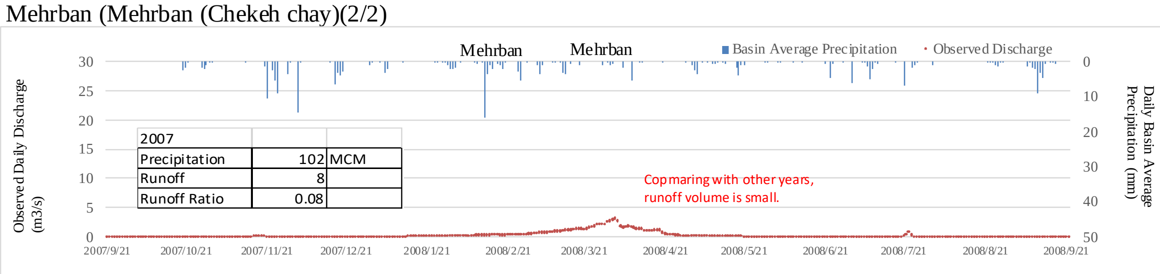


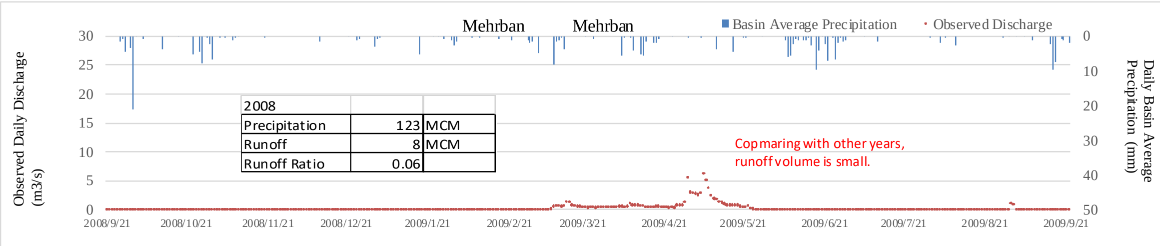


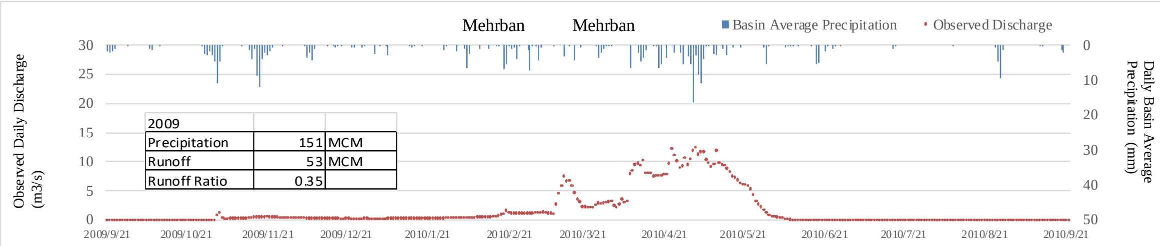


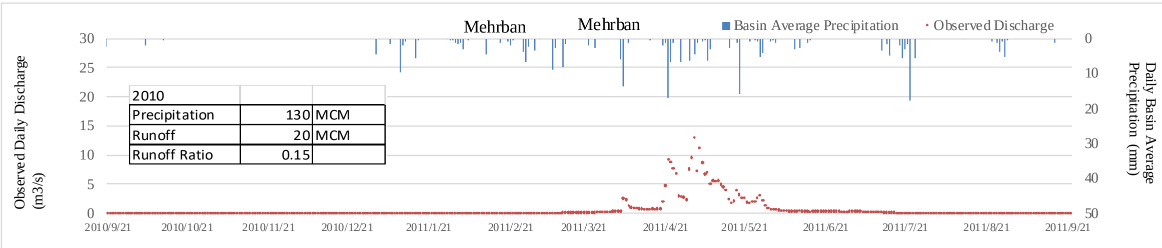


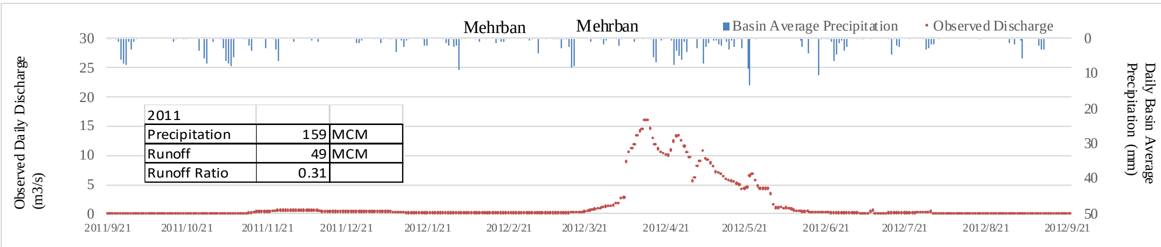
E-4 Mehrban (Mehrban (Chekeh chay)(2/2)

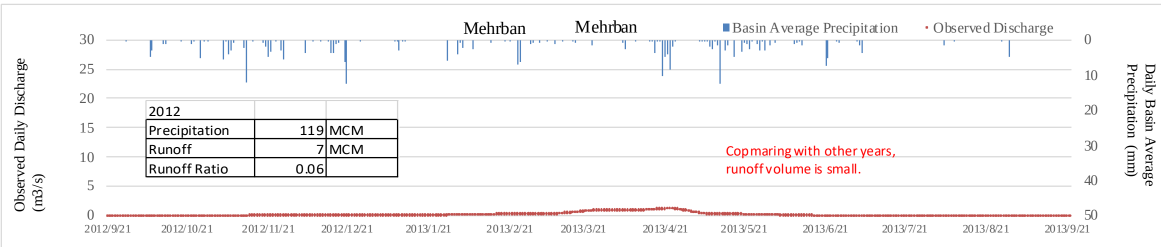


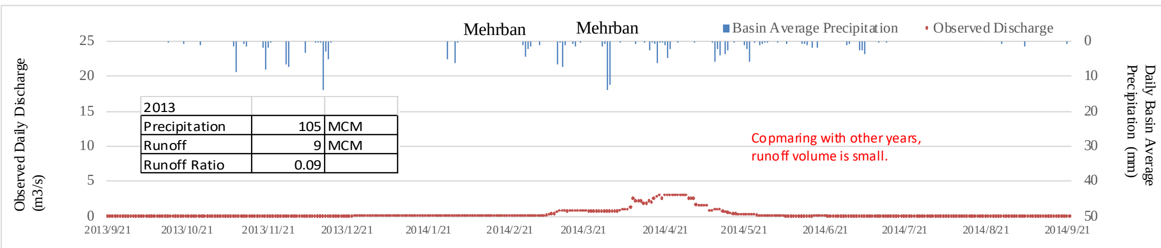




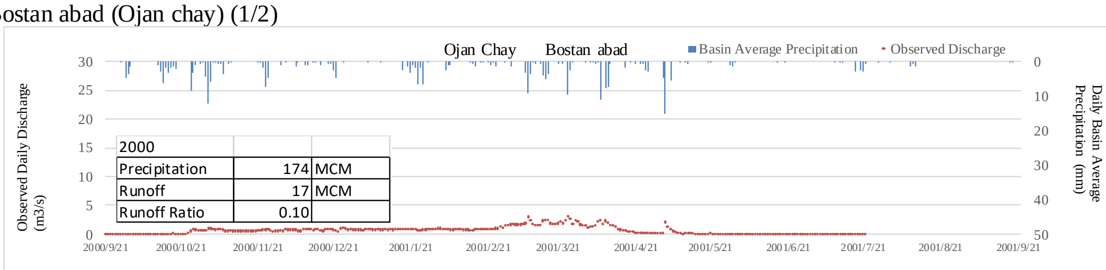


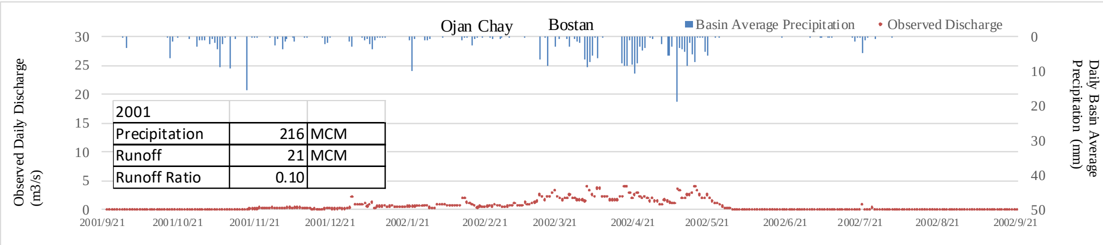


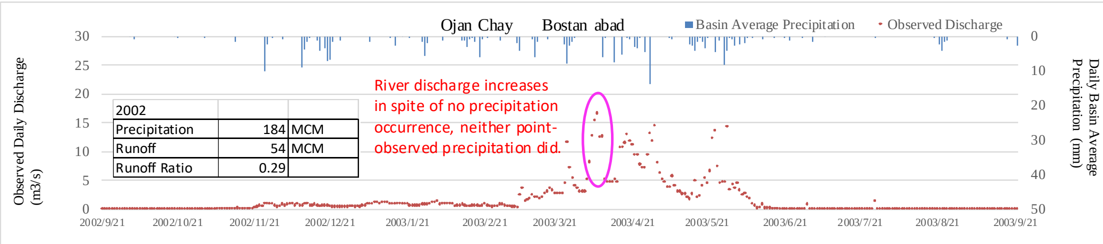


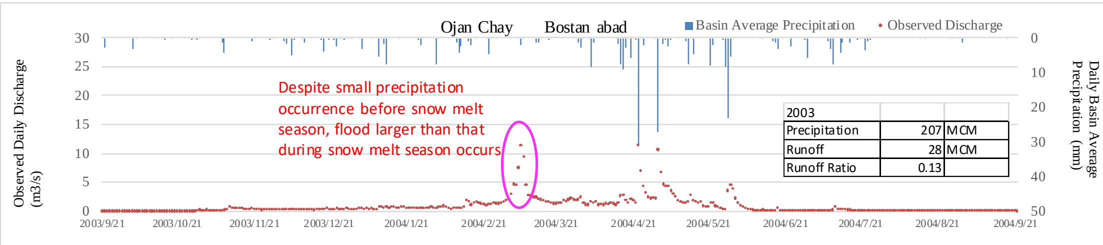


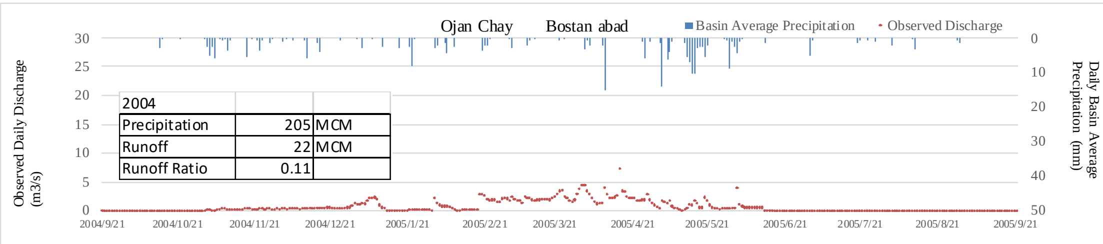
E-5 Bostan abad (Ojan chay) (1/2)

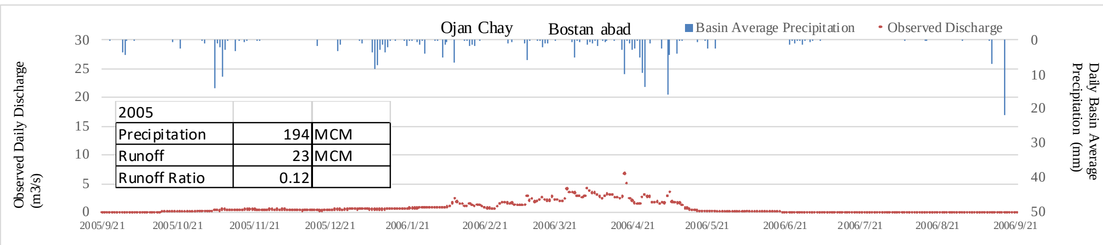


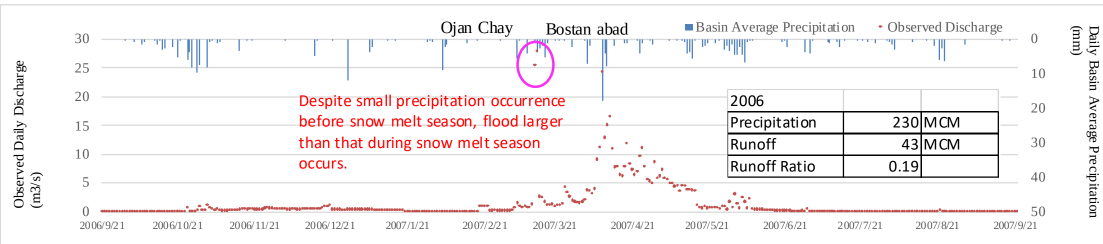




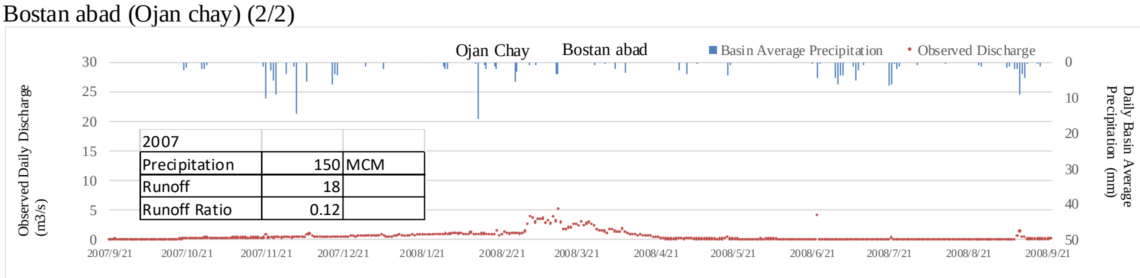


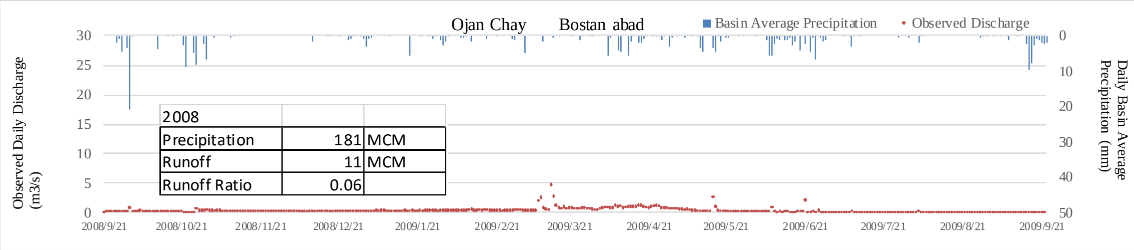


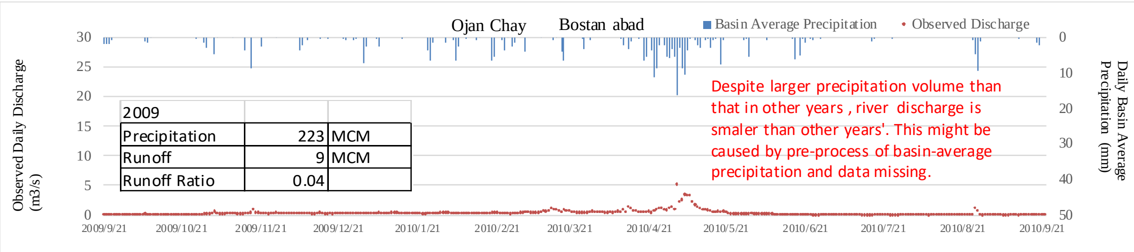


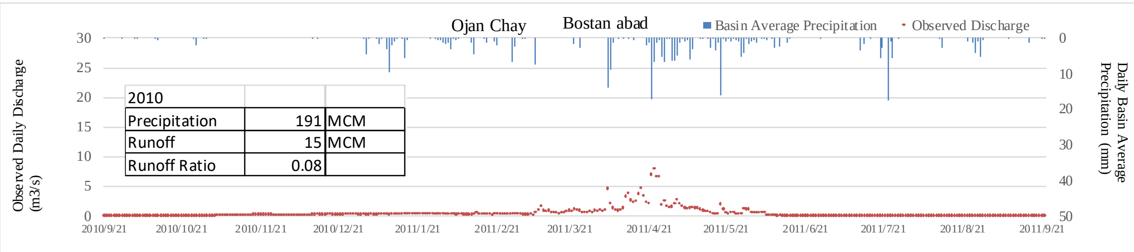


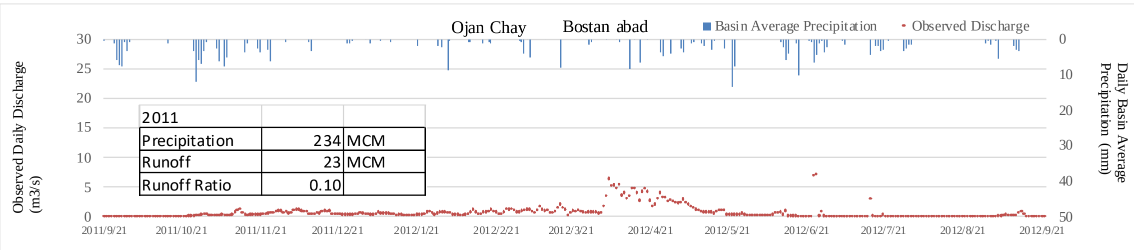
E-5 Bostan abad (Ojan chay) (2/2)

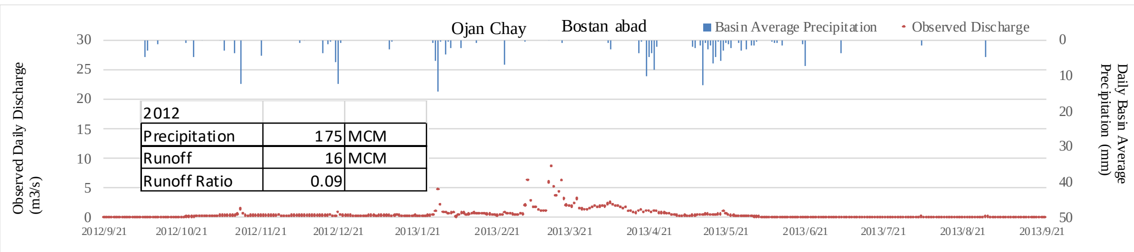


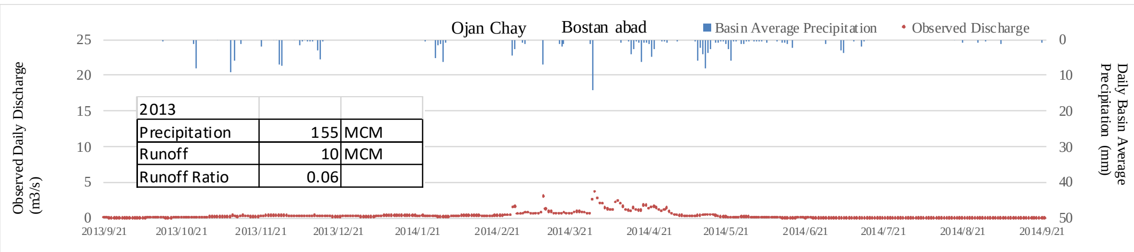




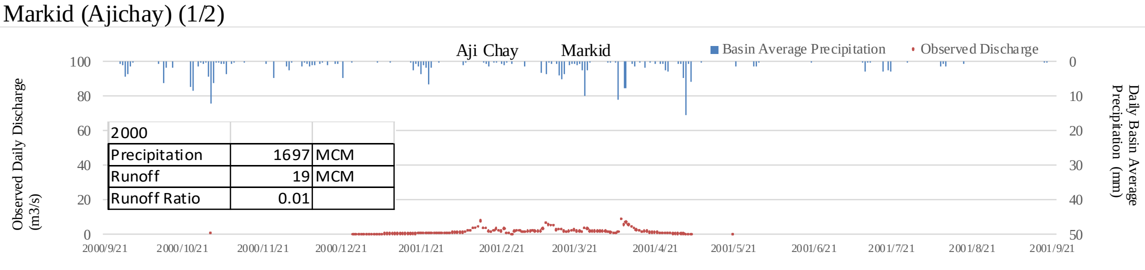


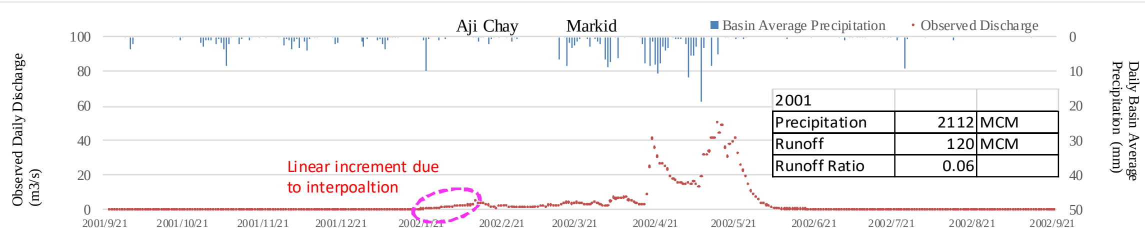


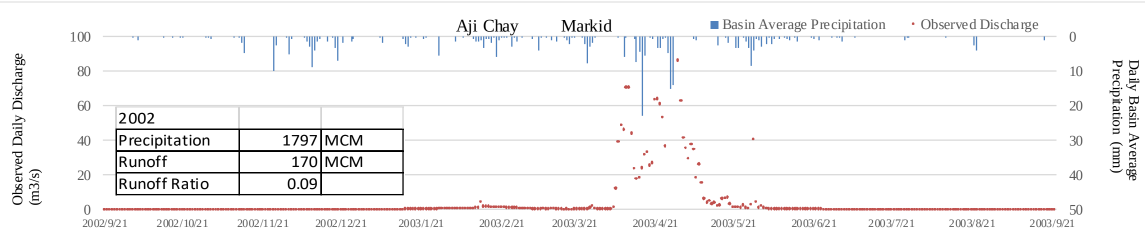


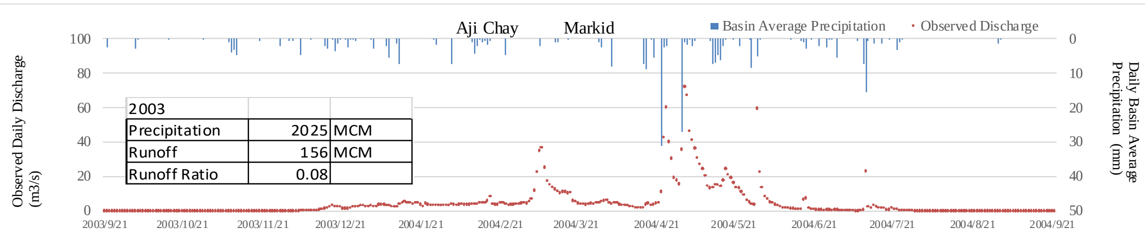


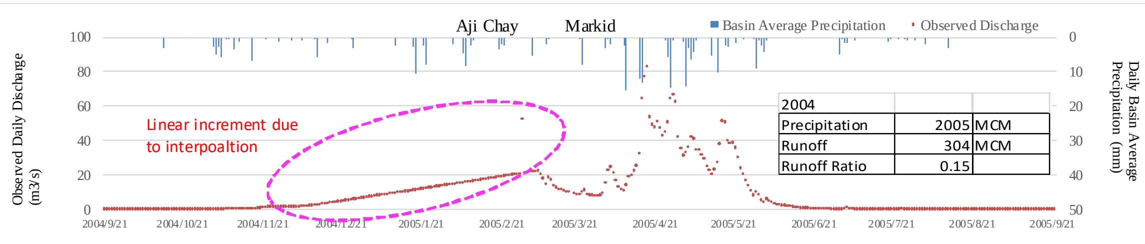
E-6 Markid (Ajichay) (1/2)

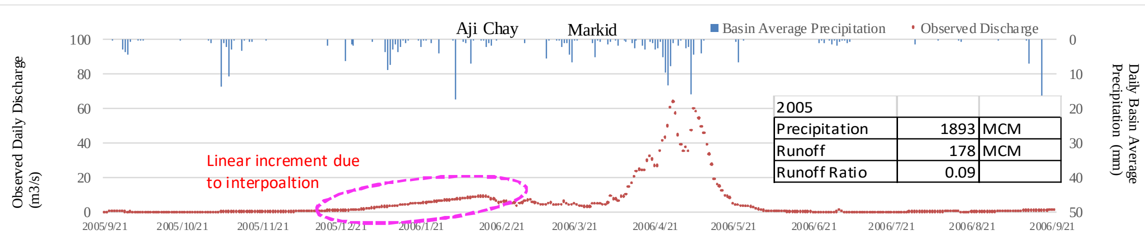


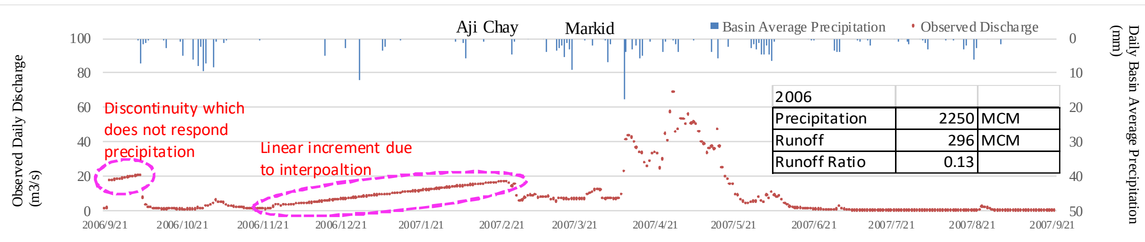




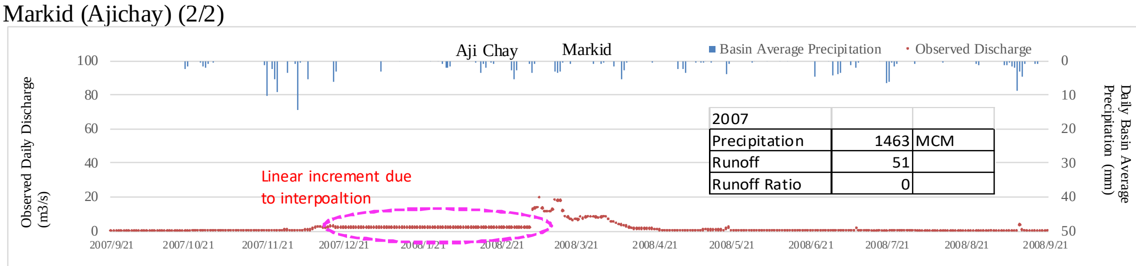


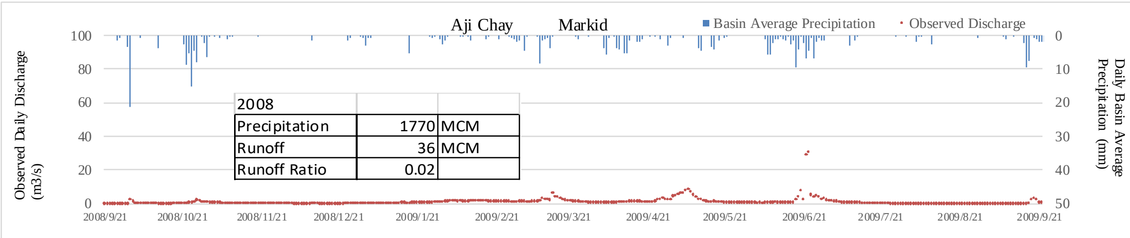


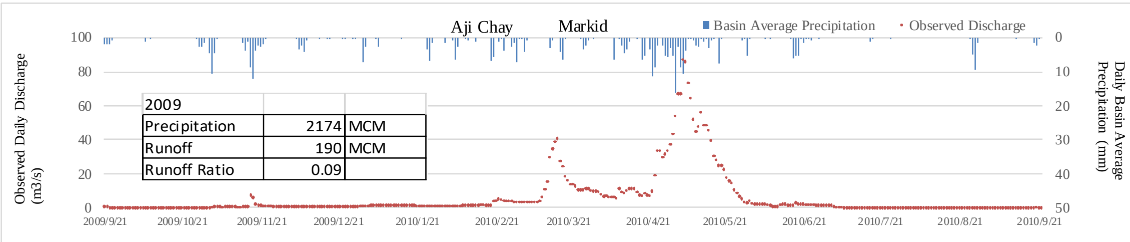


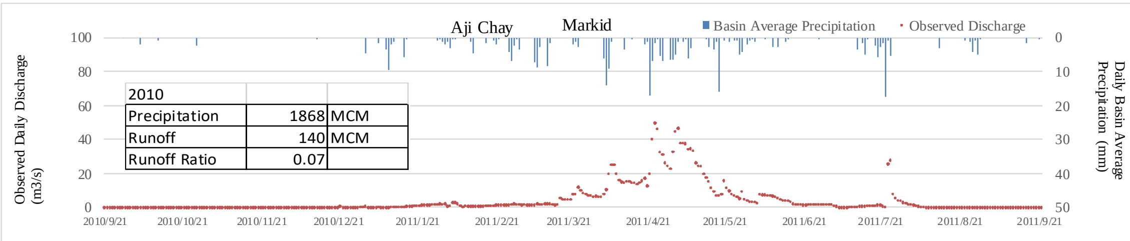


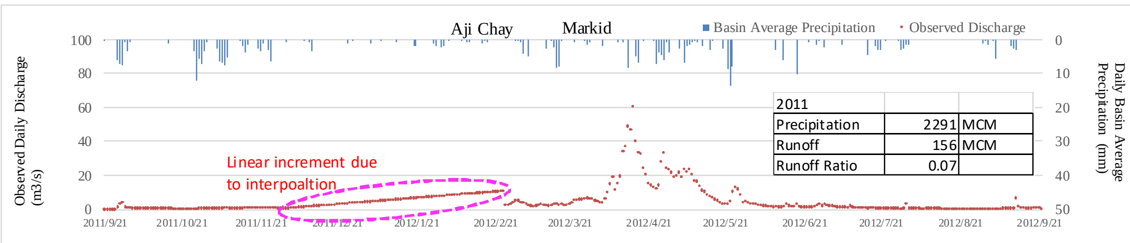
E-6 Markid (Ajichay) (2/2)

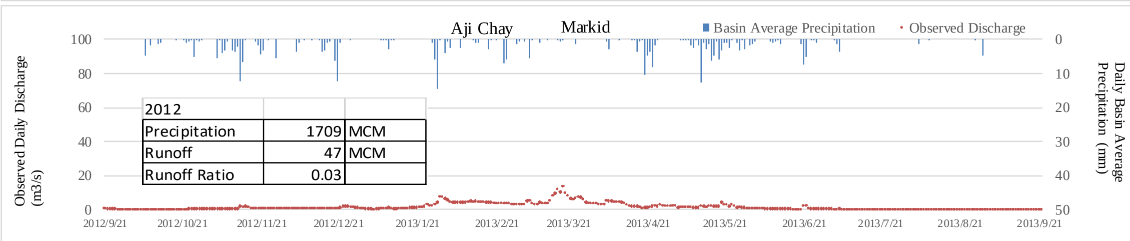


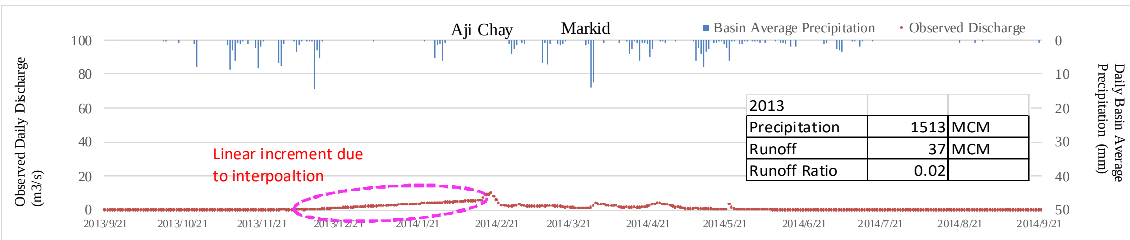




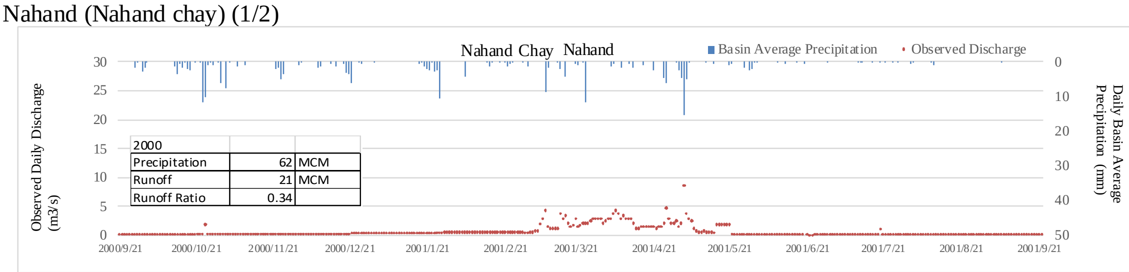


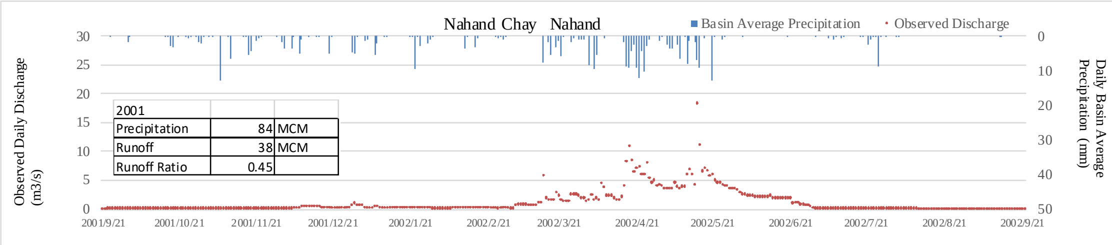


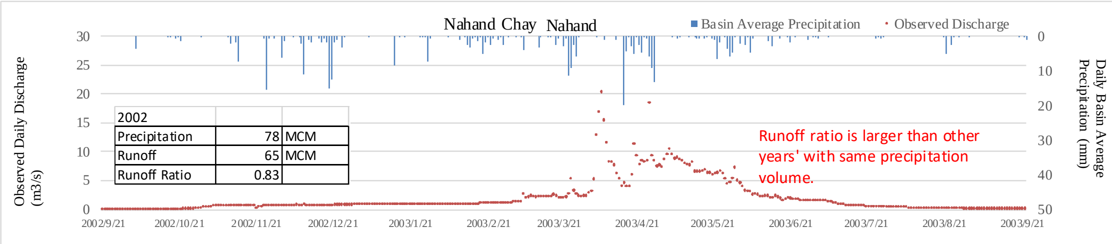


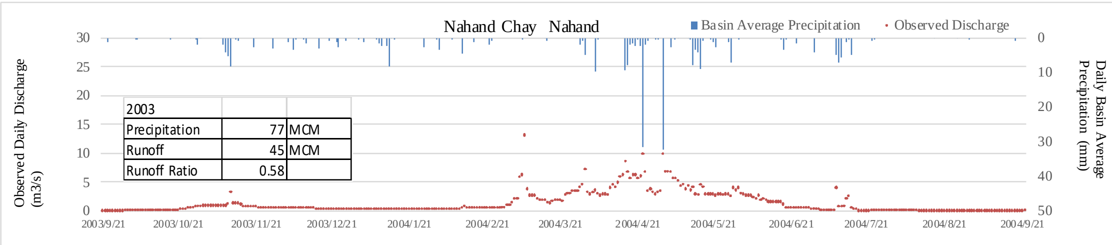


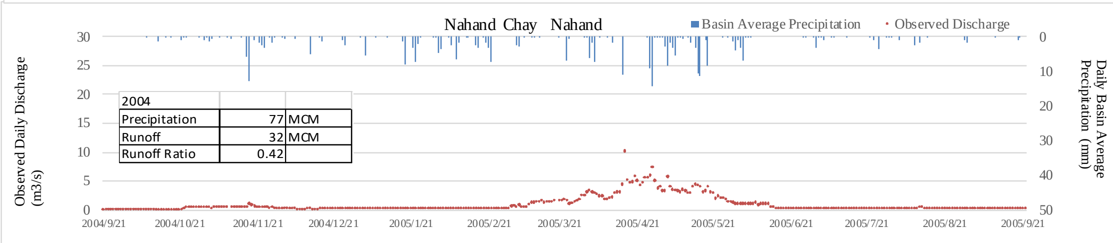
E-7 Nahand (Nahand chay) (1/2)

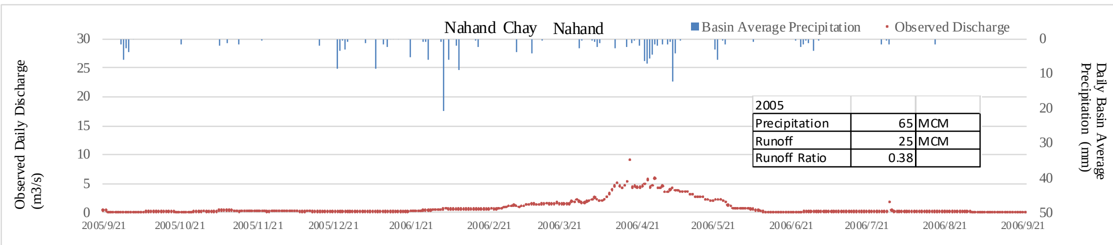


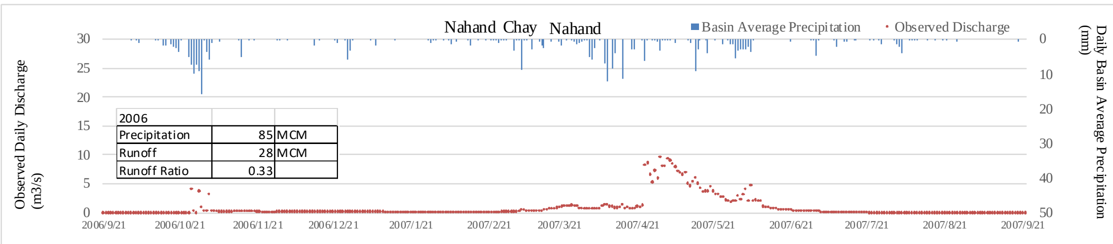




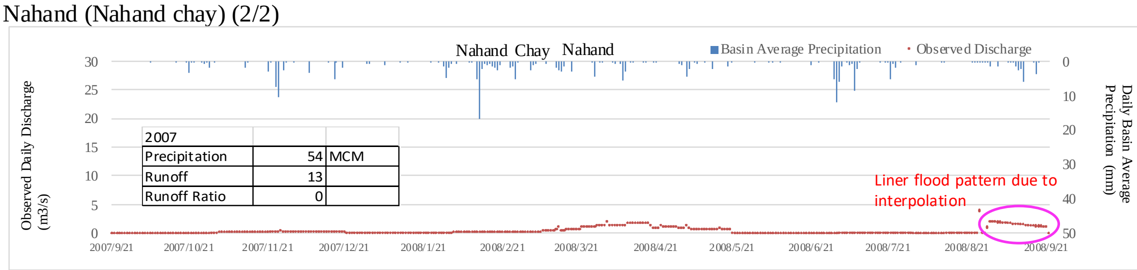


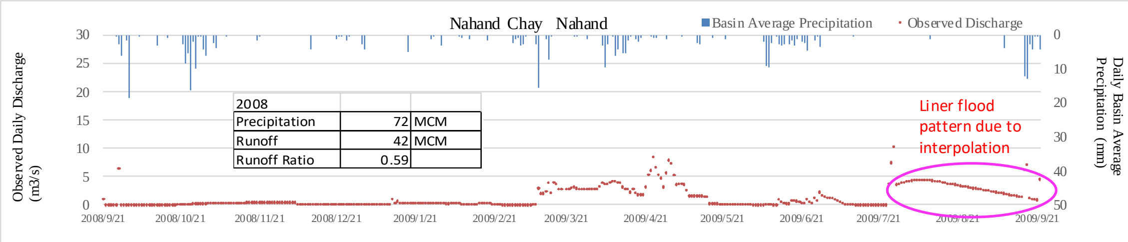


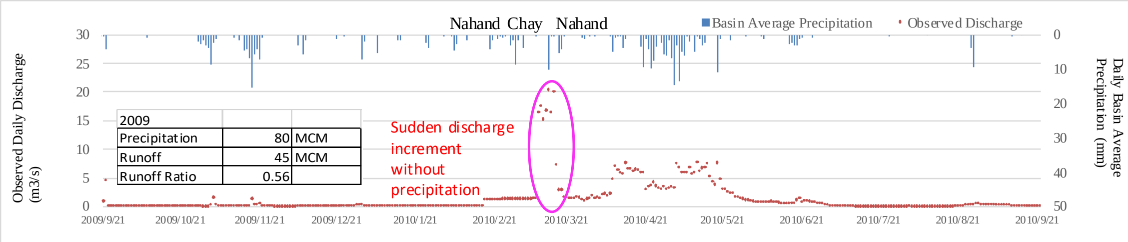


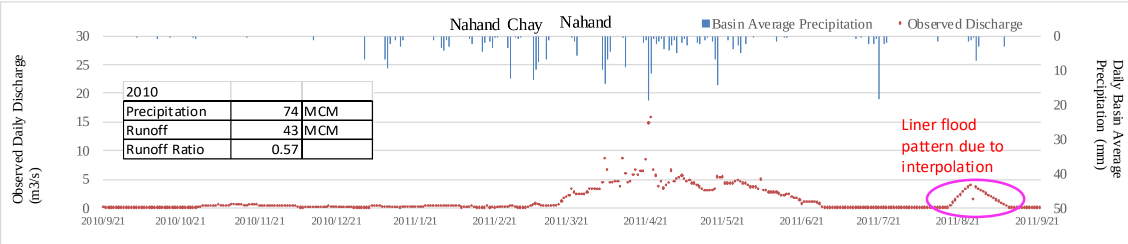


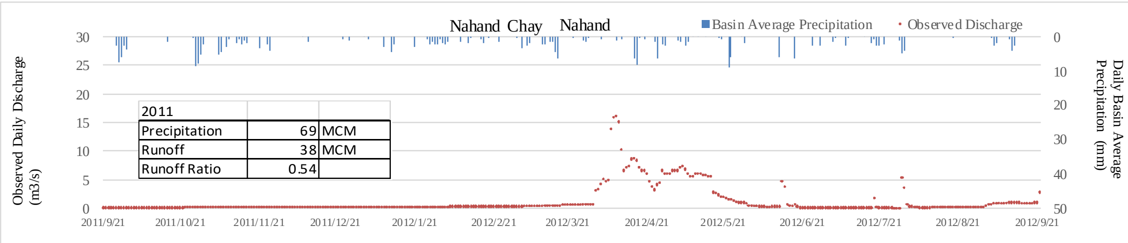
E-7 Nahand (Nahand chay) (2/2)

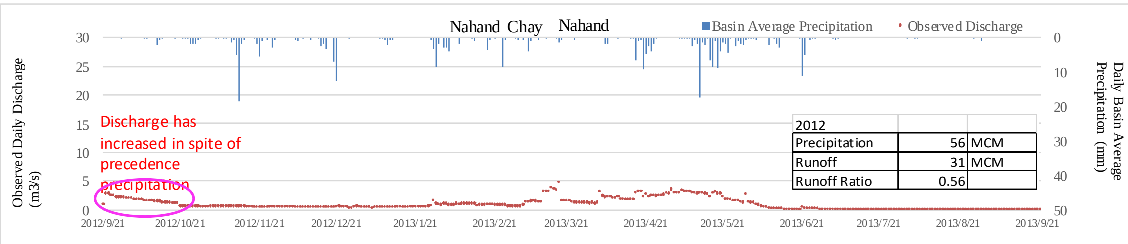


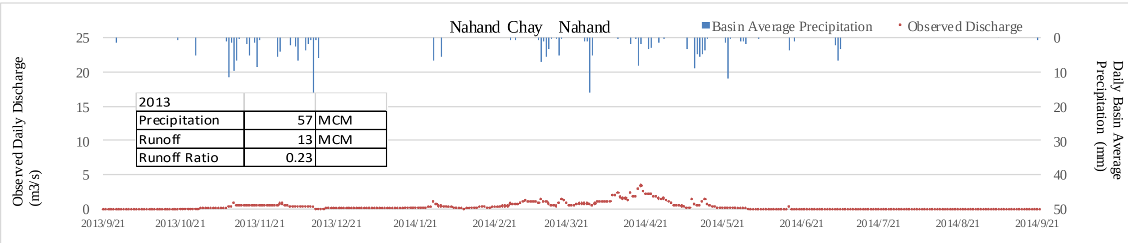




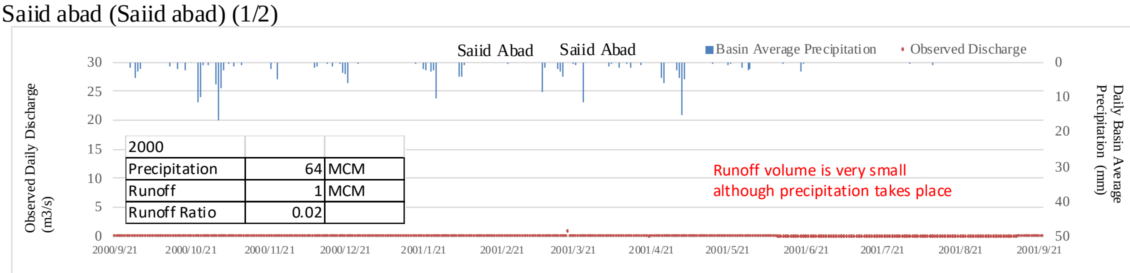


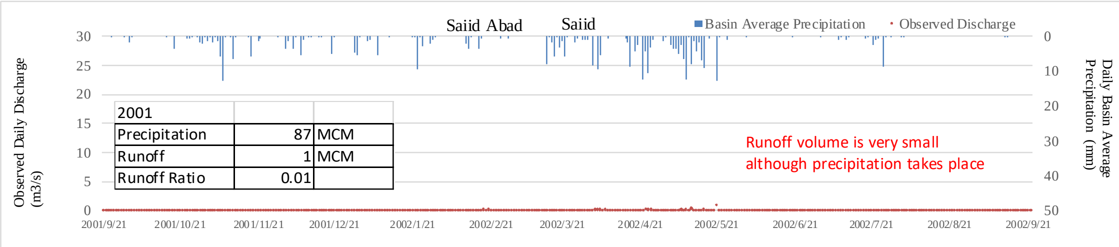


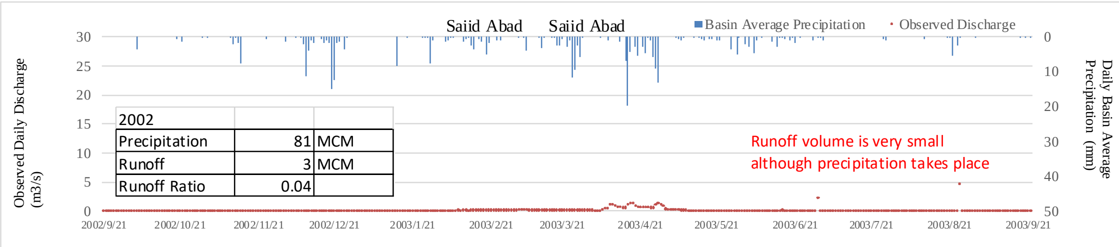


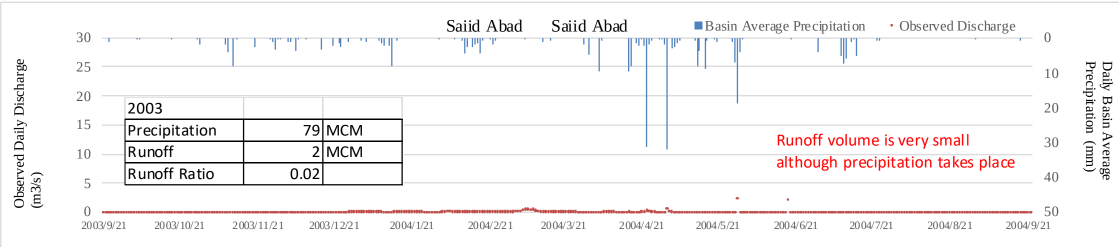


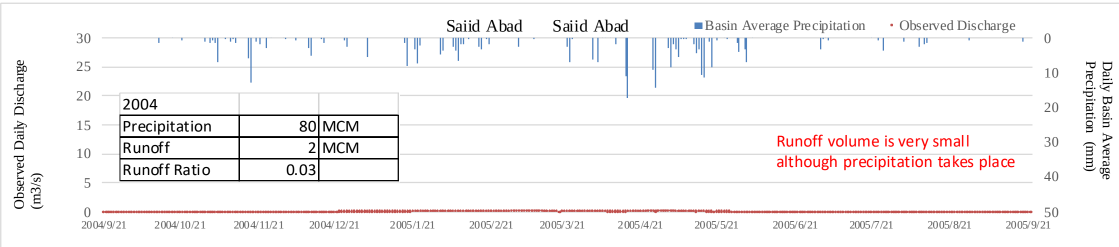
E-8 Saiid abad (Saiid abad) (1/2)

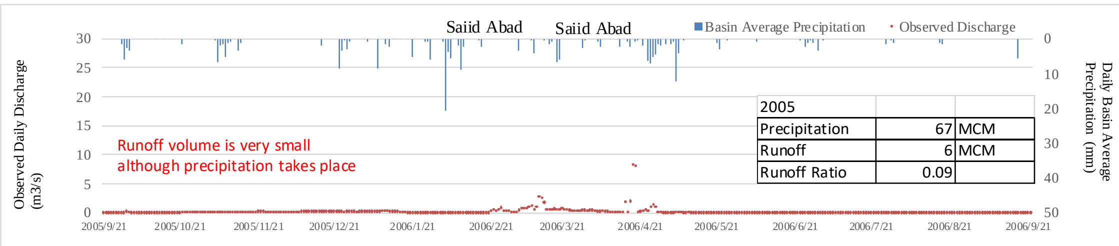


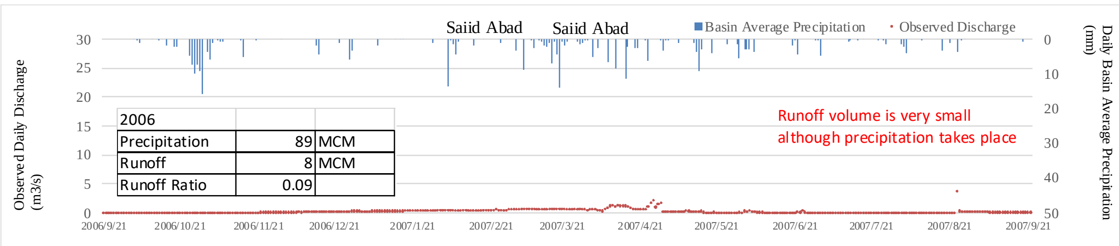




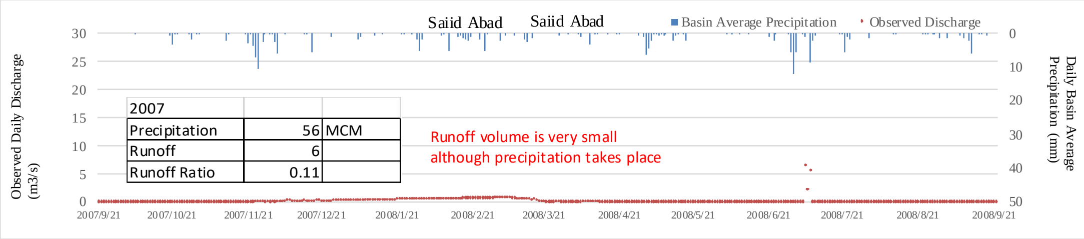


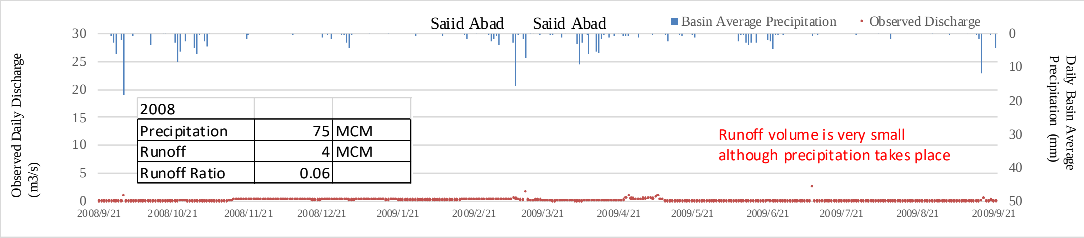


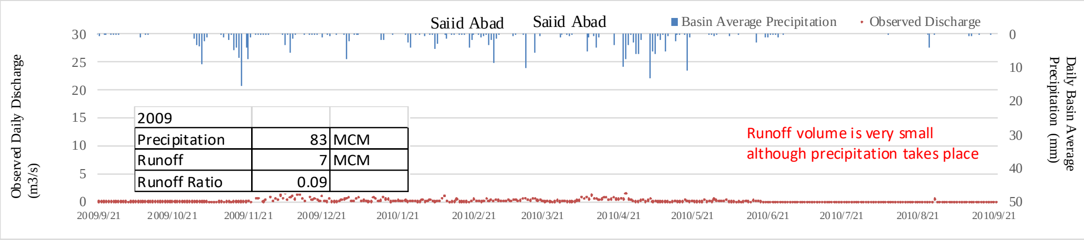


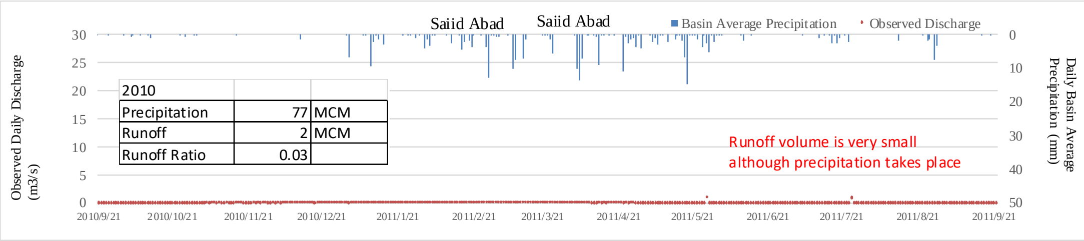


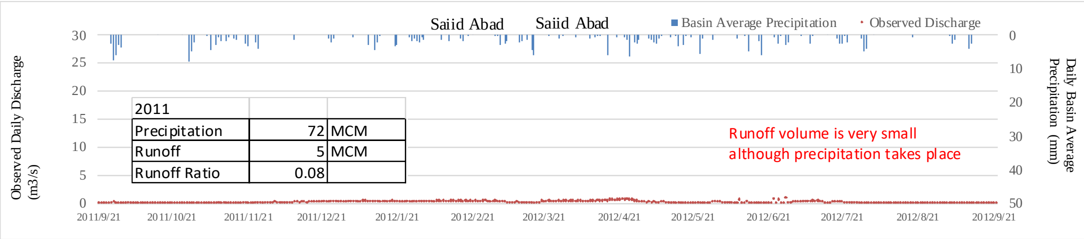
E-8 Saiid abad (Saiid abad) (2/2)

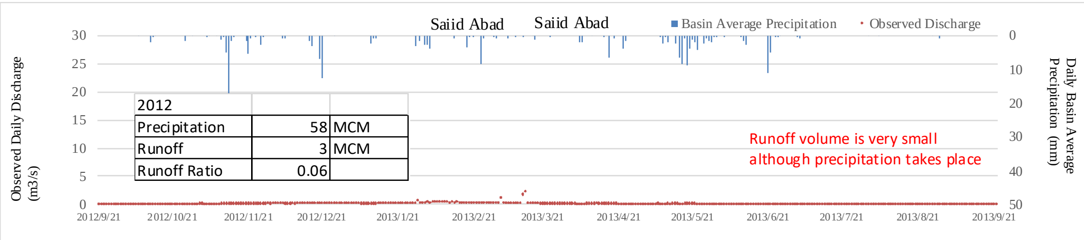


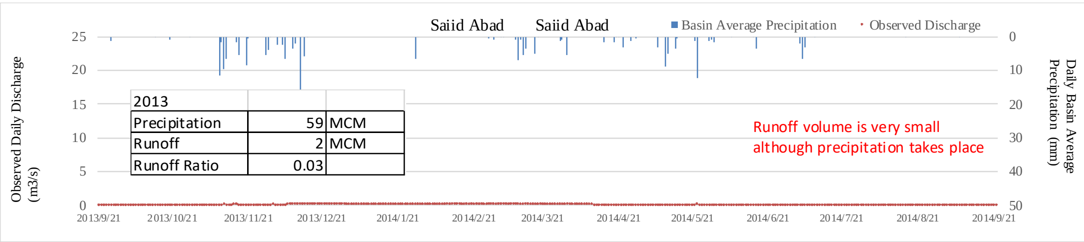




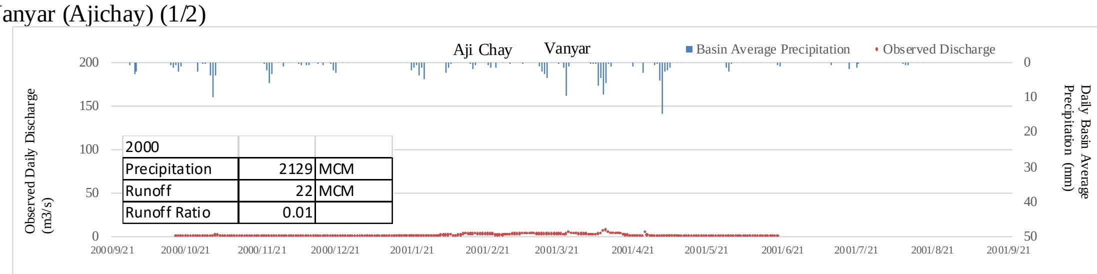


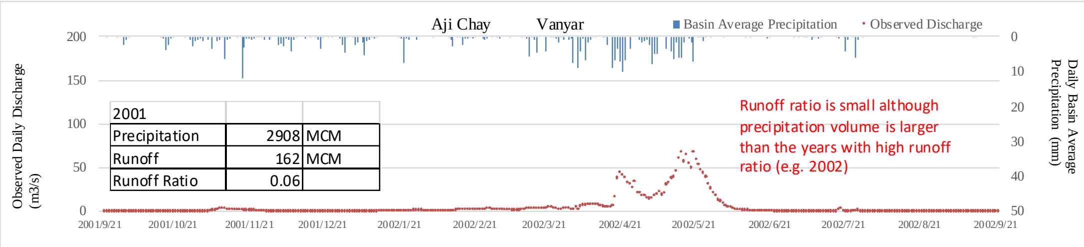


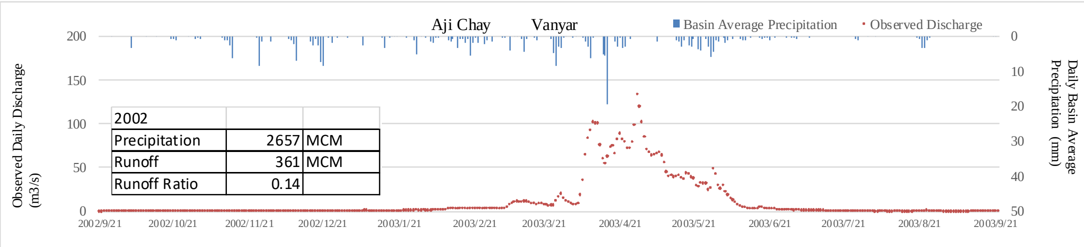


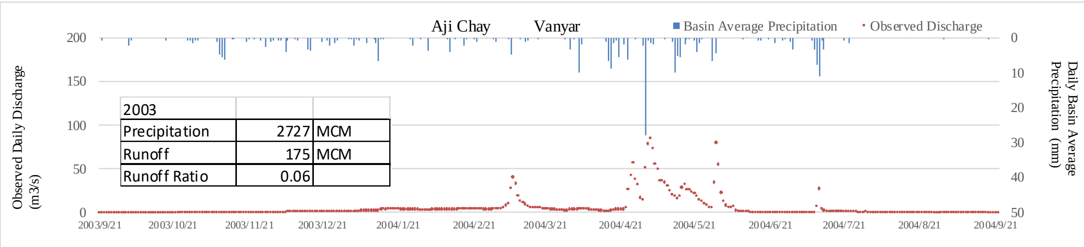


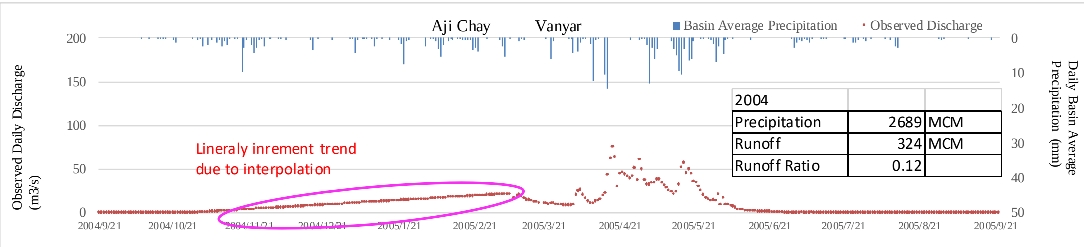
E-9 Vanyar (Ajichay) (1/2)

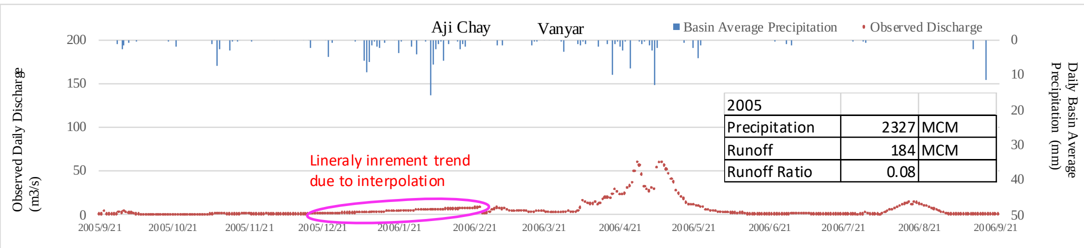


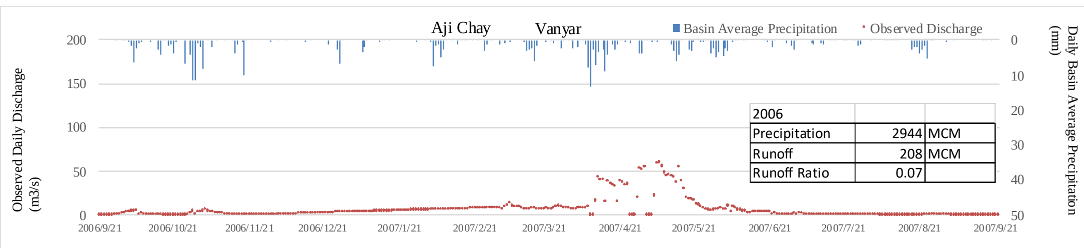




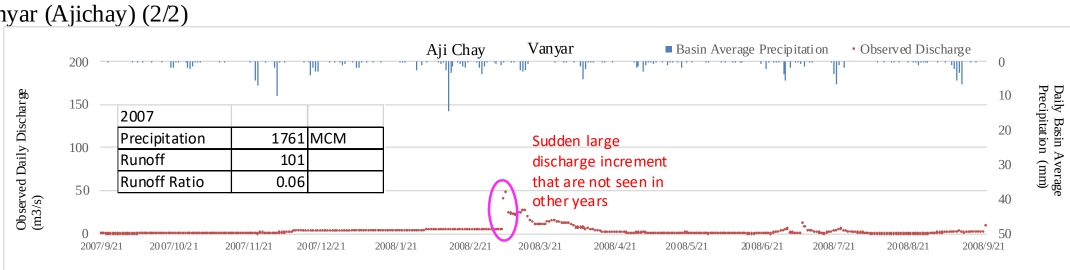


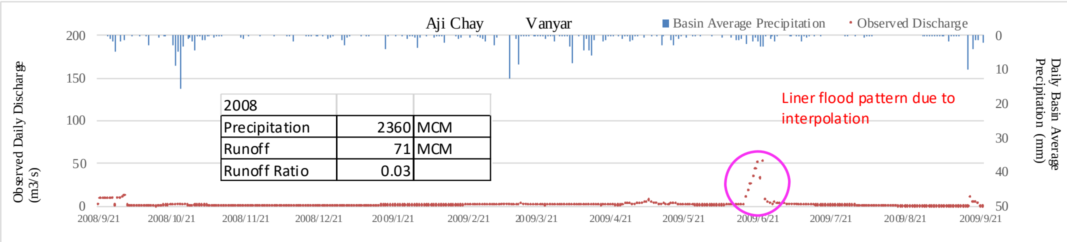


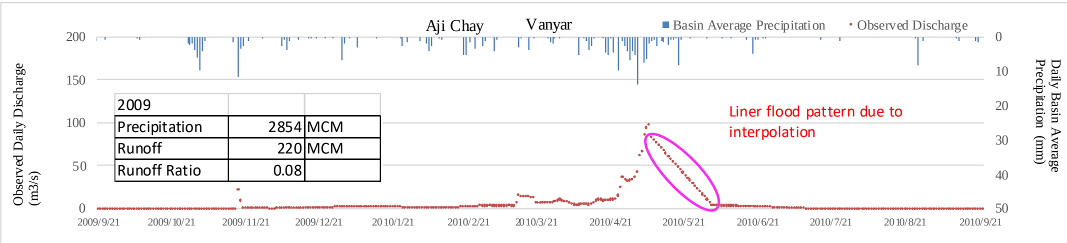


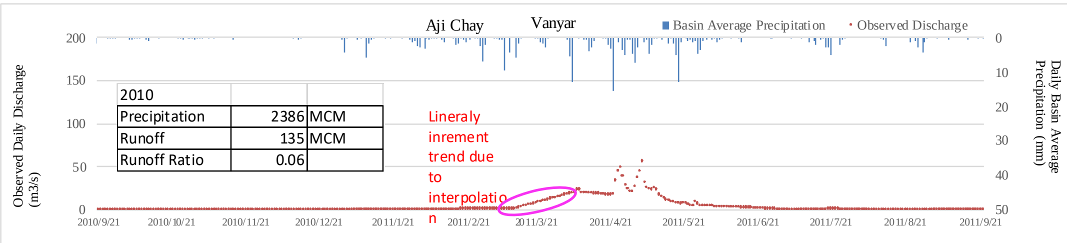


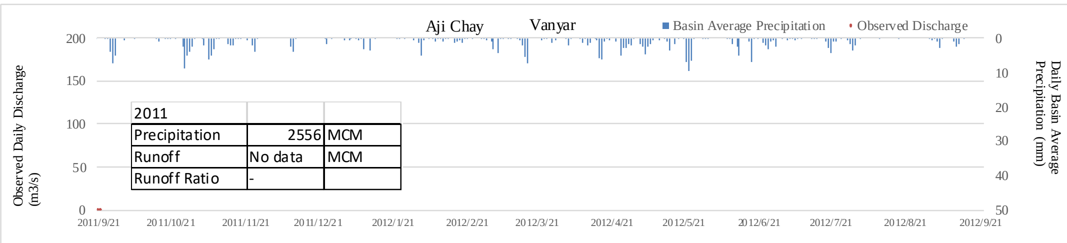
E-9 Vanyar (Ajichay) (2/2)

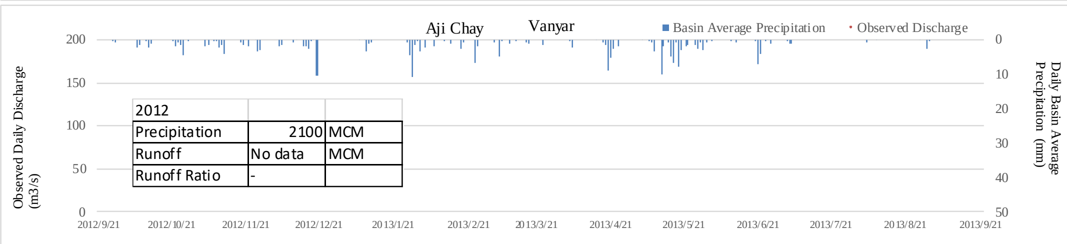


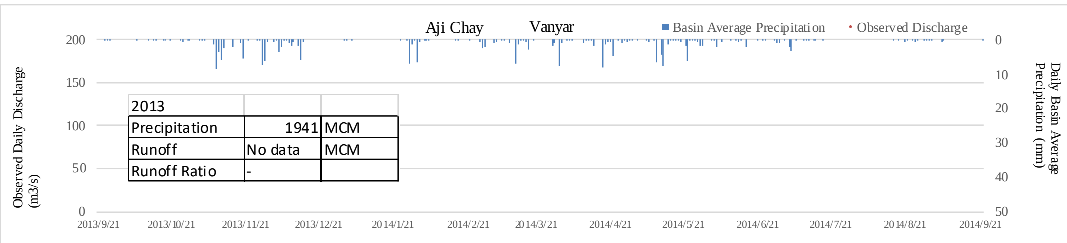




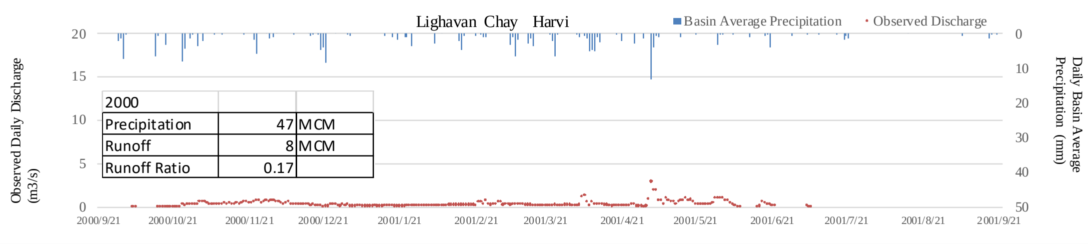


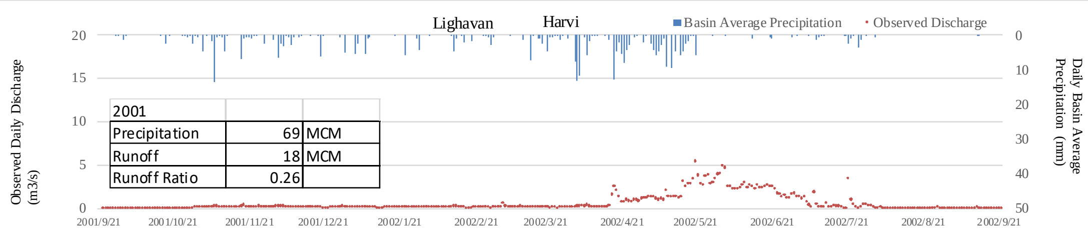


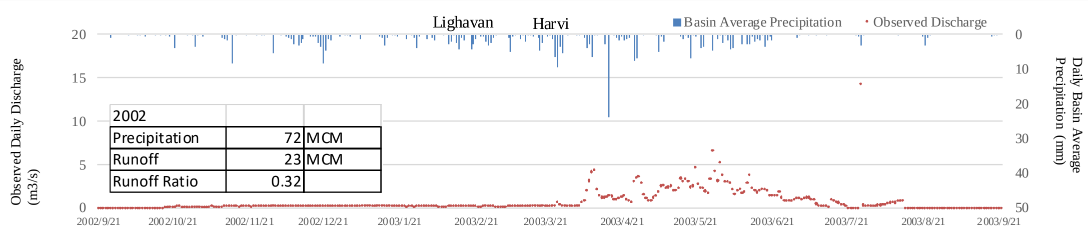


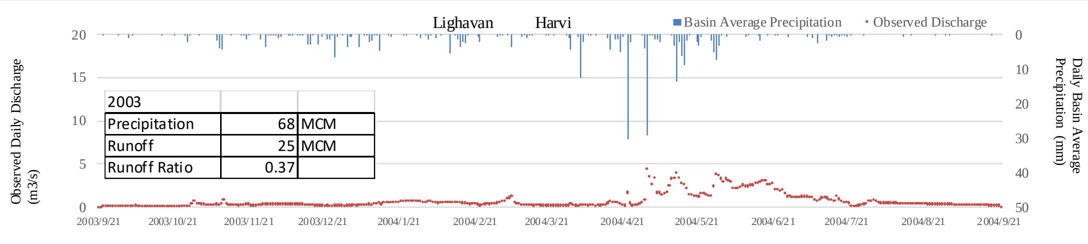


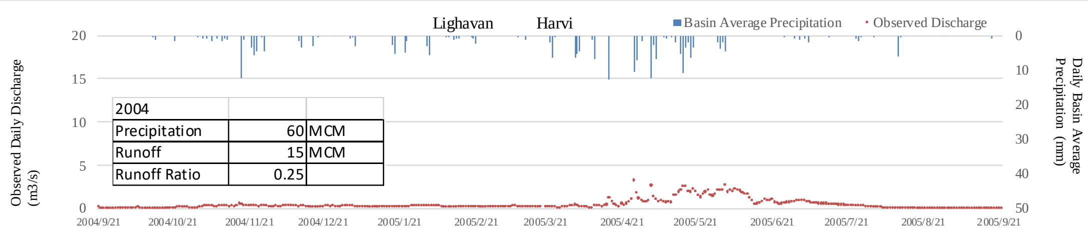
E-10 Harvi (Lighavan) (1/2)

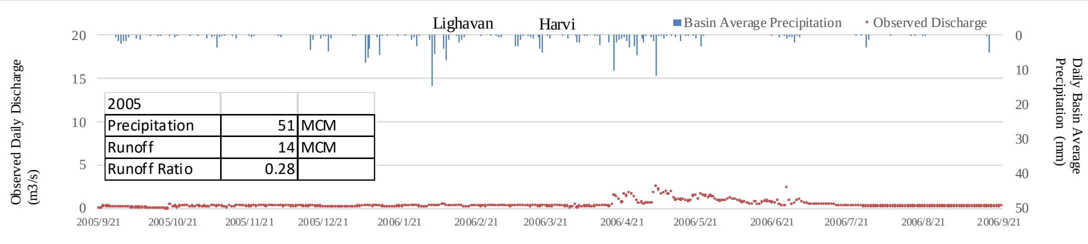


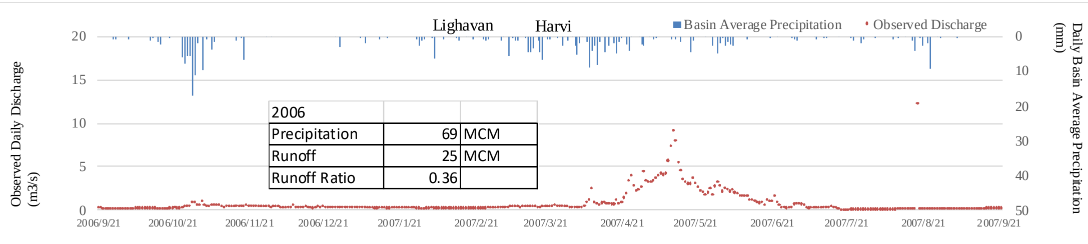




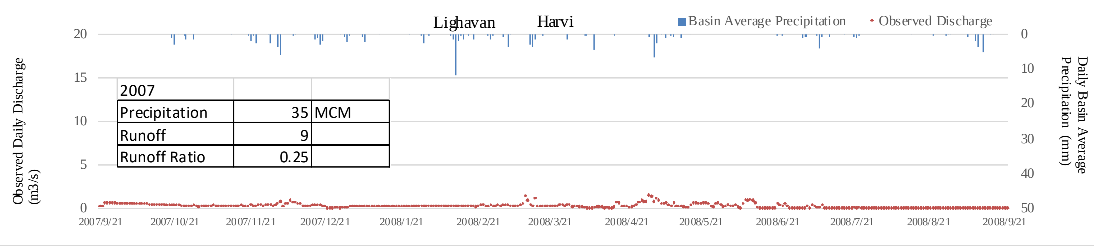


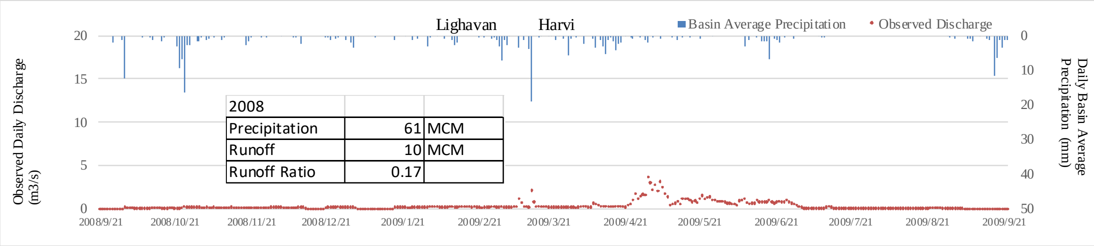


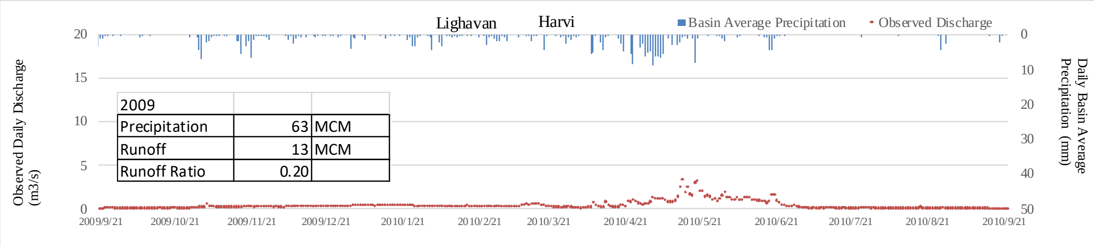


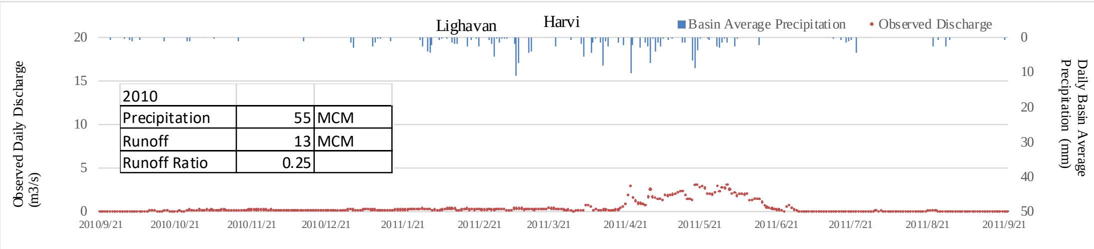


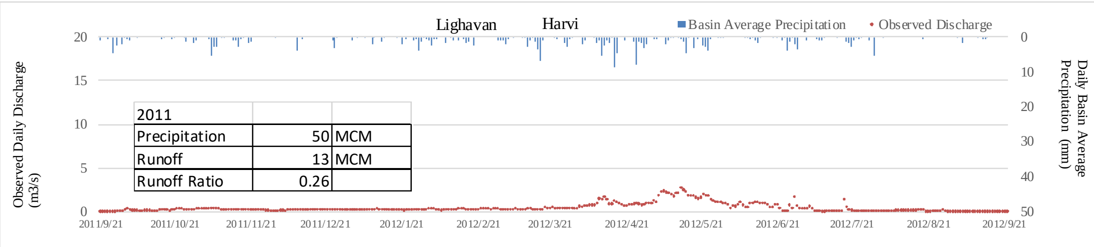
E-10 Harvi (Lighavan) (2/2)

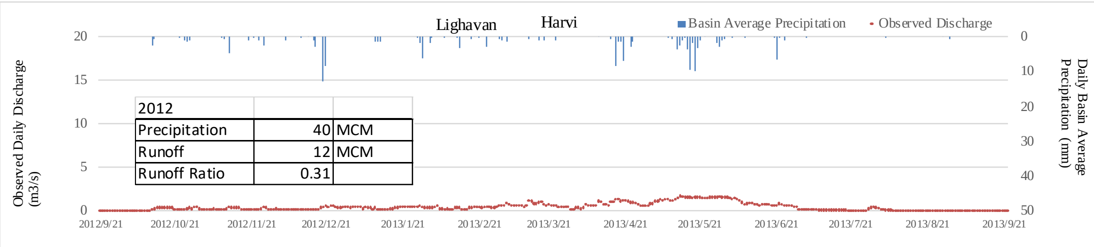


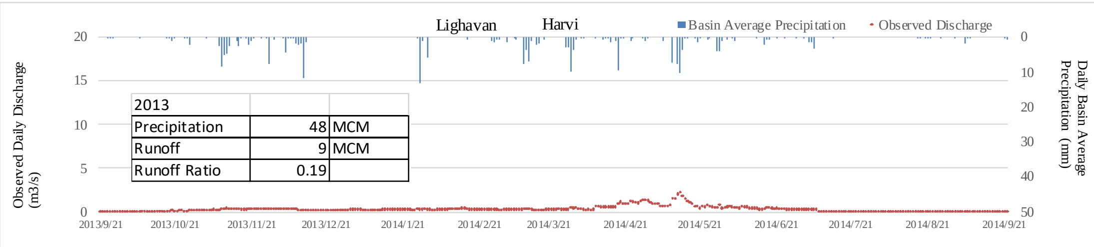




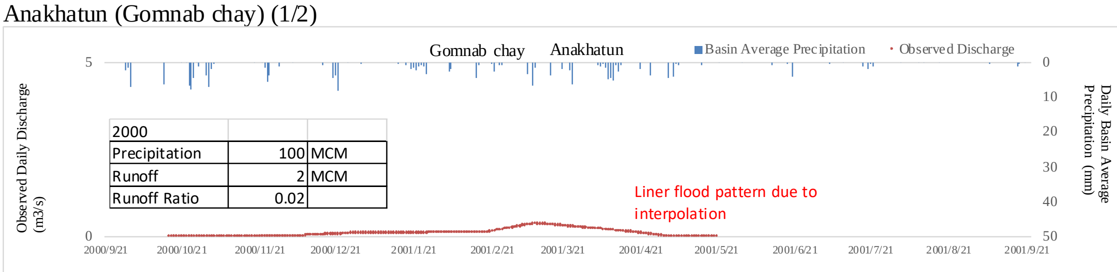


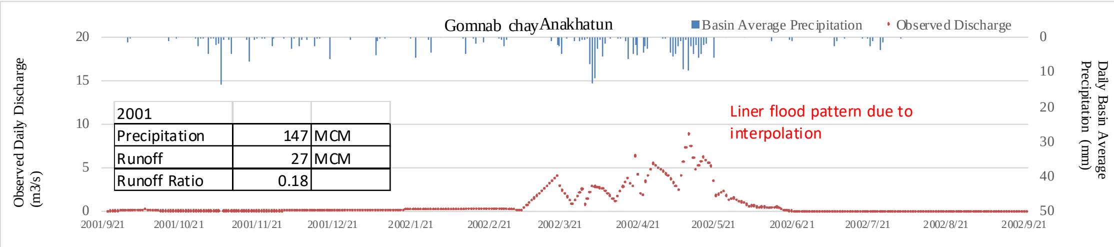


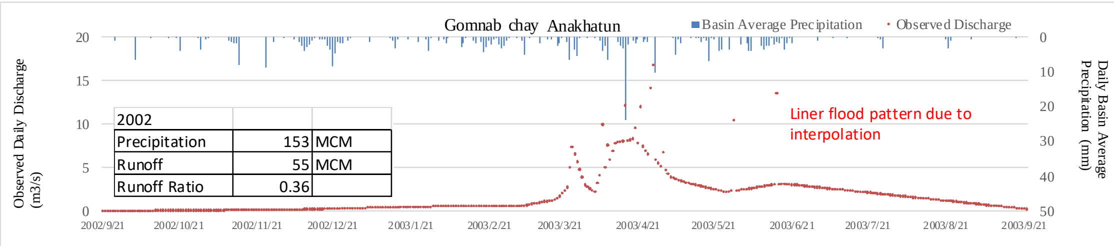


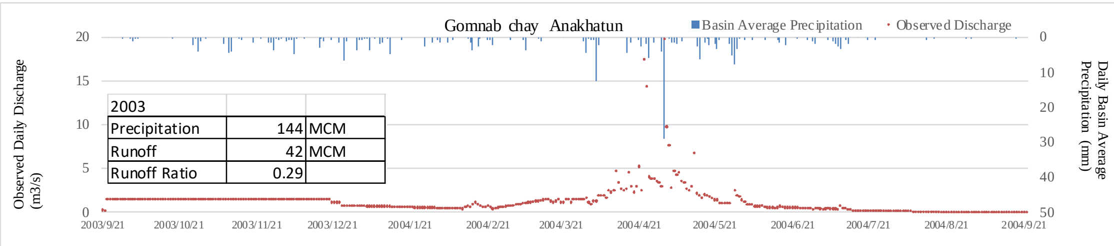


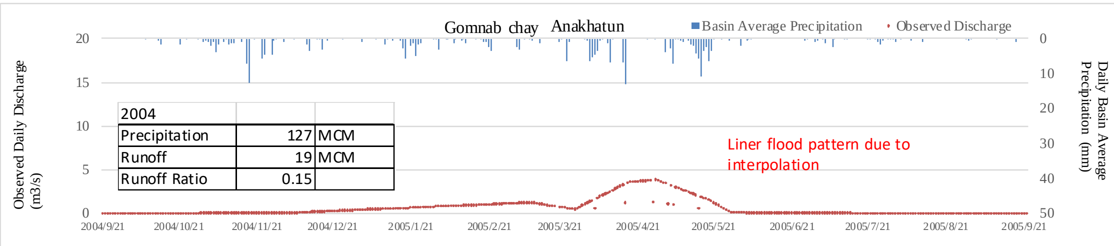
E-11 Anakhatun (Gomnab chay) (1/2)

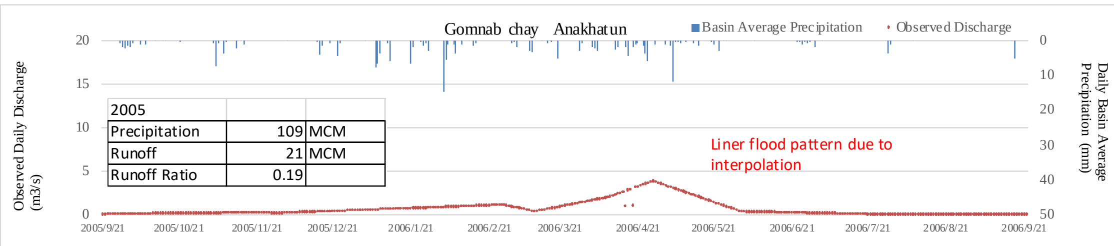


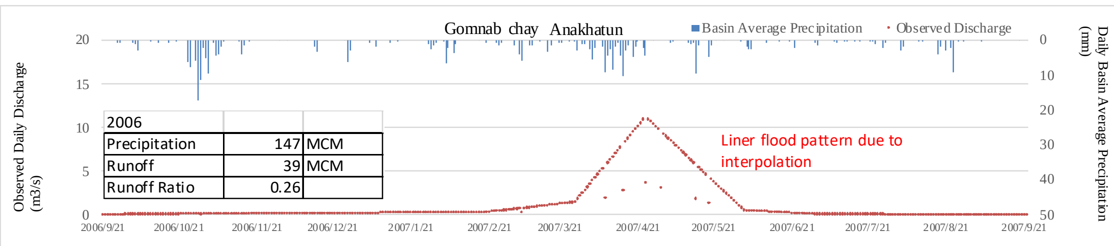




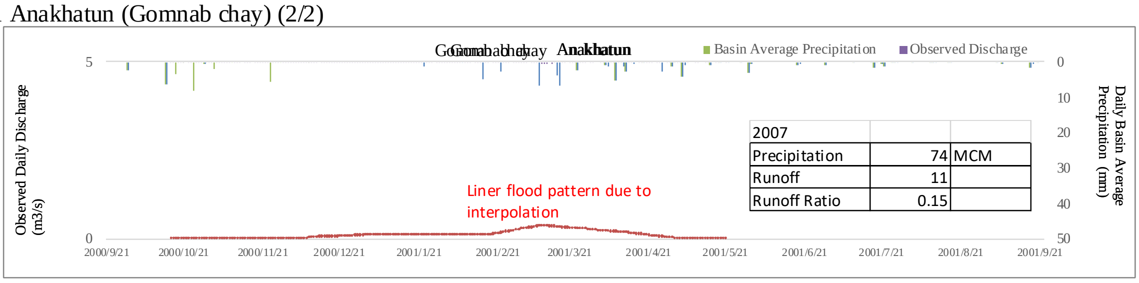


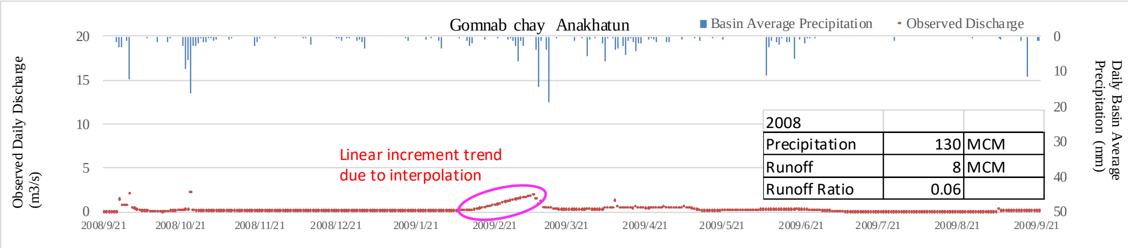


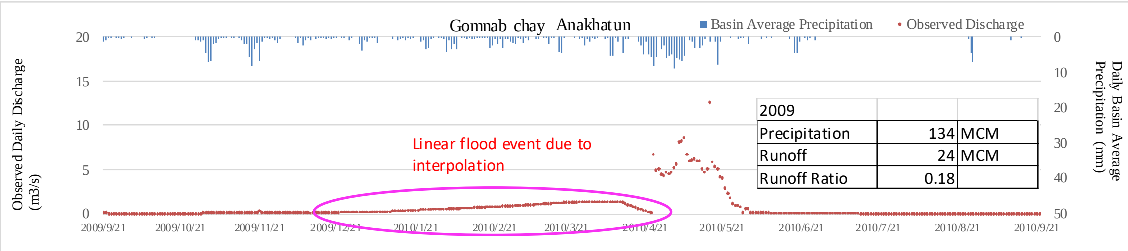


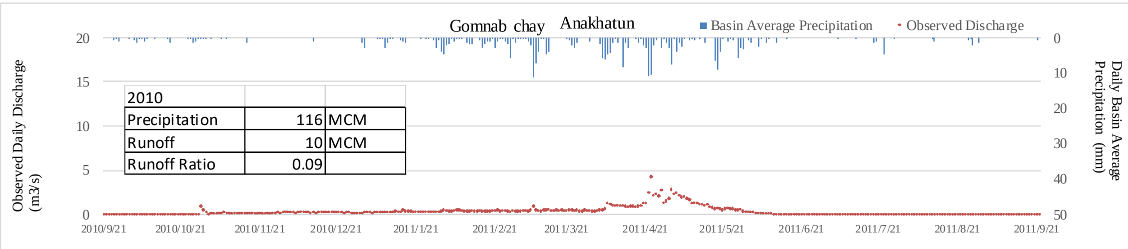


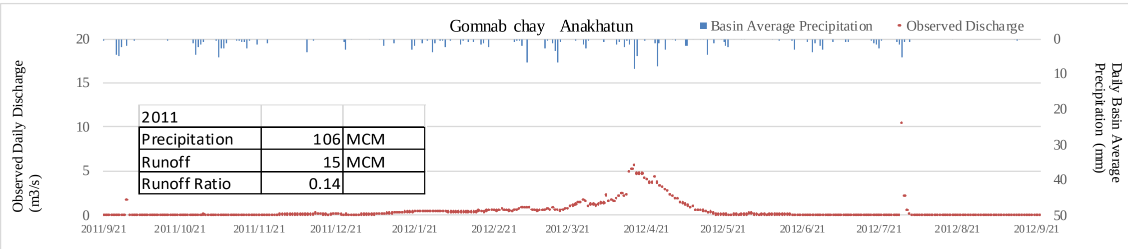
E-11 Anakhatun (Gomnab chay) (2/2)

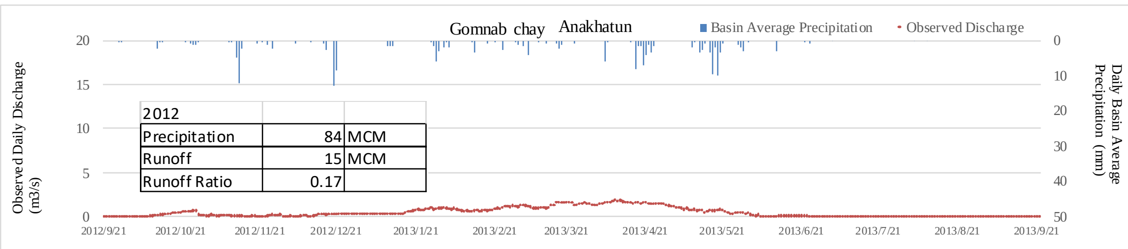


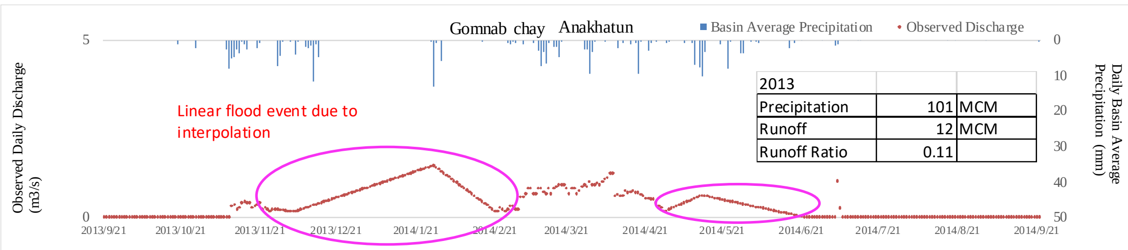




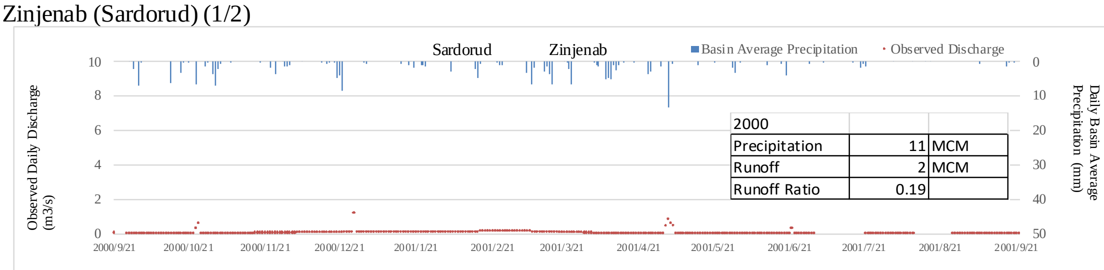


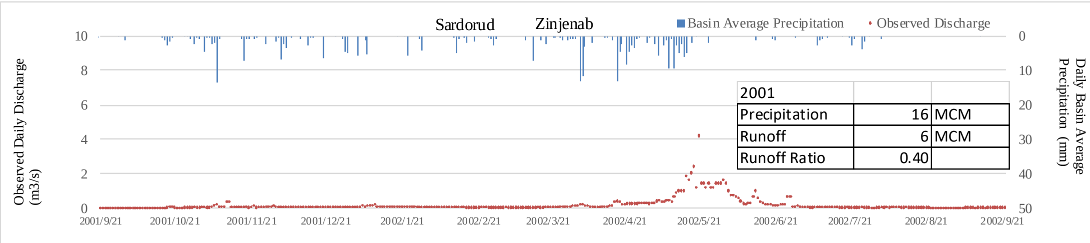


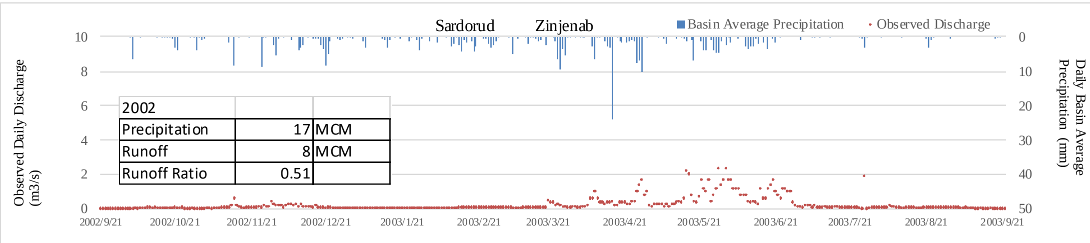


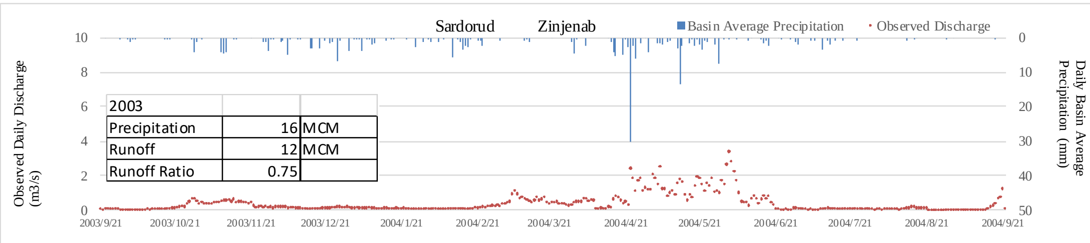


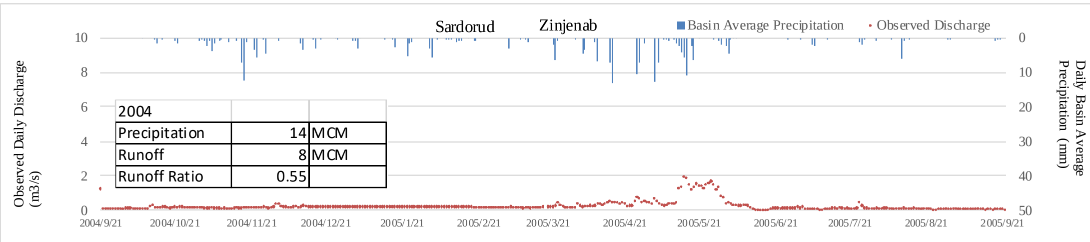
E-12 Zinjenab (Sardorud) (1/2)

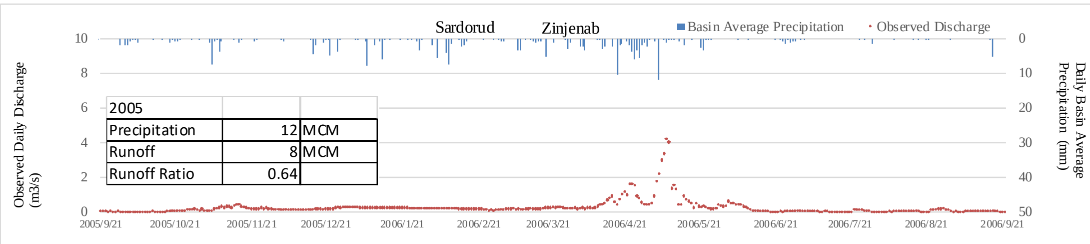


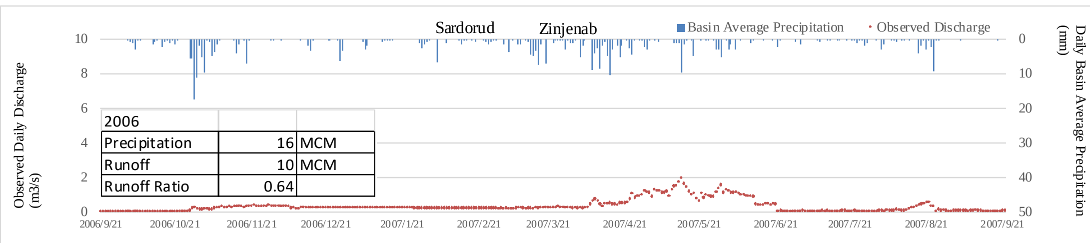




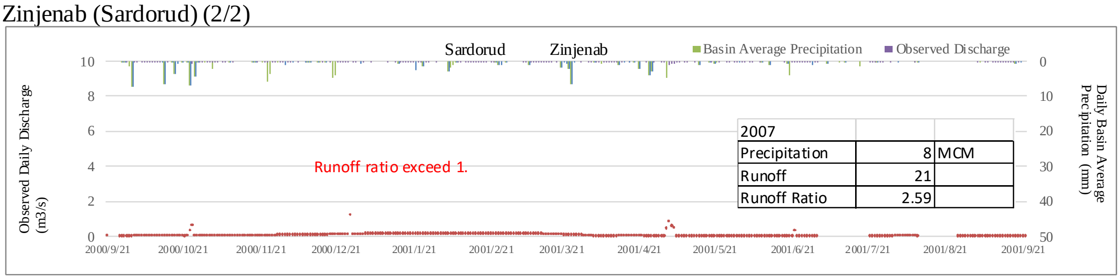


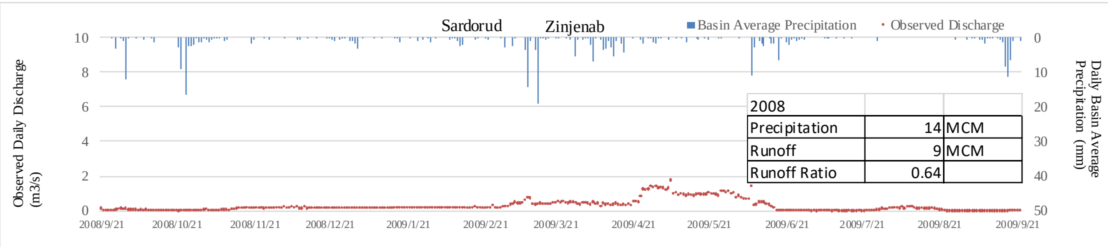


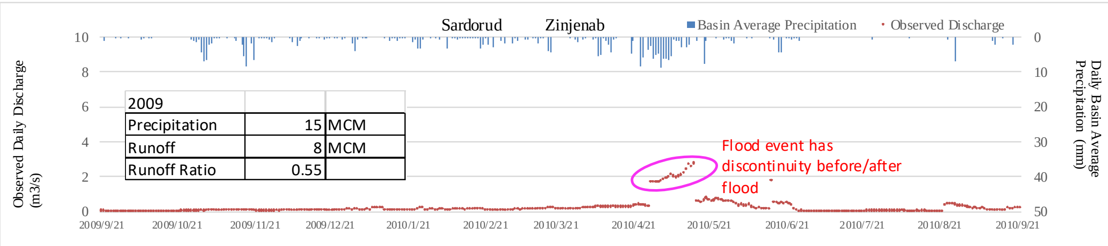


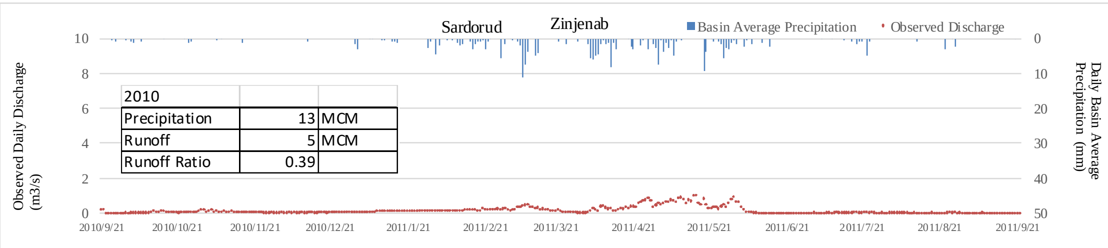


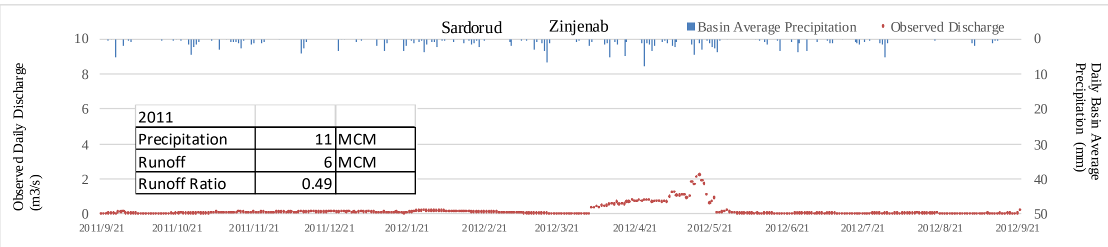
E-12 Zinjenab (Sardorud) (2/2)

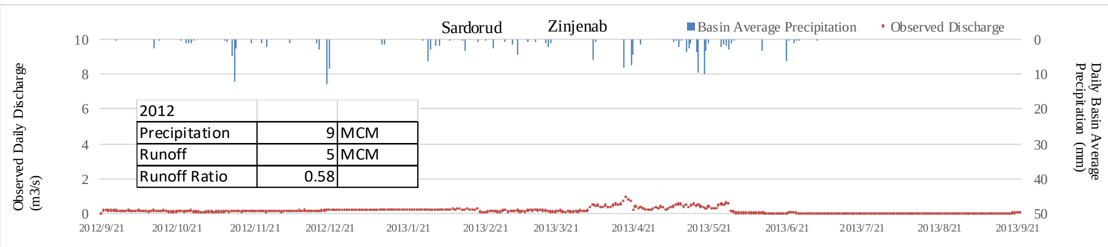


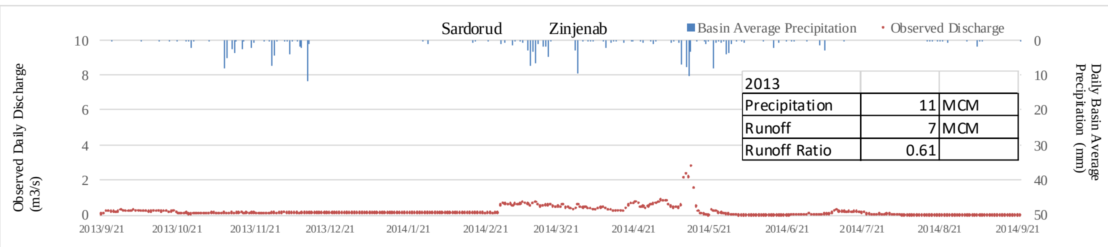




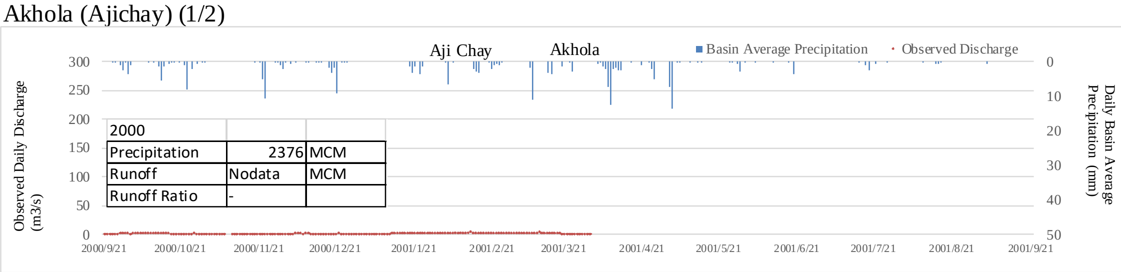


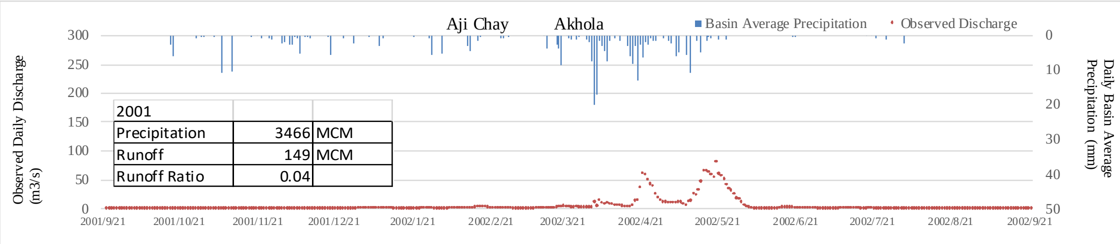


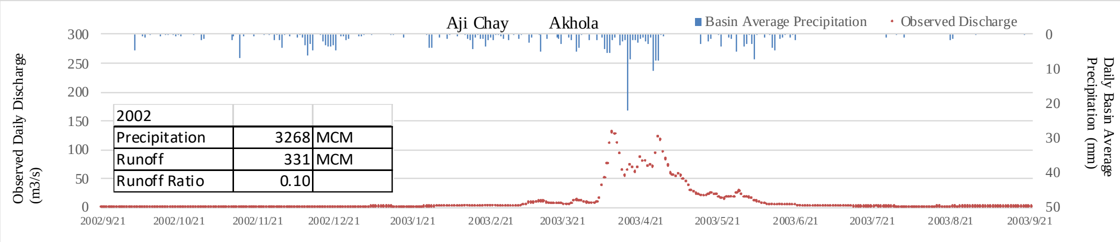


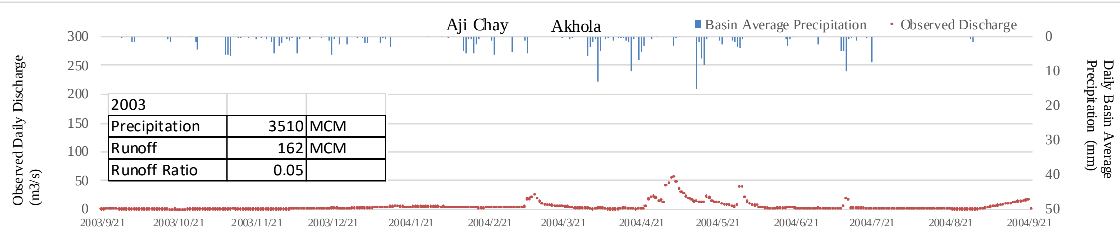


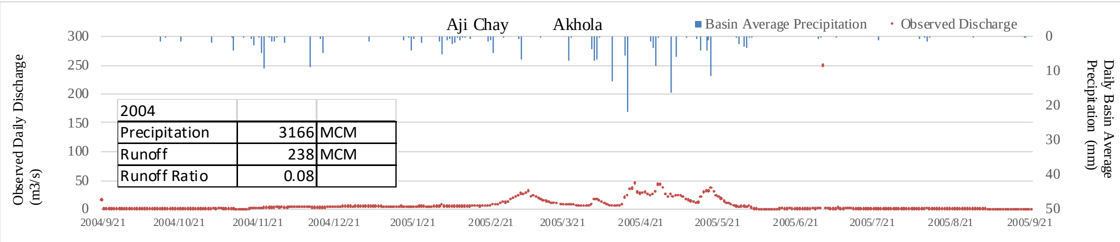
E-13 Akhola (Ajichay) (1/2)

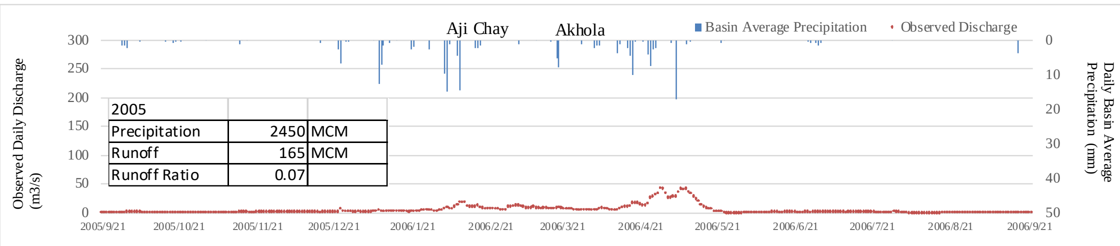


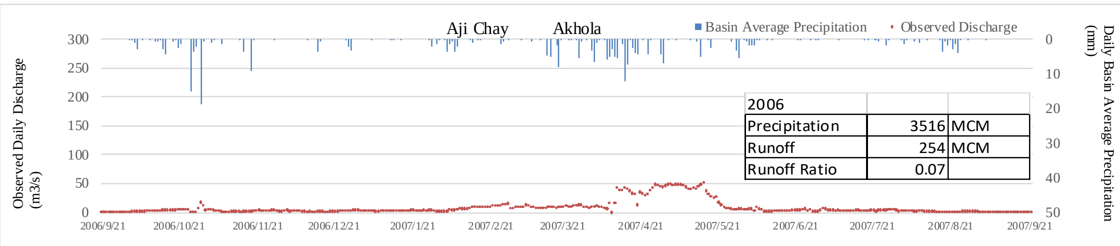




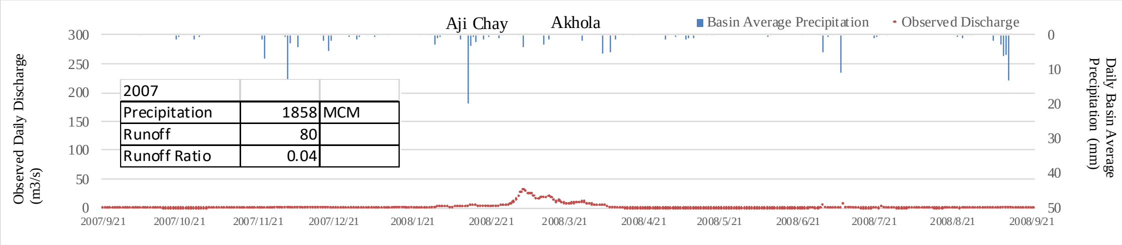


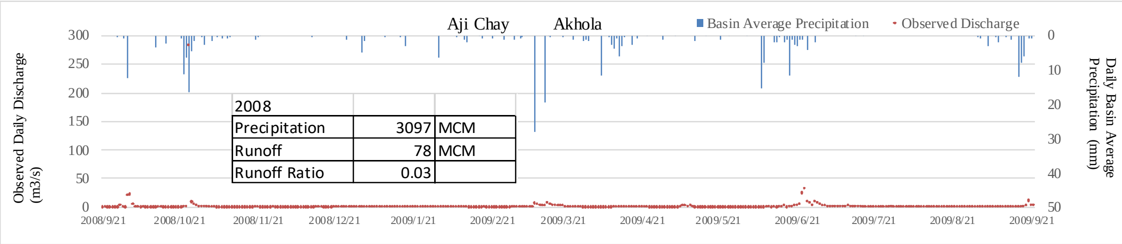


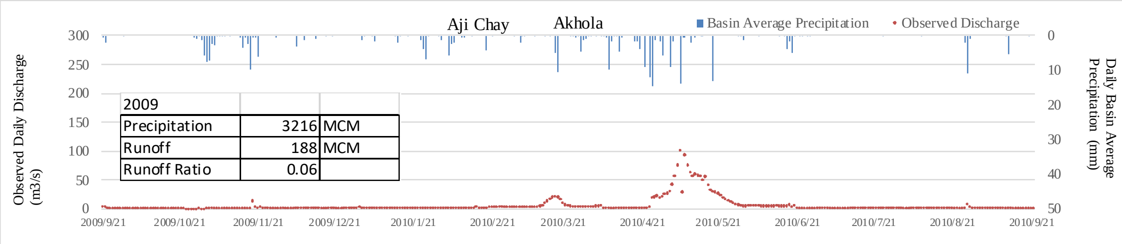


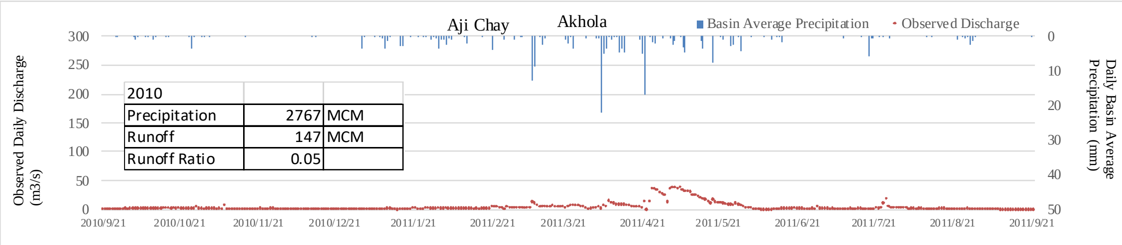


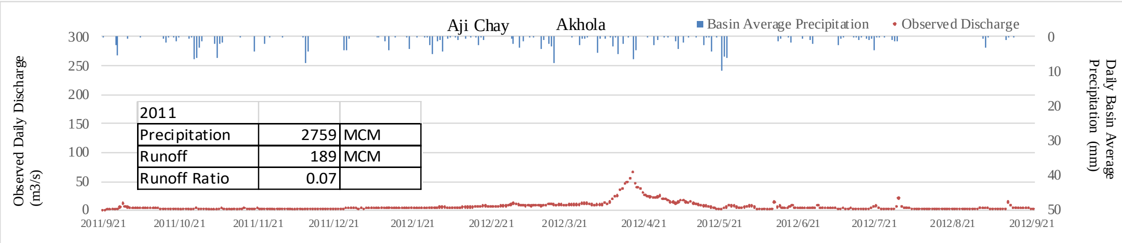
E-13 Akhola (Ajichay) (2/2)

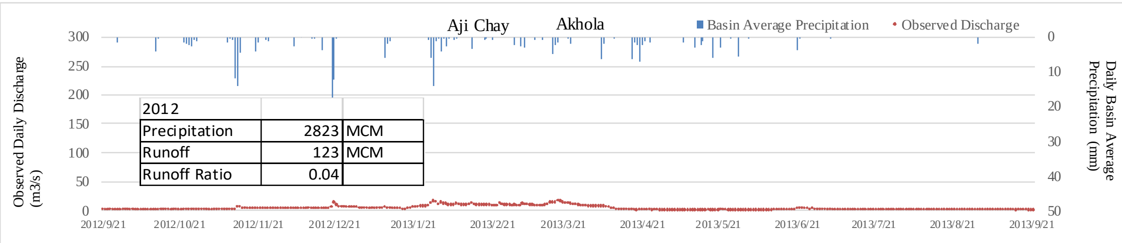


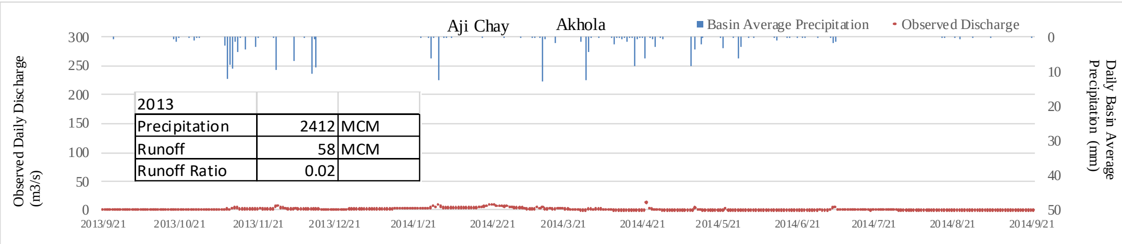




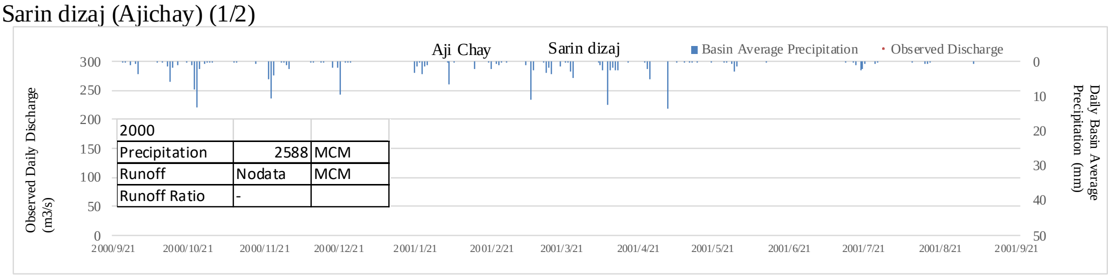


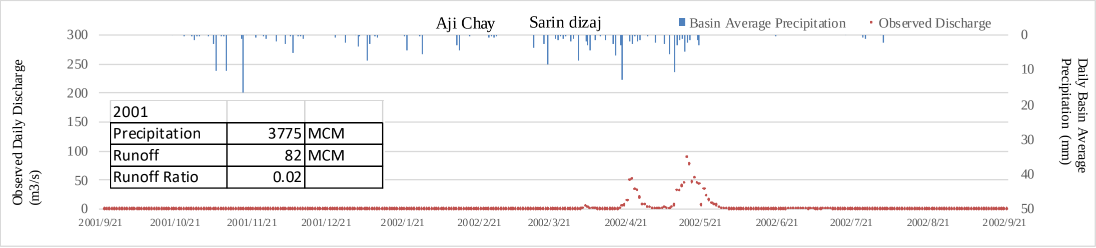


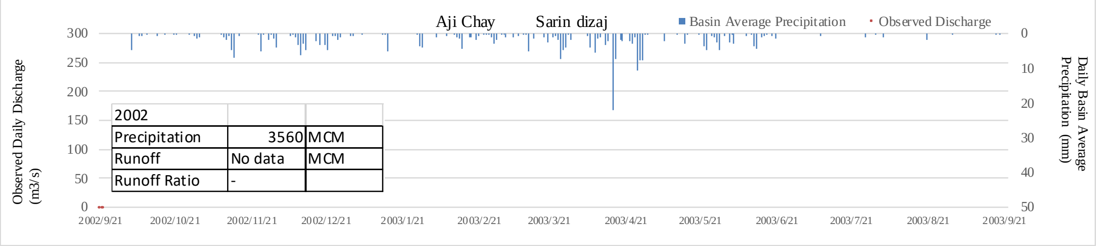


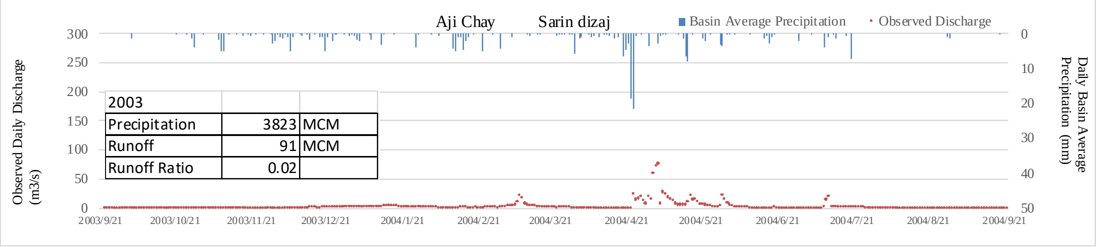


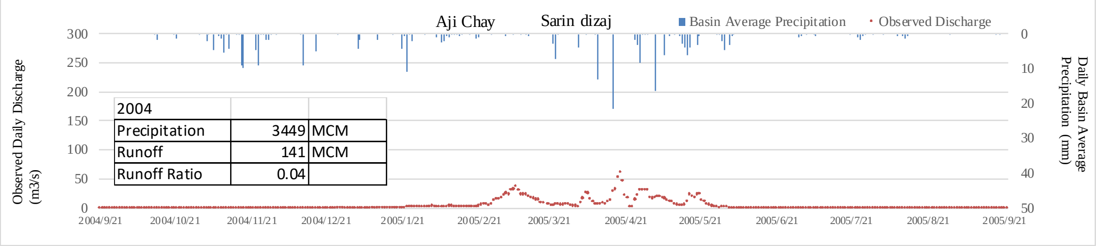
E-14 Sarin dizaj (Ajichay) (1/2)

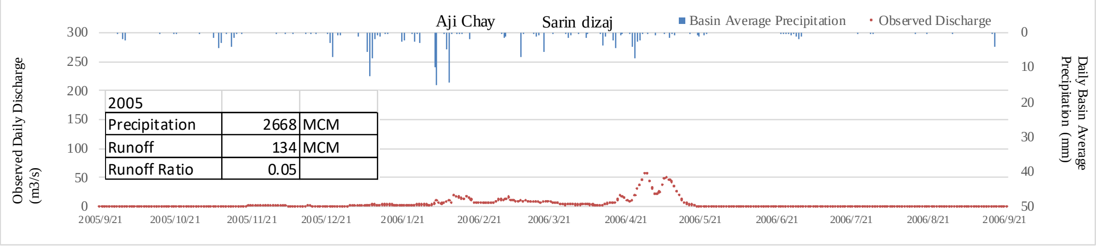


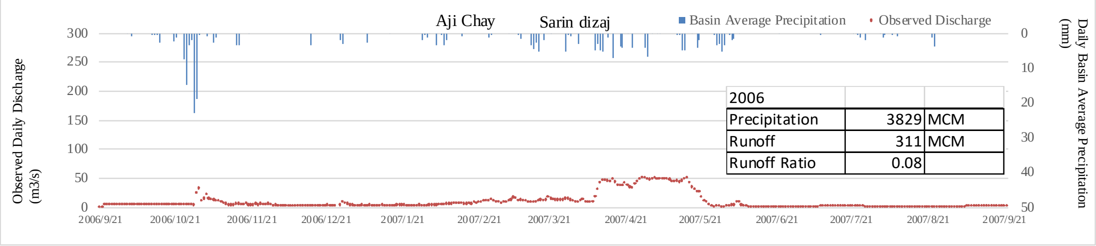




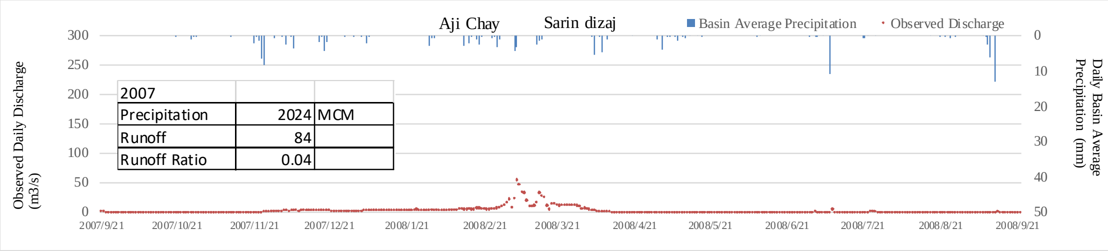


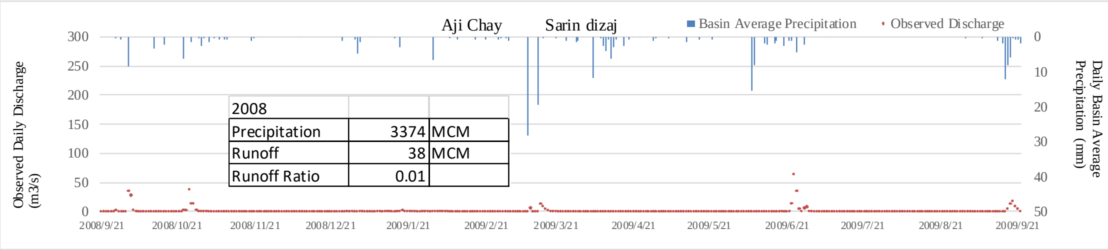


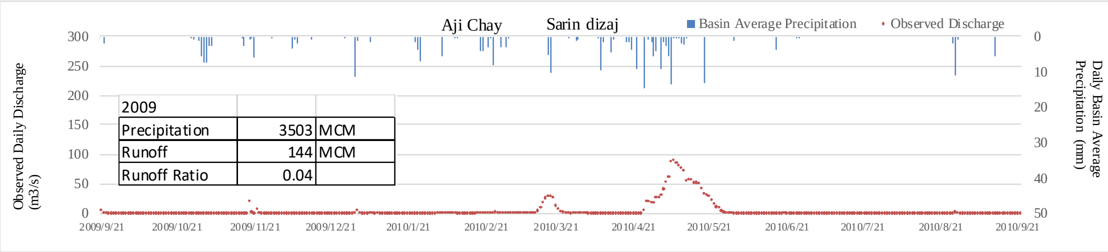


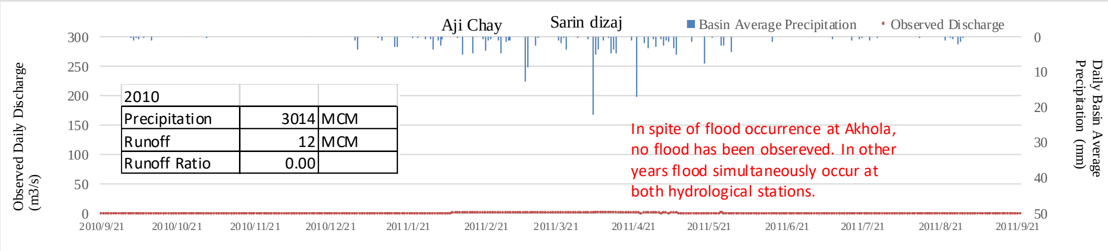


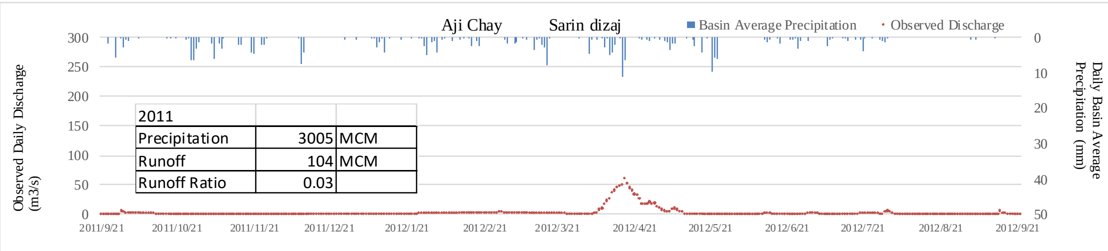
E-14 Sarin dizaj (Ajichay) (2/2)

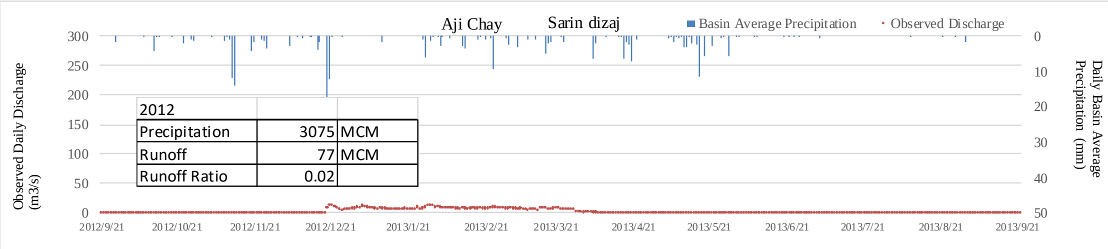


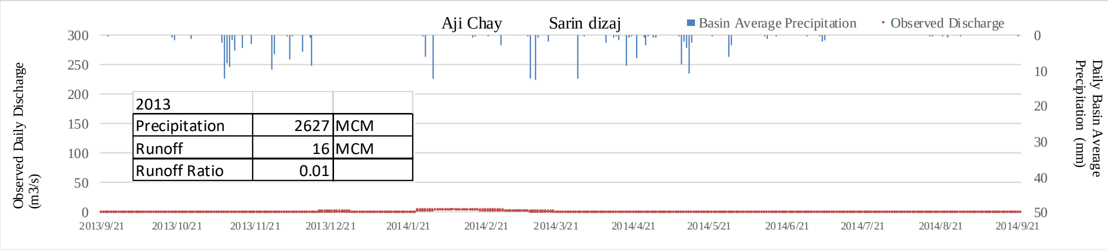




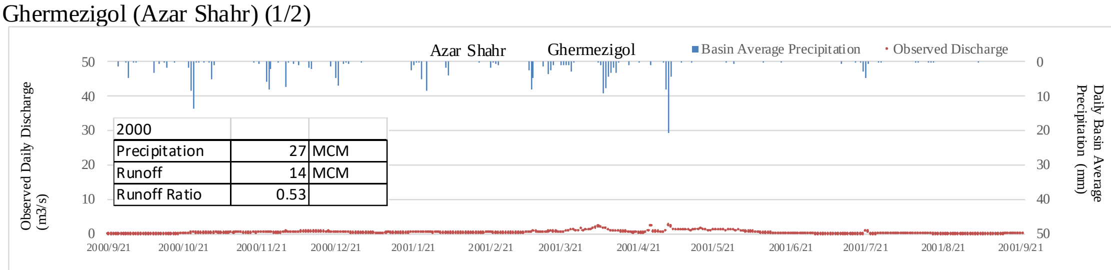


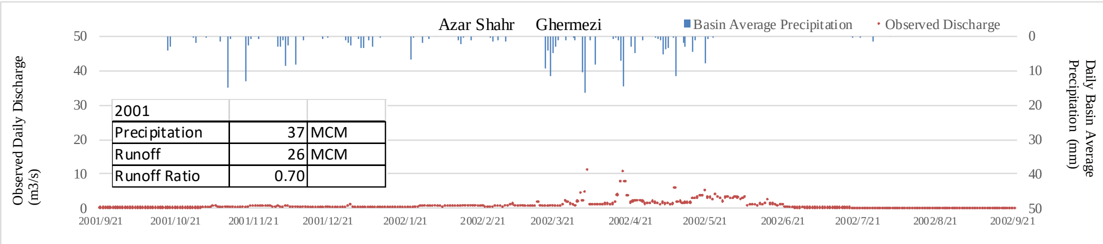


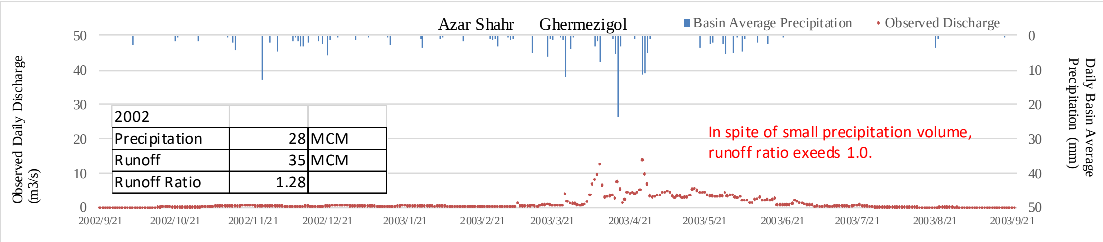


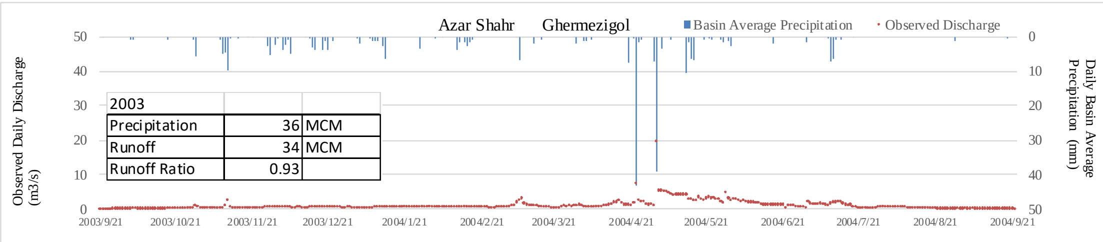


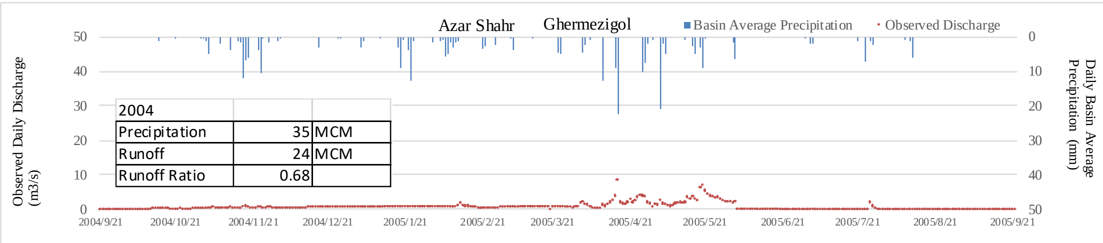
E-15 Ghermezigol (Azar Shahr) (1/2)

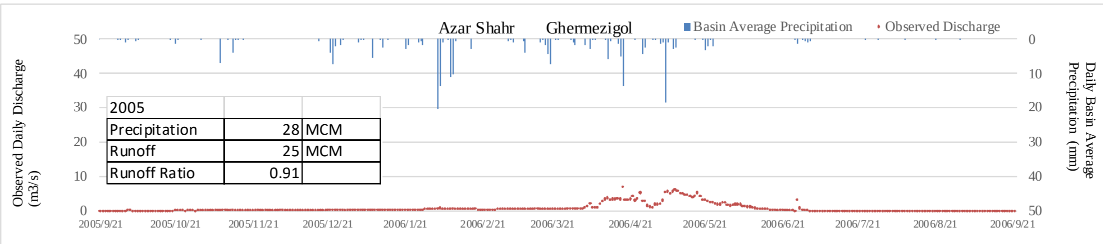


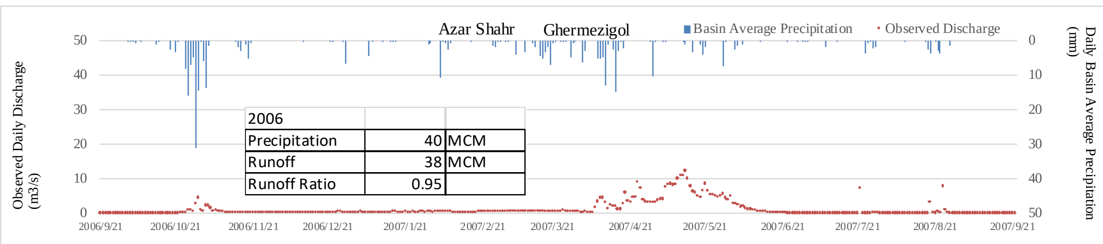




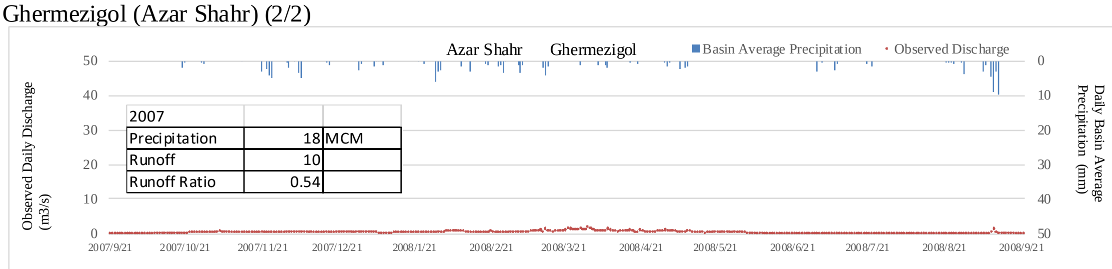


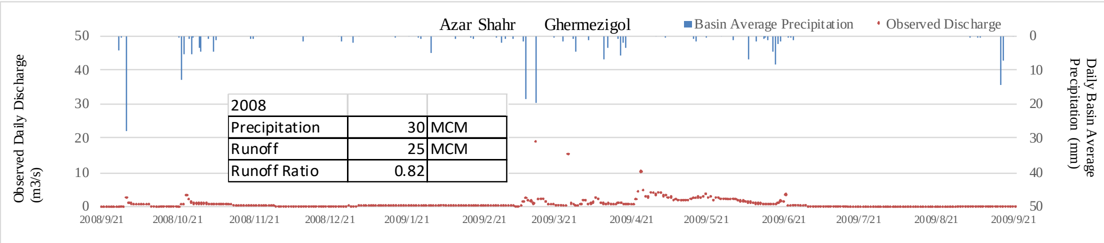


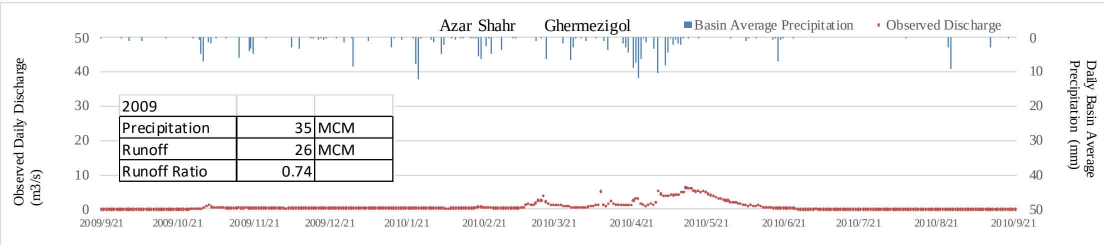


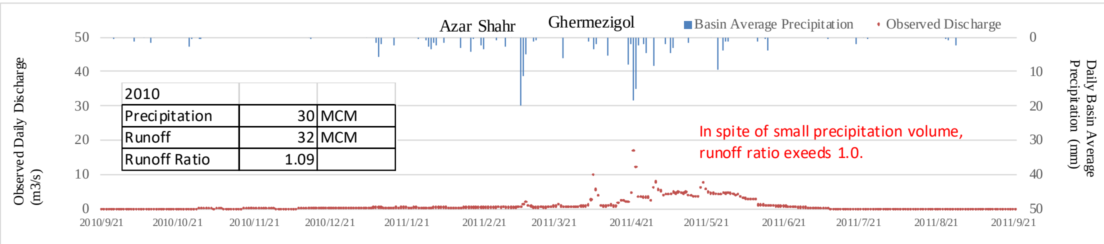


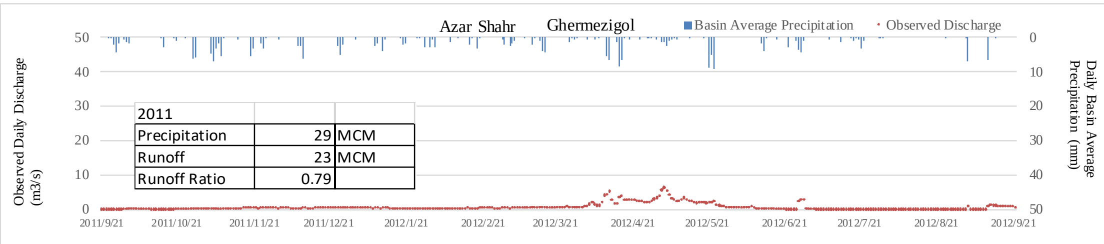
E-15 Ghermezigol (Azar Shahr) (2/2)

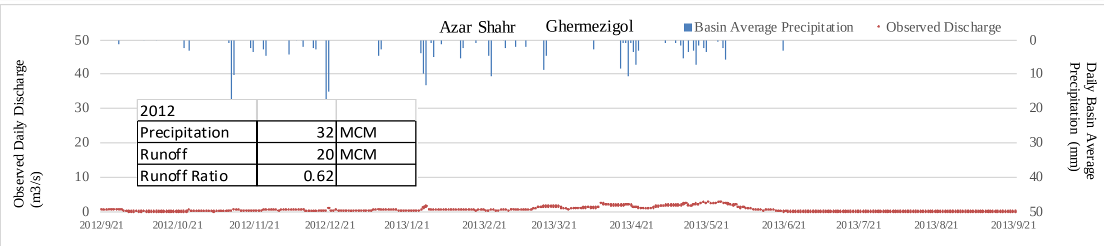


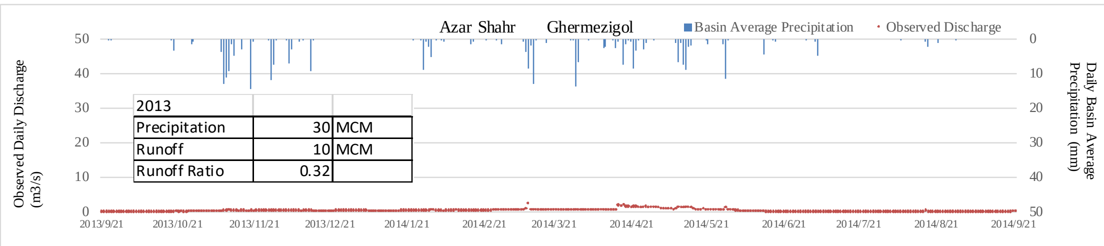




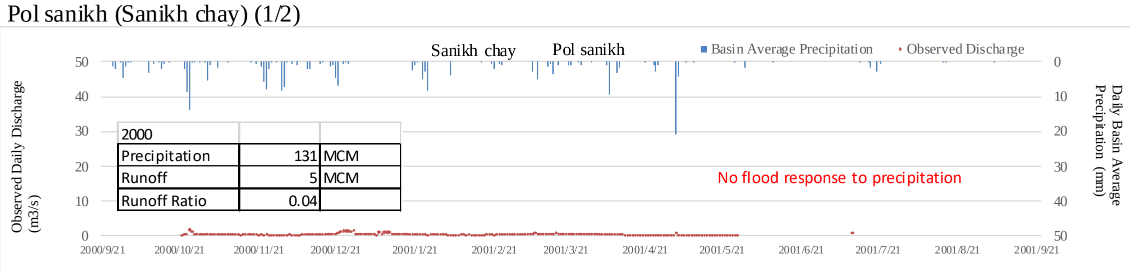


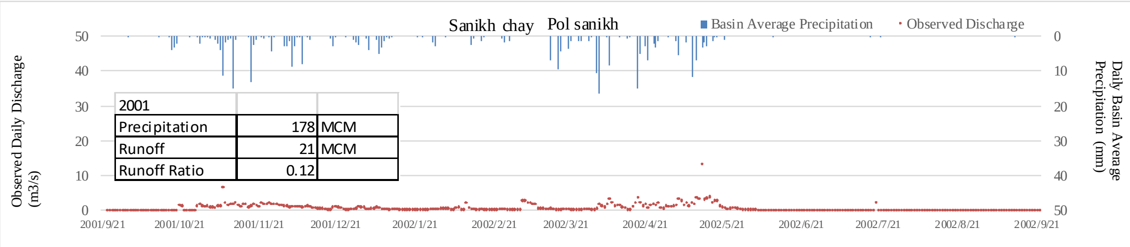


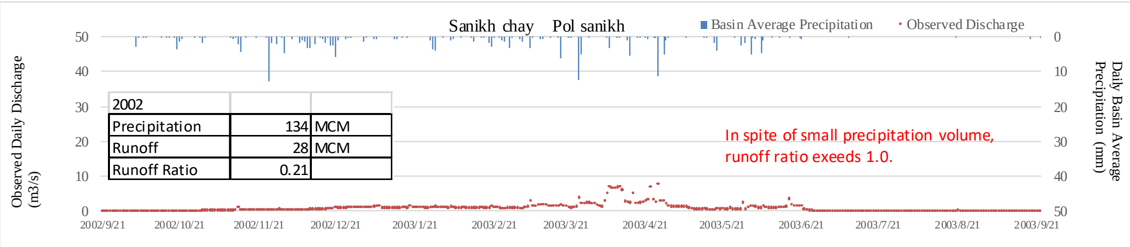


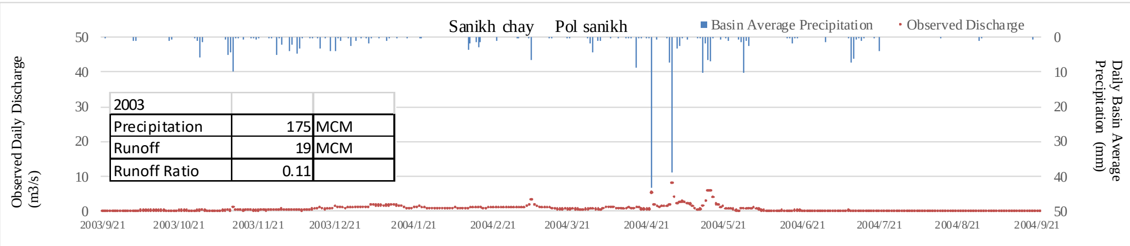


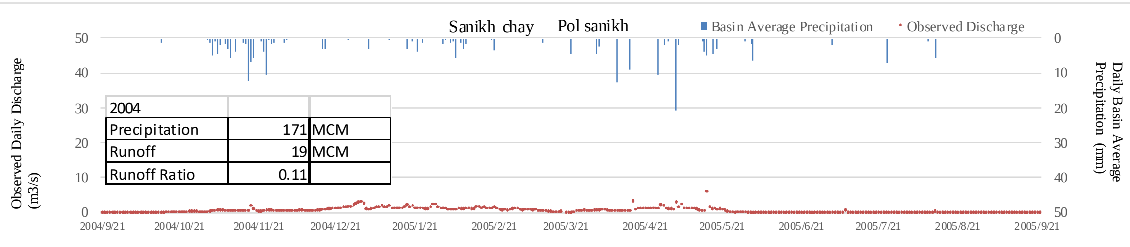
E-16 Pol sanikh (Sanikh chay) (1/2)

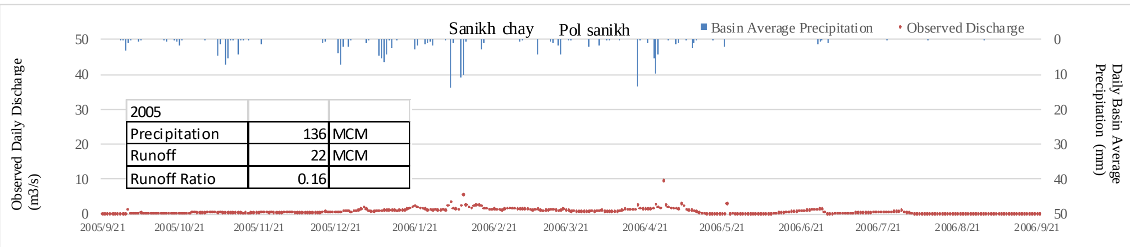


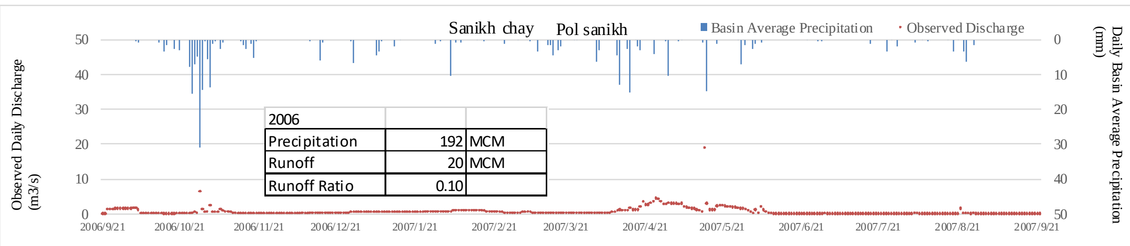




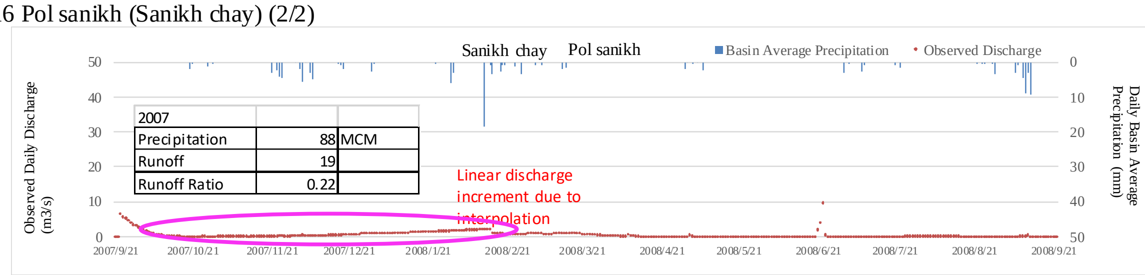


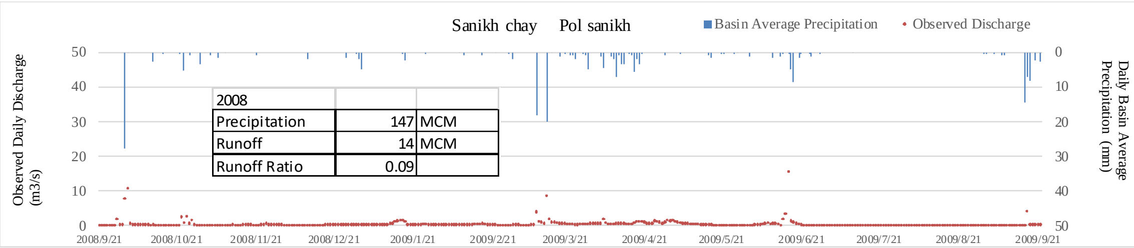


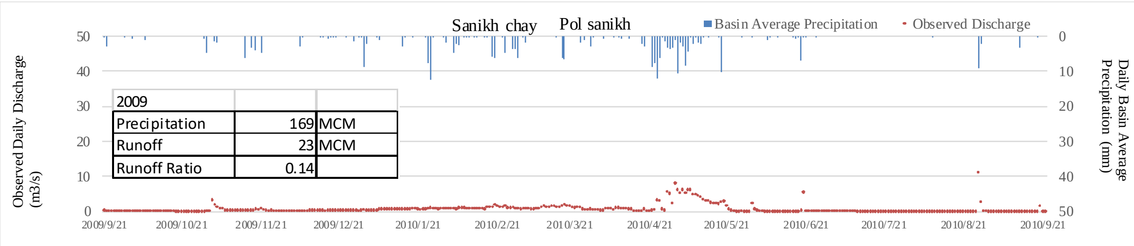


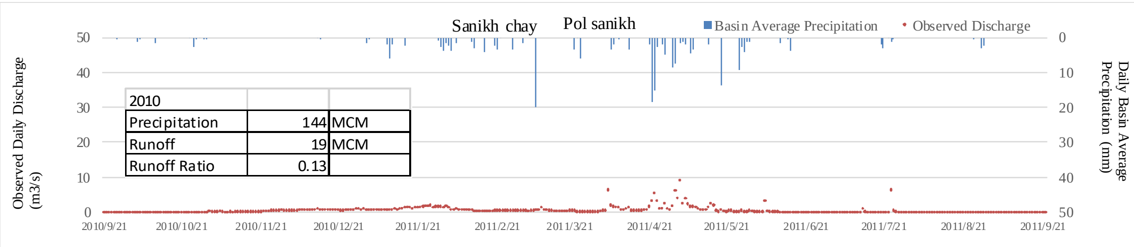


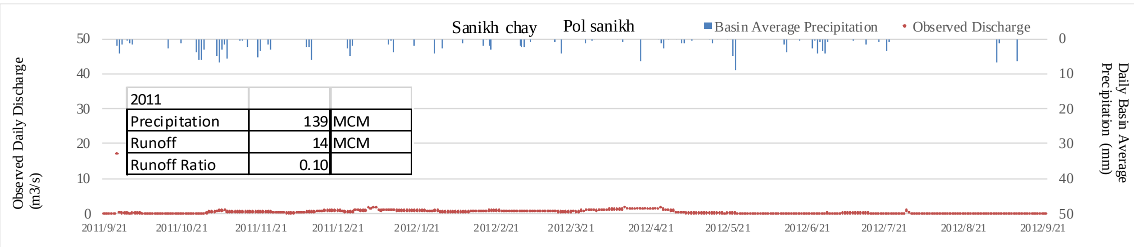
E-16 Pol sanikh (Sanikh chay) (2/2)

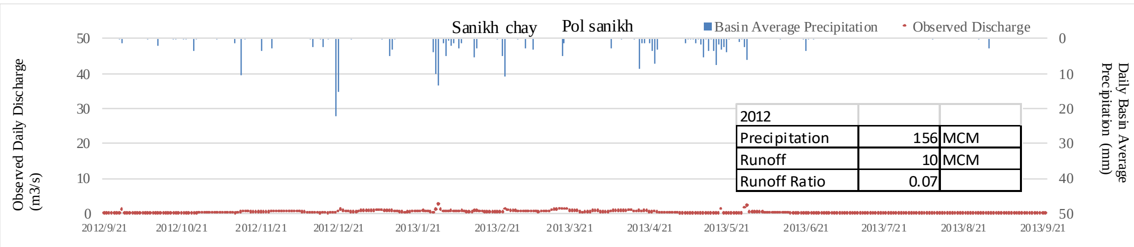


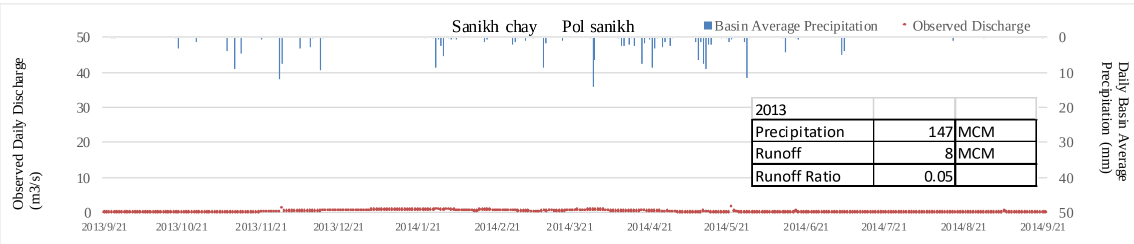




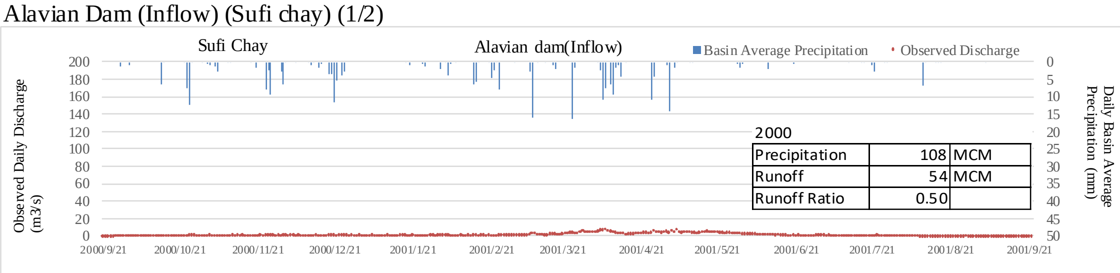


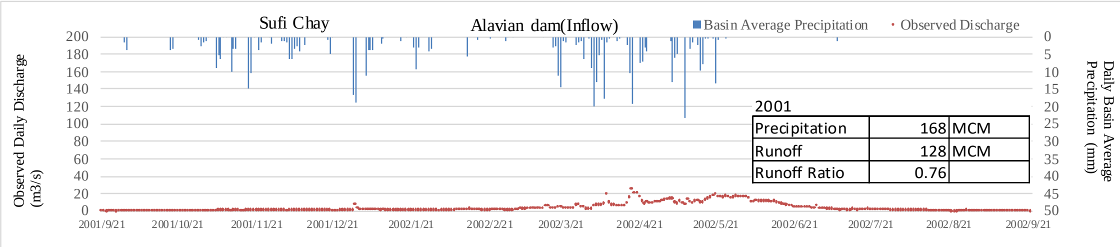


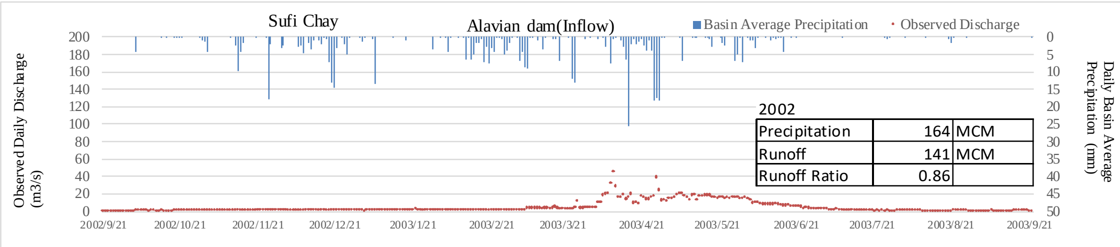


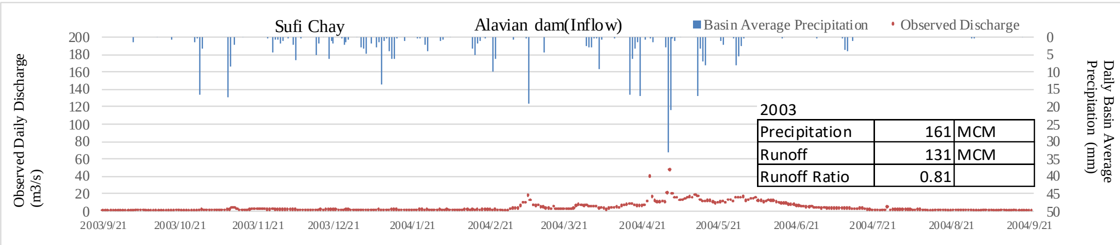


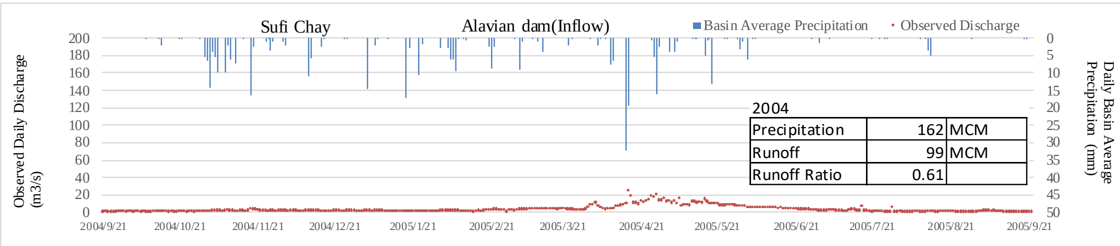
E-17 Alavian Dam (Inflow) (Sufi chay) (1/2)

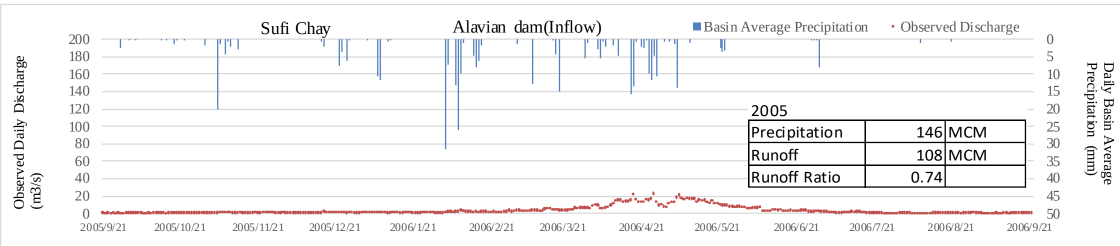


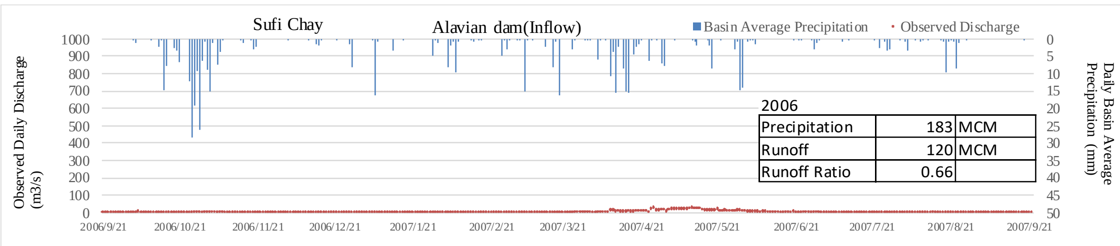












E-17 Alavian Dam (Inflow) (Sufi chay) (2/2)