ISLAMIC REPUBLIC OF IRAN
MINISTRY OF ENERGY (MOE)
URMIA LAKE RESTORATION PROGRAM (ULRP)

DATA COLLECTION SURVEY ON IMPROVEMENT OF THE HYDROLOGICAL CYCLE MODEL IN URMIA LAKE BASIN IN THE ISLAMIC REPUBLIC OF IRAN

FINAL REPORT

SEPTEMBER 2020

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

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1. OUTLINE OF THE SURVEY (Chapter 1 of the Final Report)

1.1 Background

Urmia Lake is located in the northwestern part of the Islamic Republic of Iran (hereinafter referred to as “Iran”). With an area of 5,700 km^2 and the storage capacity of 36,750 million cubic meters (MCM), Urmia Lake used to be ranked as the 6th largest inland saline lake in the world. Since around the year 2000, however, the area of the lake gradually shrunk, concurrently, with the decrease in water inflow, As of September 2014, the area and the storage capacity of Urmia Lake have been 1,440 km^2 and 1,640 MCM, respectively.

The principal cause of decline of the lake surface area has been attributed to the chronic drought and the increase in water intake for agriculture brought about by water resources development in the Urmia Lake Basin. Although the Iranian government had made studies on how to stop the reduction of lake area, no practical measure was implemented until His Excellency, President Hassan Rouhani, who made a public commitment on the restoration of Urmia Lake, assumed office in August 2013. The President hammered out measures, and called for assistance from international institutions.

Accordingly, JICA implemented the Survey entitled “The Data Collection Survey on the Hydrological Cycle of Urmia Lake Basin in the Islamic Republic of Iran (herein after referred to as “the previous survey”)” from November 2014 to March 2016, for the quantitative evaluation of various restoration measures for Urmia Lake. In the Survey, the collection of basic information, study on water circulation system by building a hydrological cycle model for the Urmia Lake Basin, and quantitative assessment of restoration measures have been conducted. The hydrological cycle model was built with limited information and data by two software, MIKE-SHE (developed by DHI) and GETFLOWS (developed by Geosphere Environmental Technology Corp.), and the model achieved a measure of legitimacy from the Iranian side.

After the previous survey, The Urmia Lake Restoration Program (herein after referred to as ULRP) has been building a Decision Support System (DSS) to select the best restoration measure considering various conditions, which contain economic and social assessment in addition to the assessment of impacts on the water circulation system. The ULRP presented the plan to utilize the hydrological cycle model built in “Data Collection Survey on Hydrological Cycle of Urmia Lake Basin in the Islamic Republic of Iran” (hereinafter referred to as “the previous survey”) as a module of DSS, and requested technical assistance from the Japan International Cooperation Agency (JICA) for accuracy improvement of the model.

In response to the request, JICA conducted a field survey in September 2016 and made a study on the background and contents of the request from the Iranian government. As a result, through discussions with the Iranian relevant agencies, JICA decided to implement the “Data Collection Survey on the Improvement of the Hydrological Cycle Model of Urmia Lake Basin” (hereinafter referred to as “the Survey”). The Minutes of Meeting (M/M) between JICA and with the Ministry of Energy and ULRP was signed in February 2017. The Survey was implemented in the period from July 2017 to July 2020.

1.2 Objective of the Survey

The objective of the Survey is to improve the existing hydrological cycle model in accordance with the DSS water circulation module.

(1) Purpose of the Survey

The Survey aims to quantitatively comprehend the water circulation system of Urmia Lake Basin and contribute to the evaluation of restoration measures for Urmia Lake.

(2) Expected Outputs

To quantitatively comprehend the water circulation system of Urmia Lake Basin and to contribute to the evaluation of restoration measures for Urmia Lake, the following items are supposed to be executed:

1) Validation of data and information from ULRP, consolidation of input data into MIKE-SHE and information for modeling;
2) Hydrological cycle modeling for each part of Urmia Lake Basin (south, west and east) and building of the whole basin model by integrating them with each other; and

3) Simulation of the hydrological cycle models based on the restoration scenario for Urmia Lake Basin given by ULRP, and the assessment of various projects and effectiveness of the scenarios.

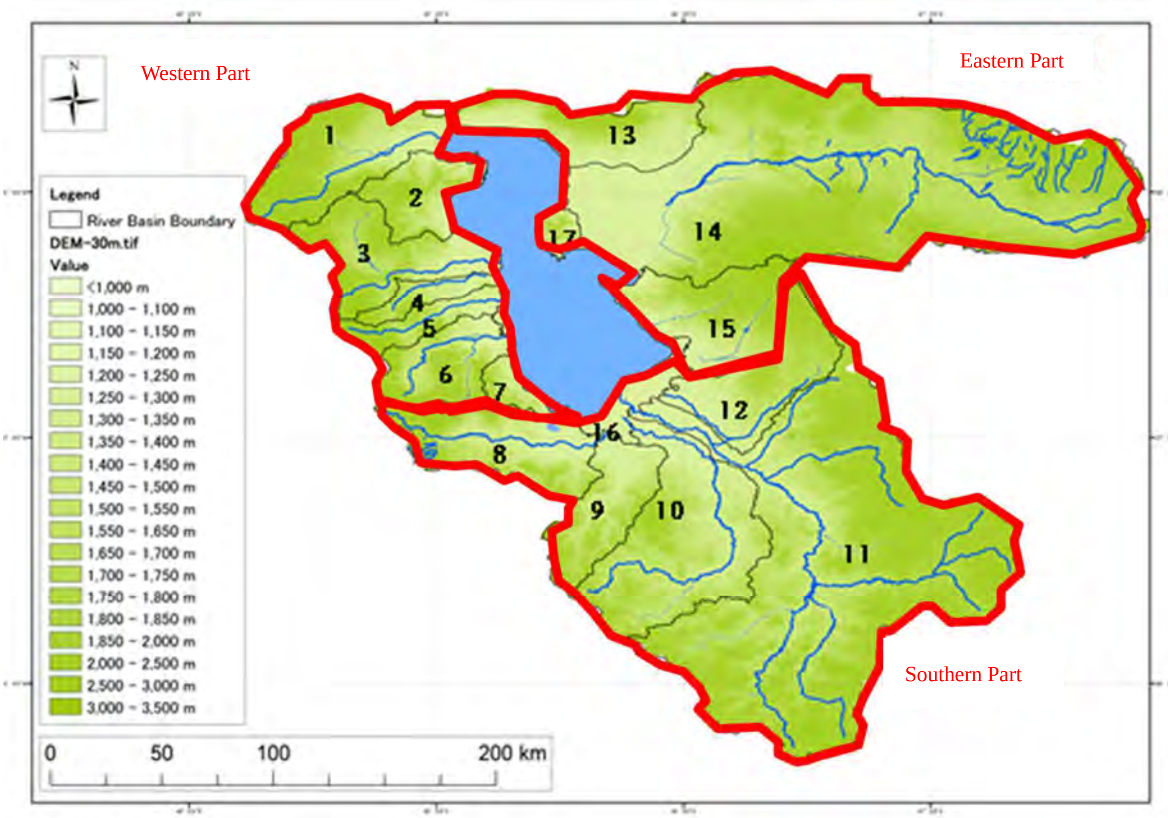
(3) Related Main Japanese Assistance

The main Japanese assistance related to the Survey are the following:

- The Study on Integrated Water Resources Management for Sefidrud River Basin in the Islamic Republic of Iran (2007-2010)
- Water Policy Advisor (2017-2019)
- Data Collection Survey on Hydrological Cycle of Urmia Lake Basin (2014-2016)

(4) Target Area

The target area covers the whole Urmia Lake Basin (West Azerbaijan Province, East Azerbaijan Province, and Kurdistan Province). For the modeling the Urmia Lake Basin was divided into three parts, south, west and east, in accordance with the counterparts' hydrological knowledge, as shown in Figure 1.2.1.



Source: This Survey

Figure 1.2.1 Areas and Sub-River Basins

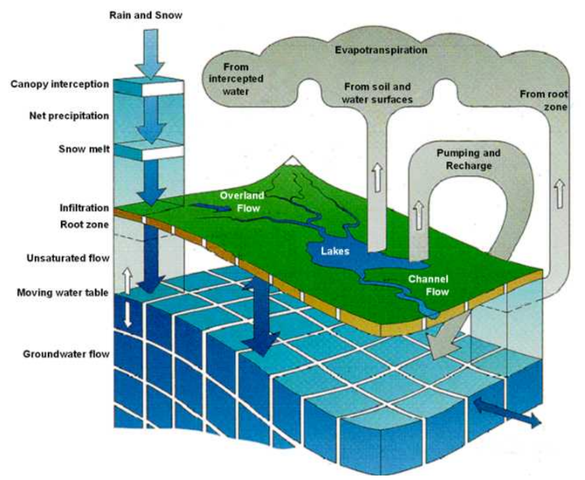
Table 1.2.1 Target River Basins

Part	Sub River Basin	Area (km^2)	Representative Dam
South	Gedar Chay(8)、Mahabad Chay(9)、Simineh Rud(10)、Zarineh Rud(11)、Lilang Chay(12)、Residual Basin of Southern Part (16)、	21,155	Mahabad Dam(190MCM) Bukan Dam (486MCM)
West	Zola Chay(1)、Residual Basin(2)、Nazlo Chay(3)、Roze Chay(4) Sahar Chay(5)、Baradoz Chay(6)、Residual Basin 2(7)	8,105	Shahr Chay Dam (213 MCM)
East	Residual Basin 3(13)、Ajichay(14)、Gale Chay(15)、Lake Urmia Island(17)	17,462	Shahid Madani-Vanyar Dam (Under Construction) (280MCM)

2. ESTABLISHMENT OF HYDROLOGICAL CYCLE MODEL FOR URMIA LAKE BASIN (Chapter 4 and Sections from 5.1 to 5.6 of the Final Report)

2.1 Establishment of MIKE-SHE Model (5.1 of the Final Report))

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. Figure 2.1.1 presents conceptual diagrams of the model.



*Source: DHI

Figure 2.1.1 Conceptual Diagrams of the Model

2.2 Basic Features of MIKE-SHE (5.2 of the Final Report)

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.

2.3 Model Setting and Input Data Processing (5.4 of the Final Report)

Table **2.3.1** shows major input data/information provided through ULRP. Based on the data/information, the Survey Team updated the hydrological cycle model in a stepwise manner.

Notably, since the information on water use was not enough in quality or quantity for building a practical model, the amount of evapotranspiration from irrigating area were estimated by satellite imaging and the estimated data were input into the hydrological cycle model instead. The data of evapotranspiration estimated by the METRIC method was provided from the Iranian side. Also, irrigation demand for each identified irrigation area is calculated back from the evapotranspiration at the agricultural fields and the irrigation efficiency.

Table 2.3.1 Data/Information Collected from ULRP

No.	Category	Input Data
1	Hydrology	Daily Precipitation and Daily River Discharge (Dam outflow)
2	Climatology	Actual Evapotranspiration estimated by METRIC (Daily-basis, Spatially- distributed) Evaporation from the Urmia Lake (pan evaporation at the climatological station adjacent to the lake), Air Temperature (for snow melt estimation)
3	Geology	Geological Layer (geology and depth of aquifer layers), Hydrogeological Parameter (e.g. hydraulic conductivity, specific storage coefficient, soil porosity)
4	Groundwater	Groundwater abstraction (location of wells with intake water amount)
5	Topology	Land elevation (DEM), Bathymetry data for Lakebed (Data surveyed in 2013 and in 2015 at the latest)
6	Natural Condition	River Line & Cross sections and Land use (as of 2010)
7	Water Use and Return flow	Irrigation Efficiency, Groundwater abstraction amount, Intake point (location and water source), Intake water amount (time series data of water use), Return flow of treated wastewater to the rivers and lake

2.4 Sensitivity Analysis (5.5 of the Final Report)

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). Percentage of variance range (difference between maximum and minimum) to average runoff volumes for the years and snowmelt seasons were calculated for each major parameter status. 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. These parameters were particularly carefully adjusted in the calibration of the hydrological cycle model constructed in the study.

Table 2.4.1 Summary of Model's Sensitivity to Parameters

Classification	Parameter	Impact to runoff volume
Land use change	**Roughness coefficient**	Small
Snow melt	**Threshold snow melt temperature**	Effective during snow melt season
Infiltration	**Depth of unsaturated zone**	Very small
Infiltration	**Soil Type**	Effective for a whole season /snow melt season
Percolation	**Horizontal hydraulic conductivity**	Effective for a whole season
Percolation	**Vertical hydraulic conductivity**	Very small

2.5 Calibration Result (5.6 to 5.10 of the Final Report)

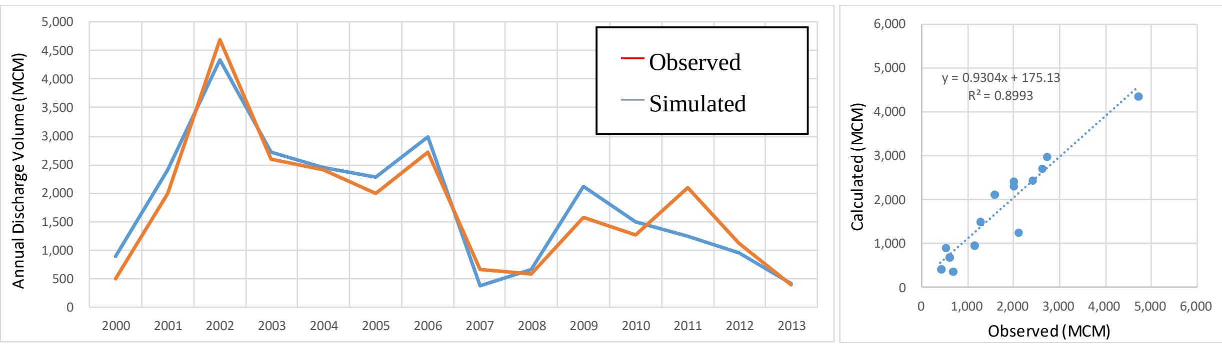
The regional hydrological cycle model ensures the high accuracy for the major water balance elements such as river flow discharge, groundwater level and evapotranspiration as described below. The combined model also shows high accuracy in the lake water level and the annual surface inflow volume to the lake.

(1) Daily Runoff Trend

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. 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

A high mutual similarity with the correlation coefficient 0.9 is obtained between observed and simulated yearly discharge (See Figure **2.5.1**). 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.



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

Figure 2.5.1 Comparison and Correlation of Total Annual Discharge Volume among Hydrological Stations between Simulated and Observed

(3) 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 Figure 2.5.2. If information of height of strainers of the monitoring wells are available, the simulation result of groundwater level will be improved in height.

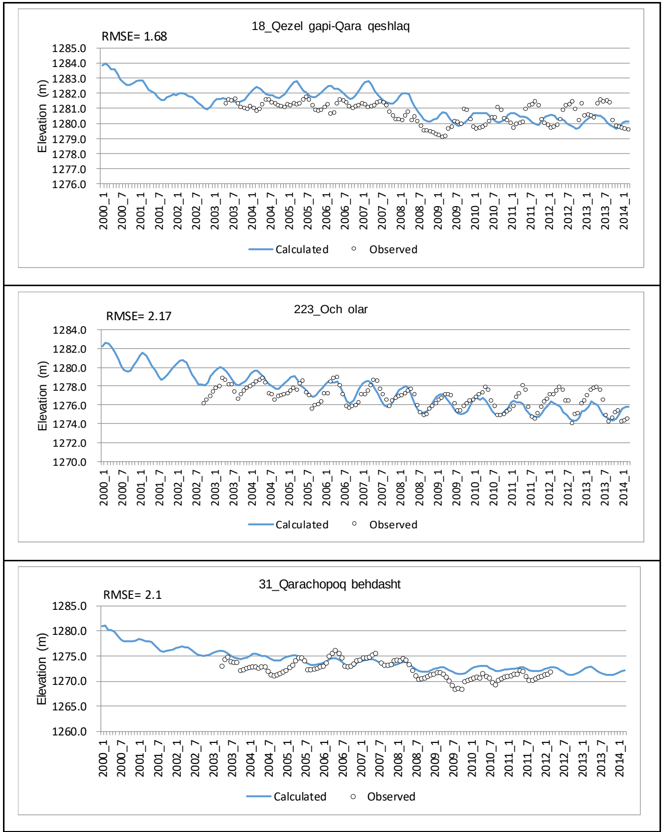


Figure 2.5.2 Comparison of Groundwater Level between Observed and Simulated

(4) Evapotranspiration and Water Use

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) 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 Figure **2.5.3**. The simulated daily water level showed an extremely high agreement of NSE 0.96 with the observed water level. The hydrological cycle model of the Survey maintains the same high accuracy level as the model in the previous survey.

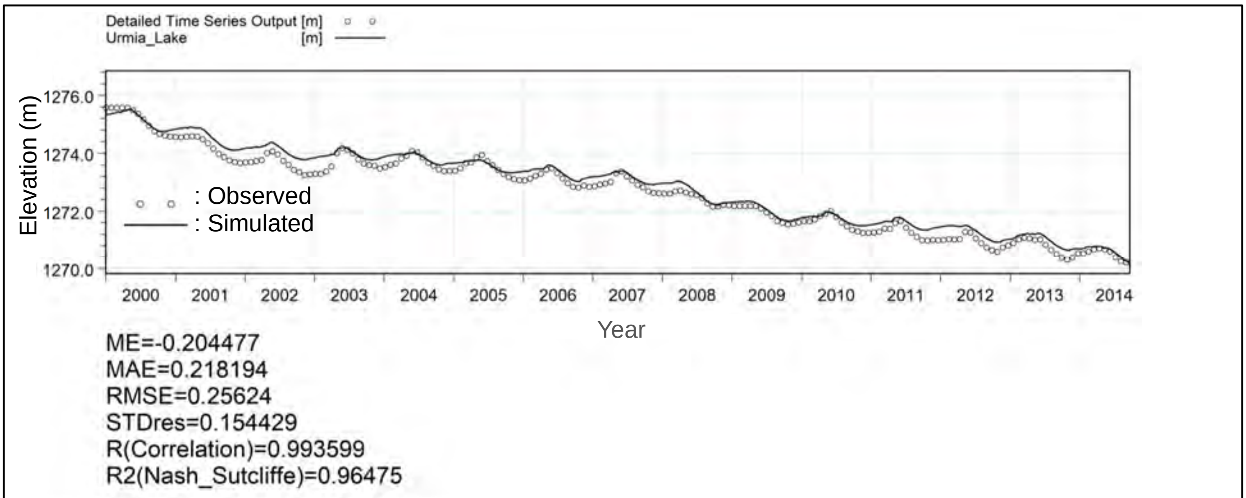


Figure 2.5.3 Comparison of Lake Water Level between Observed and Simulated

3. Water Balance of the Urmia Lake based on the Calibration Results (5.11 of the Final Report)

3.1 Annual total volume for each element

In hydrological years 2002, 2006 and 2009, the simulated lake water balance approaches zero (see Figure 3.1.1). 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 3.1.1 and Figure 3.1.2) which is suggesting the most stable condition of lake water level during the period. The water balance in 2002 is summarized in Table 3.1.1

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 the table. 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.

Table 3.1.1 Water Balance Calculation

Cases		Lake Water Level (m)	In-Volume (MCM) to the lake				Out-Volume from the lake (MCM)
			Rainfall	River Flow*	Groundwater	Total	
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
	Rainfall=287mm (Average for 14 years)	1274.1	1,454	4,289	14.1	5,757	5,757

*Only river flow volume was back calculated to sustain the water level 1274.1m in case of out-volume 5,757 MCM.

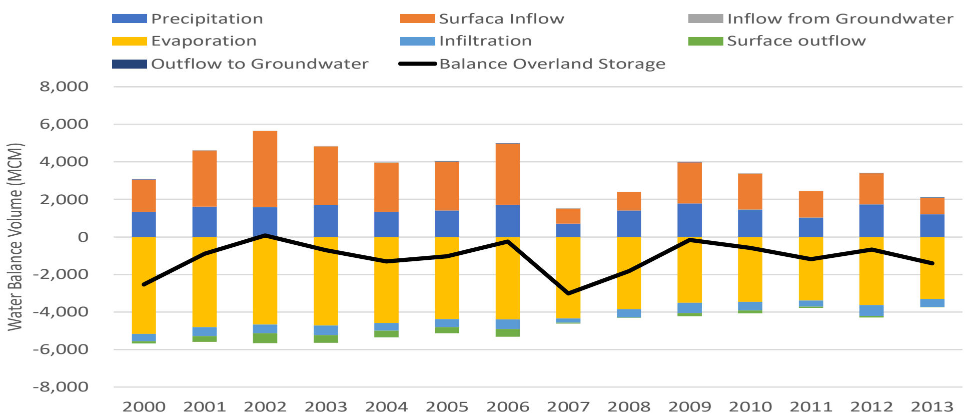
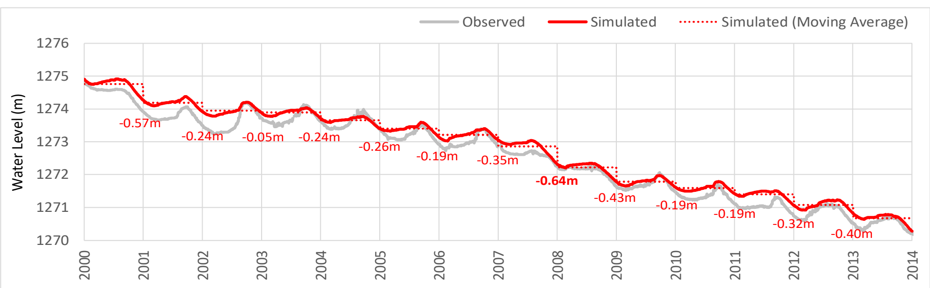


Figure 3.1.1 Water Balance for the Urmia Lake (unit: MCM)



*Aggregation period is between September and August

Figure 3.1.2 The Urmia Lake Water Level and Change of the Water Level(unit: m)

4. SCENARIO SIMULATION (Chapter 6 of the Final Report)

4.1 Basic Conditions of Scenario Simulation (6.1 of the Final Report)

Table 4.1.1 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 (see Table 4.1.2) consist of some of five countermeasures which are summarized in the description of Table 4.1.1 (see (a) to (e) of countermeasures proposed by Urmia Lake Restoration Program (ULRP)).

Table 4.1.1 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.
<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</td></tr>
<tr><td>(b)</td><td>Dredging channel between the lowest hydrological station and lake</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.</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).</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.</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.</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 utilized the results for future decision making.</td></tr>
</table>

In order to evaluate the countermeasures, eight cases of scenario simulation were conducted with combination of current-proposed countermeasures, as shown in Table 4.1.2. 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 4.1.2 Components by Case of Scenario Simulation

Target Area	Whole Basin	Specific River Basin			
Counter Measures	Improvement of IE	Dredging Channel in Gedar Chay	Interbrain Transfer to Gedar Chay	Return flow of treated wastewater to Aji Chay and Rose Chay	Improvement/Change of Dam Operation in Aji Chay
Case001	0.30	-	-	-	-
Case002	0.60	-	-	-	-
Case003	0.70	-	-	-	-
Case004	0.85	-	-	-	-
Case005	0.30	✓	✓	✓	✓
Case006	0.60	✓	✓	✓	✓
Case007	0.70	✓	✓	✓	✓
Case008	0.85	✓	✓	✓	✓

4.2 Result of Scenario Simulation (6.2 of the Final Report)

4.2.1 Annual Inflow Water Volume Necessary to Restore the Lake

As described in Section 3, in order to obtain the recovery trend of the lake water level toward 1274.1m (Minimum Ecological Balance Level), the required annual inflow volume to the lake is estimated at about 4,200MCM. On the other hand, the recent inflow volume from 2000 to 2013 was reduced to about 1,900 MCM on yealy average. Therefore, on the assumption that the meteorological condition of the basin will continue as set in the simulation period, the increment of water volume of about 2,300 MCM per year should be additionally secured through the addistional countermeasures.

Figure **4.2.1** 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.

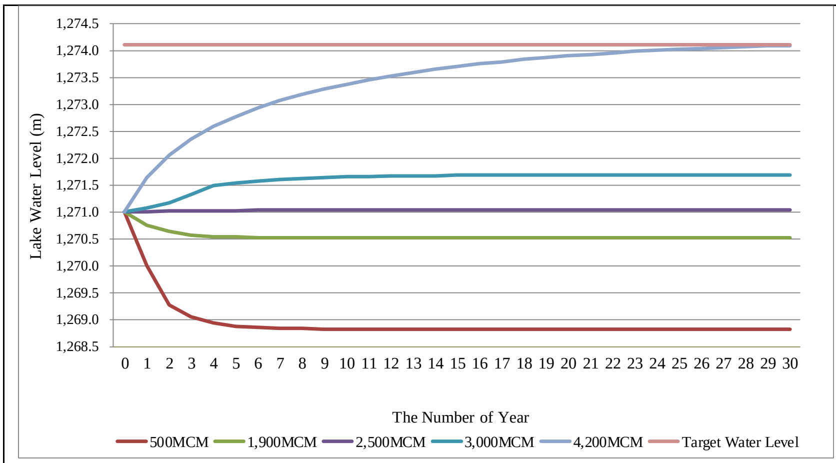


Figure 4.2.1 Lake Water Level Corresponding to Annual Inflow Volume

4.2.2 Time Span of Recovery to Minimum Ecological Balance Level

The result of ramp-sum water balance calculation shows that in case the required river 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 **4.2.2**). For instance, to shorten the restoration time span to about 10 years, further countermeasures should be conducted to earn the total annual river inflow volume around 5,000 MCM.

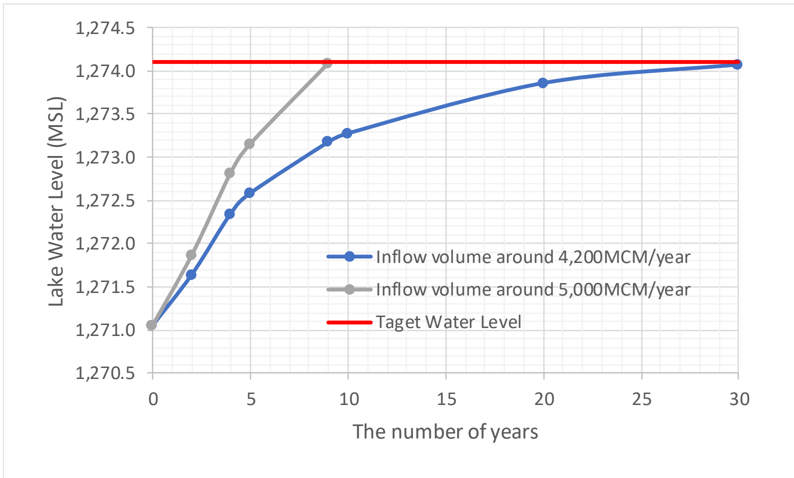


Figure 4.2.2 Time Scale of Lake Water Level Restoration

4.2.3 Effectiveness of Each Countermeasure

Based on the 14 years hydrological simulation on the condition described in Table 4.1.1, the increment of river inflow volume to the lake is summerized by countermeasure in Table 4.2.1. The individual river inflow is very low (from 3 to 250 MCM/year) in comparison with the required river inflow volume (about 2,300 MCM/year as mentiond in Subsection 4.2.1) to attain the target water level.

The Number of Year

Table 4.2.1 Effect of Individual Countermeasures

Unit:MCM

Case Name	Current Condition (w/o proposed countermeasures)	River Structural Countermeasures					(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)

4.2.4 Effectiveness of the Countermeasures Components

As arranged in Table 4.2.2, the results of simulation based on the scenarios indicate that the yearly river inflow volume was estimated at about 2,462 MCM (Case 008: all countermeasures proposed by ULRP with irrigation efficiency 0.85) at a maximum from exisiting yealy average 1,867 MCM (Case 001: Existing Conditions and Measures). The volume of each scenario can not secure the required river inflow volume (about 4,200MCM/year) mentiond in Subsection 4.2.1, 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 **4.2.3**). The average water level would gradually decrease and settle at a lower level on the condition of recurrence of the past decade rainfall volume/pattern and water use (see Figure **4.2.3**).

Table 4.2.2 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)

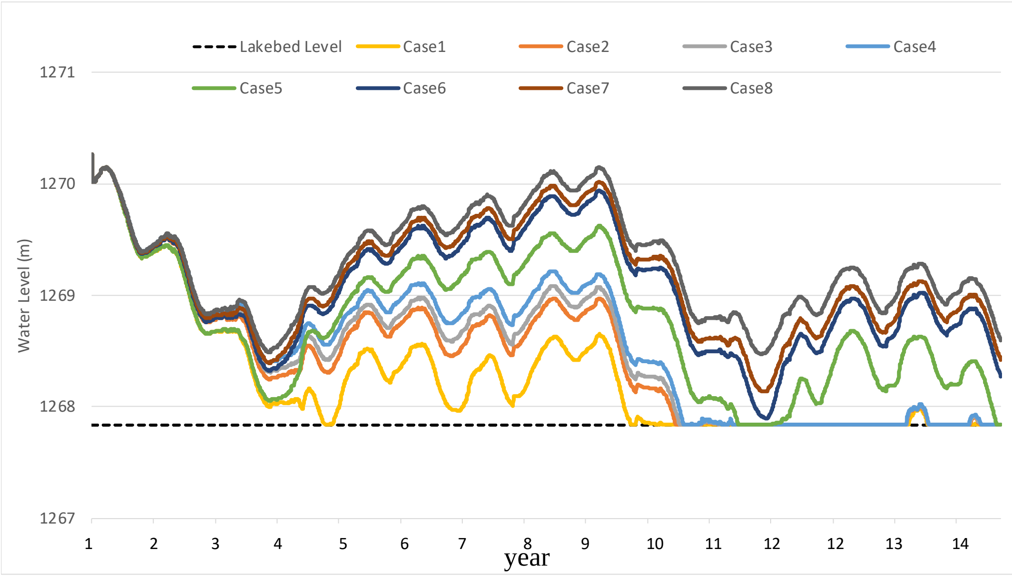


Figure 4.2.3 Lake Water Level in Each Simulation

5. Conclusion

5.1 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 accuracy of the model was improved by focusing on the keys which is 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) of the Final Report)

(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 the all three elements was well calibrated for the model.

5.2 Effect of Measures

The recovery of lake water level requires the yearly river inflow water volume of more than 4,200 MCM per year on the condition of continuity of current lakebed and average rainfall in the basin. Because of the current total river inflow to the lake of about 1,900 MCM/year with the effects of past restoration measures, the increment river inflow of about 2,300 MCM/year by future restoration measures is necessary. 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.

5.3 Conceivable Future Direction for Recovery of the Lake Water Level

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 more than 4,200MCM/year is a minimum requirement as to prepare the recovery tendency for the target lake water level 1274.1 with the recent degree of direct average rainfall to the lake. In case of less than about 4,200MCM/year, the lake water level will be settled in a lower water level than the target water level. If necessary, the climate change impact also should be considered for setting the condition of average rainfall.
- 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.
- 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/year. The target water level may also should be determined in this case.

5.4 Grasp of Actual Evapotranspiration (ET)

Collecting time series 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. The estimated ET will tell the “net” amount of withdrawal (including unregistered irrigation water), which is more important for considering basin-scale hydrology.

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.

6. Recommendations

6.1 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.

6.2 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.

6.3 Incorporation into Decision Support System and Model Maintenance

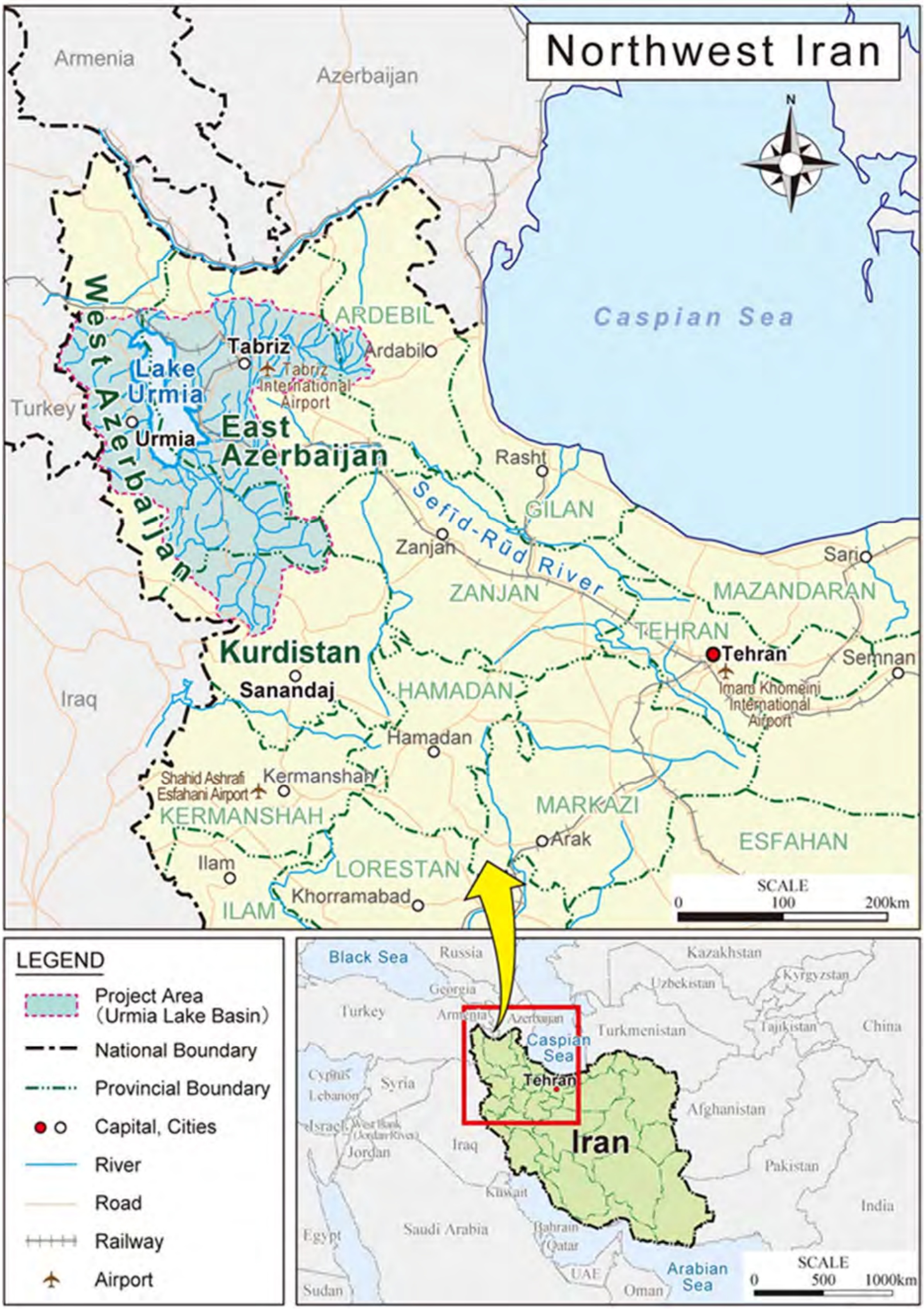
The established model is expected to mount into the DSS as a water balance simulation module. ULRP also had the vision that modules for analyzing climate change and socio-economic condition are built-in. The data and results between each model should be linked in the DSS in order to analyze the effects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

6.4 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 6.1, 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.

6.5 Regulation of Unauthorized Intake Water

The model calibration indicates that groundwater is pumped up several times to attain the intake amount approved by Iran Water Resources Management Company (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.



Source (Urmia Lake Basin) United Nations Environment Program (UNEP)

LOCATION MAP

DATA COLLECTION SURVEY
ON IMPROVEMENT OF THE HYDROLOGICAL CYCLE MODEL
IN URMIA LAKE BASIN

FINAL REPORT

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APPENDIX

ACRONYMS AND ABBREVIATIONS

CIWP	:	Conservation of Iranian Wetlands Project
C/P	:	Counterpart
DEM	:	Digital Elevation Model
DF/R	:	Draft Final Report
DHI	:	Danish Hydraulic Institute
DOE	:	Department of Environment
FAO	:	Food and Agriculture Organization
F/R	:	Final Report
GOI	:	Government of Iran
GOJ	:	Government of Japan
IC/R	:	Inception Report
IDW	:	Inverse Distance Weighted
IRIMO	:	IRAN Meteorological Organization
IWRM Co.	:	Iran Water Resources Management Company
IWRM	:	Integrated Water Resources Management
JICA	:	Japan International Cooperation Agency
ULRC	:	Urmia Lake Restoration Committee
ULRP	:	Urmia Lake Restoration Program
MCM	:	Million Cubic Meter
M/M	:	Man-month
MOE	:	Ministry of Energy
MOH	:	Ministry of Health
MOJA	:	Ministry of Agriculture - Jihad
M/P	:	Master Plan
O&M	:	Operation and Maintenance
PRMU	:	Plannning and Resource Mobilization Unit
PWRI	:	Public Works Research Institute
SC	:	Steering Committee
TOR	:	Terms of Reference
TRWR	:	Total Renewable Water Resources
UNDP	:	United Nations Development Plan
UNEP	:	United Nations Environment Programme
USGS	:	United States Geological Survey
UTM	:	Universal Transverse Mercator
RWC	:	Regional Water Company
RCUWM	:	The Regional Centre on Urban Water Management
SRTM	:	Shuttle Radar Topography Mission
WA	:	West Azerbaijan

CHAPTER 1 INTRODUCTION

1.1 Background

Urmia Lake is located in the northwestern part of The Islamic Republic of Iran (hereinafter referred to as “Iran”). With an area of 5,700 km^2 and the storage capacity of 36,750 million cubic meters (MCM), Urmia Lake used to be ranked as the 6th largest inland saline lake in the world. Since around the year 2000, however, the area of the lake gradually shrunk, concurrently, with the decrease in water inflow, As of September 2014, the area and the storage capacity of Urmia Lake have been 1,440 km^2 and 1,640 MCM, respectively.

The principal cause of decline of the lake surface area has been attributed to the chronic drought and the increase in water intake for agriculture brought about by water resources development in the Urmia Lake Basin. Although the Iranian government had made studies on how to stop the reduction of lake area, no practical measure was implemented until His Excellency, President Hassan Rouhani, who made a public commitment on the restoration of Urmia Lake, assumed office in August 2013. The President hammered out measures, and called for assistance from international institutions.

Accordingly, JICA implemented the Survey entitled “The Data Collection Survey on the Hydrological Cycle of Urmia Lake Basin in the Islamic Republic of Iran,” from November 2014 to March 2016, for the quantitative evaluation of various restoration measures for Urmia Lake. In the Survey, the collection of basic information, study on water circulation system by building a hydrological cycle model for the Urmia Lake Basin, and quantitative assessment of restoration measures have been conducted. The hydrological cycle model was built with limited information and data by two software, MIKE-SHE (developed by DHI) and GETFLOWS (developed by Geosphere Environmental Technology Corp.), and the model achieved a measure of legitimacy from the Iranian side.

The Urmia Lake Restoration Program (ULRP) has been building a Decision Support System (DSS) to select the best restoration measure considering various conditions, which contain economic and social assessment in addition to the assessment of impacts on the water circulation system. The ULRP presented the plan to utilize the hydrological cycle model built in “Data Collection Survey on Hydrological Cycle of Urmia Lake Basin in the Islamic Republic of Iran” (hereinafter referred to as “the previous survey”） as a module of DSS, and requested technical assistance from the Japan International Cooperation Agency (JICA) for accuracy improvement of the model.

In response to the request, JICA conducted a field survey in September 2016 and made a study on the background and contents of the request from the Iranian government. As a result, through discussions with the Iranian relevant agencies, JICA decided to implement the “Data Collection Survey on the Improvement of the Hydrological Cycle Model of Urmia Lake Basin” (hereinafter referred to as “the Survey”). The Minutes of Meeting (M/M) between JICA and with the Ministry of Energy and ULRP was signed in February 2017.

1.2 Objective of the Survey

The objective of the Survey is to improve the existing hydrological cycle model in accordance with the DSS water circulation module.

(1) Purpose of the Survey

The Survey aims to quantitatively comprehend the water circulation system of Urmia Lake Basin and contribute to the evaluation of restoration measures for Urmia Lake.

(2) Expected Outputs

To quantitatively comprehend the water circulation system of Urmia Lake Basin and to contribute to the evaluation of restoration measures for Urmia Lake, the following items are supposed to be executed:

1) Validation of data and information from ULRP, consolidation of input data into MIKE-SHE and information for modeling;

2) Hydrological cycle modeling for each part of Urmia Lake Basin (south, west and east) and building of the whole basin model by integrating them with each other; and
3) Simulation of the hydrological cycle models based on the restoration scenario for Urmia Lake Basin given by ULRP, and the assessment of various projects and effectiveness of the scenarios.

(3) Target Area

The target area covers the whole Urmia Lake Basin (West Azerbaijan Province, East Azerbaijan Province, and Kurdistan Province).

(4) Related Main Japanese Assistance

The main Japanese assistance related to the Survey are the following:

- The Study on Integrated Water Resources Management for Sefidrud River Basin in the Islamic Republic of Iran (2007-2010)
- Water Policy Advisor (2017-2019)
- Data Collection Survey on Hydrological Cycle of Urmia Lake Basin (2014-2016)

1.3 Implementation Period

The Survey is to be implemented in about three (3) years from July 2017 to April 2020, as shown in Table 1.3.1. Field and domestic works are to be conducted in Iran and in Japan for the data collection and modeling works, respectively. To present the survey progress and results, seven (7) reports are to be submitted to ULRP, which has the responsibility for distributing the reports and related documents to the related organizations.

Table 1.3.1 Overall Implementation Schedule

1st Field Work

	2017									2018		
	4	5	6	7	8	9	10	11	12	1	2	3
Field Work				━	━	━	━	━			━	━
Domestic Work						━	━	━	━	━		
Data Collection					━	━						
Modeling Work						━	━	━		━	━	━
Report				△ IC/R				△ P/R1				

2nd Field Work

	2018									2019		
	4	5	6	7	8	9	10	11	12	1	2	3
Field Work				━	━		━					
Domestic Work		━	━	━			━	━	━	━	━	━
Data Collection				━	━	━			━			
Modeling Work		━	━	━		━	━	━	━	━	━	━
Report				△ P/R2					△ P/R3			

3rd Field Work

	2019									2020		
	4	5	6	7	8	9	10	11	12	1	2	3
Field Work	━	━				━	━		━			
Domestic Work	━	━	━	━			━	━	━	━	━	━
Data Collection		━	━			━	━					
Modeling Work			━	━		━	━	━		━	━	━
Report	Updated P/R3											

	2020				
	4	5	6	7	8
Field Work					
Domestic Work	━	━	━	━	━
Data Collection					
Modeling Work	━				
Report		△ DF/R			△ F/R

IC/R: Inception Report; P/R: Progress Report; DF/R: Draft Final Report; F/R: Final Report

1.4 Staffing Plan

The composition of the JICA Survey Team (hereinafter referred to as "the Survey Team") is as shown in Table 1.4.1.

Table 1.4.1 Composition of the JICA Survey Team

Name of Expert	Designation or Field of Specialty
Toshihiro GOTO	Team Leader / Water Resource Management 1
Masanori SUZUKI	Deputy Team Leader / Water Resource Management 2 / Hydrometeorology / Data Quality
Hitoshi NAGATA	Hydrological Cycle Modeling
Masahiro TASUMI	Satellite Image Analysis / Meteorology
Takao SASAKI	Geology

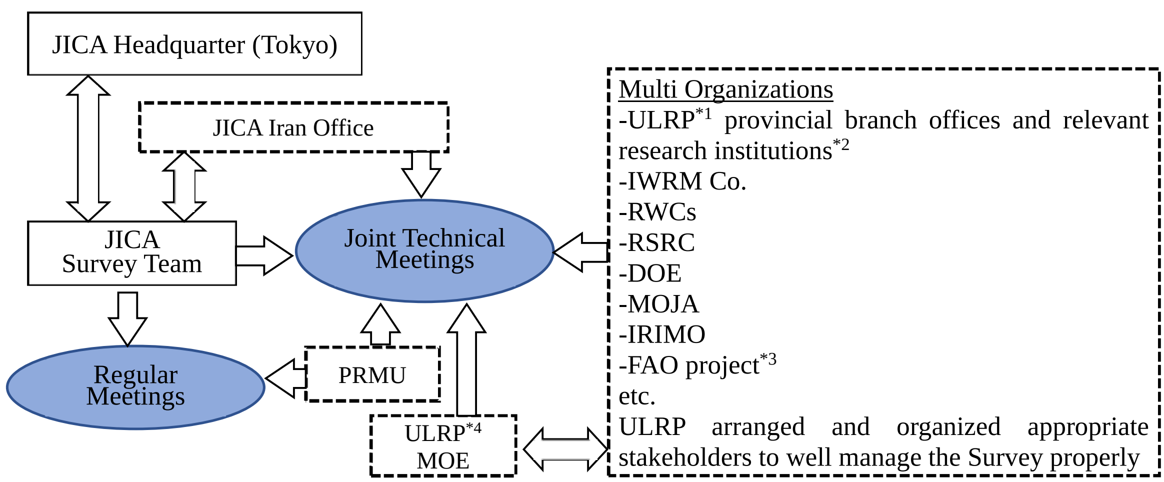
1.5 Working System

To ensure the smooth cooperation and partnership between multiple organizations, a counterpart structure has been established on the Iranian side as shown in Table 1.5.1 and Figure 1.5.1.

Table 1.5.1 Counterpart Structure on the Iranian Side

Responsible Person		
Responsibility	Name	Position (As of March 2018)
Overall Administration	Dr. Bahram Taheri	Senior Advisor to the Minister and Director General of Environment, Health and Safety & Social Affairs, Minister of Energy (MOE)
Implementation Manager	Dr. Masoud Tajrishy	Head of Planning and Resources Mobilization Unit (PRMU) of Urmia Lake Restoration Program (ULRP)
Focal Point	Dr. Behdad Chehrenegar	Head of International Cooperation Office, PRMU, ULRP
DSS Formulation	Dr. Mehdi Ahmadi	Head of DSS Sub-committee, Research Office, PRMU, ULRP

Counterpart Organizations	
Role	Organization
Main counterparts	- Ministry of Energy (MOE) - Urmia Lake Restoration Program (ULRP)
Implementation and coordination	- Planning and Resource Mobilization Unit (PRMU), ULRP
Supporting organizations	- ULRP provincial branch offices and research partners such as Urmia University and Tabriz University - Iran Water Resources Management Company (IWRM Co.) - Regional Water Companies (RWCs) - Remote Sensing Research Center (RSRC), Sharif University of Technology - Ministry of Agriculture - Jahad (MOJA) - Department of Environment (DOE) - Iran Meteorological Organization (IRIMO)



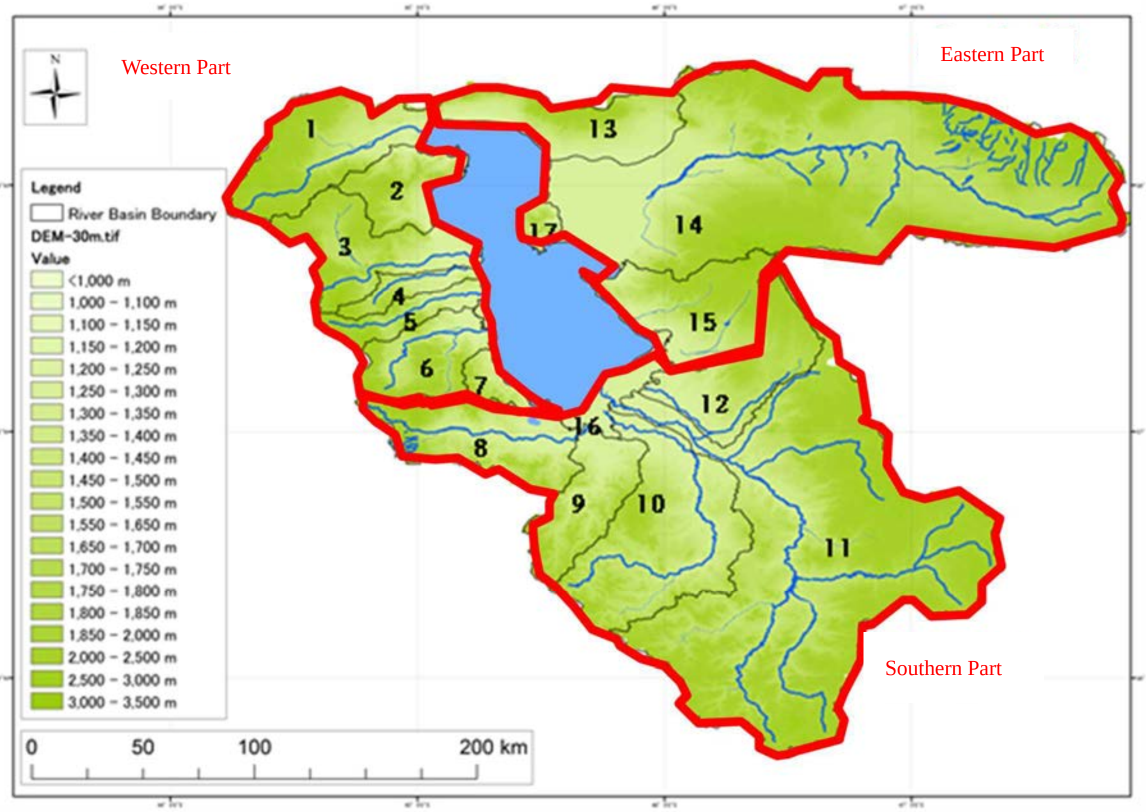
*1: ULRP is an Advisory body directly under the President for Urmia Lake Restoration Project.
*2: Sharif, Urmia, Tabriz, Tehran, Tabiat-Modares Universities, etc.
*3: Integrated Programme for Sustainable Water Resources Management in Urmia Lake Basin
*4: Tehran, Urmia and Tabriz ULRP

Figure 1.5.1 Organizational Framework of the Survey

CHAPTER 2 FIELD SURVEY

2.1 Outline of the Field Survey for Hydrological Cycle Modelling

To build the hydrological cycle models (south, west, east parts and their integration), field and interview surveys have been conducted by the Survey Team and ULRP in the Urmia River Basin, in association with the related organizations such as RWC and MOJA in each area, for the purpose of data collection and confirmation of the model status. The Urmia River Basin was divided into three parts, south, west and east, in accordance with the counterparts' hydrological knowledge, as shown in Figure 2.1.1. Results of the surveys are as described in Subsections 2.2, 2.3 and 2.4 for the southern, eastern and western areas, respectively.



Source: This Survey

Figure 2.1.1 Areas and Sub-River Basins

Table 2.1.1 Target River Basins

Part	Sub River Basin	Area (km^2)	Representative Dam
South	Gedar Chay(8)、Mahabad Chay(9)、Simineh Rud(10)、Zarineh Rud(11)、Lilang Chay(12)、Residual Basin of Southern Part (16)、	21,155	Mahabad Dam(190MCM) Bukan Dam (486MCM)
West	Zola Chay(1)、Residual Basin(2)、Nazlo Chay(3)、Roze Chay(4) Sahar Chay(5)、Baradoz Chay(6)、Residual Basin 2(7)	8,105	Shahr Chay Dam (213 MCM)
East	Residual Basin 3(13)、Ajichay(14)、Gale Chay(15)、Lake Urmia Island(17)	17,462	Shahid Madani-Vanyar Dam (Under Construction) (280MCM)

2.2 Southern Area of the Basin

The locations of field investigations and interviews in the southern area are as indicated in Figure 2.2.1. Numbers in the figure correspond to the site visited areas and are referred to in the subsections of 2.2.

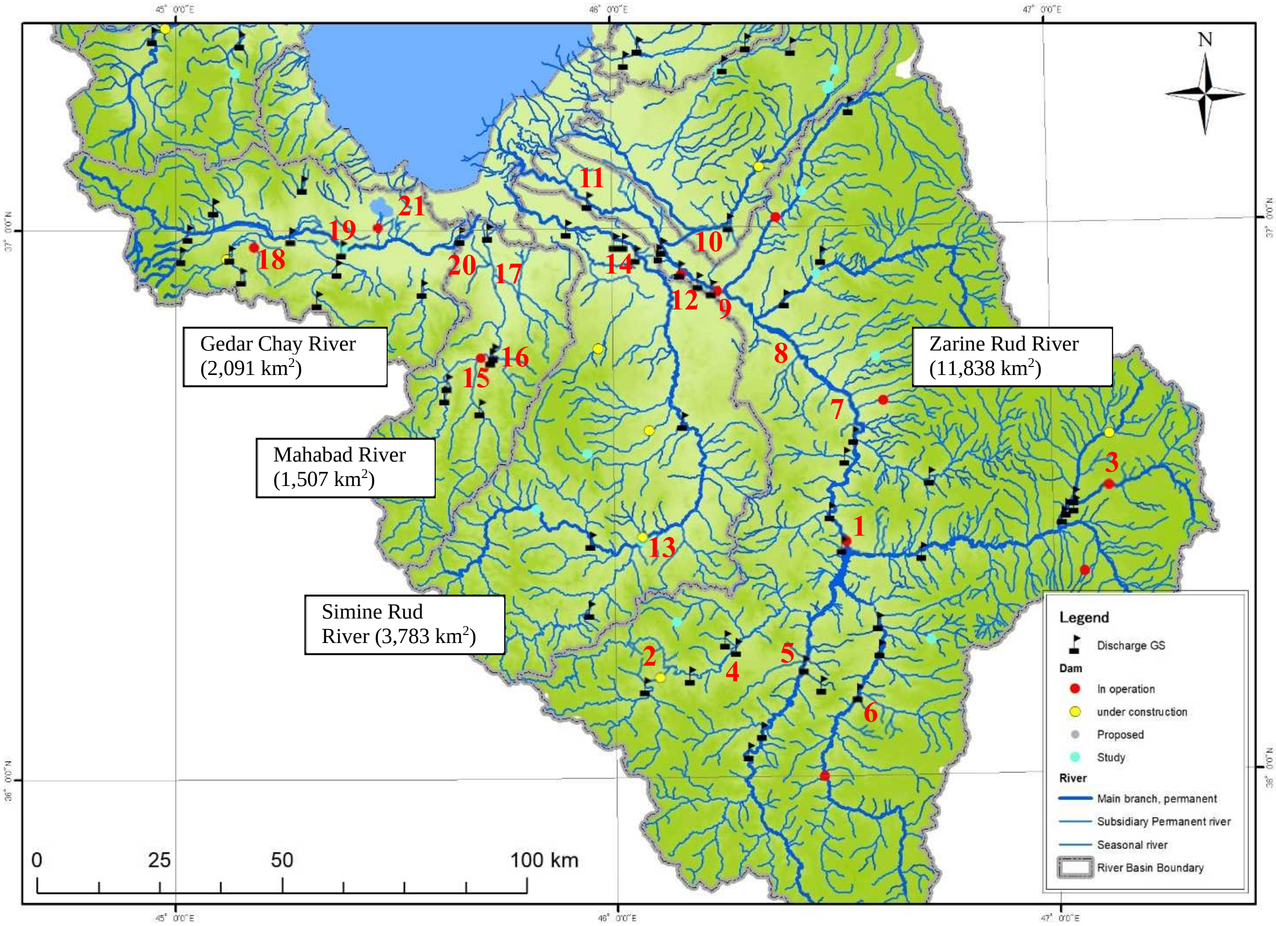


Figure 2.2.1 Main Places Visited for Field Investigation (Southern Area)

2.2.1 Zarine Rud River Basin

(1) Bukan Dam

Bukan Dam (No. 1 in Figure 2.2.1) is the largest dam in the Urmia Lake Basin and it is located nearby the boundary between the Kurdestan and West Azerbaijan provinces. The main construction purpose is to supply agricultural and drinking water to the downstream regions (East and West Azerbaijan provinces). As of August 2017, it has been confirmed that about 40 m^3/s of water was released mainly for the agricultural purpose.

According to RWC, residents of Kurdestan Province have been insisting on their right to use water from the dam in the context that most parts of the water source exists in Kurdestan Province. Portable pumps are installed on the lakeshore to directly intake the water of the dam. According to ULRP and IWRM Co., some of these intakes were illegally constructed and used for farmlands around the dam. Besides, in the case of permitted ones, part of the sales is paid to WA, which, among others, contributes to the O&M of the dam.

Dam Embankment

Dam Lake

Release of Water from Gate

Figure 2.2.2 Bukan Dam

(a) Description of Bukan Dam

Table 2.2.1 give descriptions based on the interview with the RWC representative at the Dam Management Office.

Table 2.2.1 Description of Bukan Dam

Items	Descriptions
Basin	Zarine Rud River Basin
Branches of the upstream	Zarine Rud River (main branch), Saghez Chay, Khor Khore Chay and Saruq Chay Annual inflow to Bukan Dam is approximately 1.1 BCM despite the planned 1.7 BCM. Inflow volume comprise of 25% from Zarine Rud River, 10-15% from Saruq Chay, 20-25% from Saghez Chay and the rest from Khor Khore Chay.
Hydrological monitoring status	Hydrological observation stations are installed in the dam lake and the above branch rivers respectively. These are gauging type, and the water level is observed once a day. According to ULRP, accuracies of gauging stations can be enhanced by having automated data loggers.
Survey Period for Planning	6 years since 1951
Purpose of Dam	Water for irrigation is supplied to part of Shahindej, Miandoab, Malekan and Bonab counties which have irrigated farmlands of 55,000ha (planned value 80,000ha), potentially supplying about 500MCM from Noruzlu Diversion Dam (each left and right bank has 250MCM). Agricultural water and drinking water for downstream region. Miandoab City, Bukan City, and Tabriz City are with drinking water supply; hydropower supply is under investigation (16 MW of electricity is possibly generated).

Items	Descriptions
Total water storage capacity	Approx. 808 MCM.
Height	52.5 m
Width	Total 530 m
Width of Spillway	150 m
Water demand	Approximately 815 MCM 1) 354 MCM Agricultural water 2) 157 MCM Drinking water for Tabriz, Bukan and Saqqez cities 3) 3 MCM Industrial water 4) 301 MCM Others (including water for Urmia Lake)
Minimum Storage Volume	199 MCM (this is to ensure the quality of drinking water to Saqqez)
Spillway	Total 2,300 m^3/s with 10 gates
Gates	Total 180 m^3/s with 4 gates
O&M	➢ 3 staff members operate 24 hours a day. In addition, three technicians are assigned for dam safety management. ➢ The amount of outflow discharge is based on the predicted inflow. Amount of released water is consistent with the monthly demand. Monthly water demand for command area is determined by IWRM Co. at the beginning of the year (based on other investigations).
Environmental Flow (Also known as "Water flow stability")	5 m^3/s "According to ULRP, the environmental flow should be monitored from releasing point to the Urmia Lake preventing any illegal water withdrawal".
Others	➢ "With the completion of the Cheraghveys Dam, inflow from the river will be reduced" (Please check the sentence and 5 MCM value)

(b) Issue on Illegal Intake at Downstream

According to the dam management office of RWC, issues on illegal intake have been reported. Based on the survey conducted by local consultants in August and September, there was an illegal intake of 65 MCM in the dry season. It was also reported that illegal water intake is expected to be more during high-water season, and the amount of direct intake from the Dam Lake is 85-90 MCM, out of which 60% of illegal water intake is estimated.

(2) Cheraghveys Dam

As of November 2017, Cheraghveys Dam (No. 2 in Figure 2.2.1) is the only dam built and almost ready for operation in the Urmia Lake Basin within Kurdistan Province.

With 363 km^2 of catchment area, the amount of average inflow to this dam is 157 MCM, in which 86 MCM can be regulated. Planed water usage for this dam are 33 MCM for drinking water, 5 MCM for industrial use, and 43 MCM for agricultural water (about 5,500 ha).

Although the planned irrigated area is 5,500ha, the provision of irrigation and drainage network is delayed by 70% due to the regulation on the reduction of agricultural water and lack of budget. According to the consultant who works with RWC Kurdistan Province, although precipitation trend does not seem to change, the flow regime has changed so that the amount of snowmelt has increased. The snowmelt water in early spring could not be used in the irrigation period as before.

Figure 2.2.3 Cheraghveys Dam

(3) Saruq Dam

Based on the supply and demand plan of large dams (February 2018), 6 MCM of available water of Saruq Dam on Saruq Chay River (No. 3 in Figure 2.2.1) was planned to be used mainly for drinking (7 MCM after 25 years). RWC staff of this dam management office does not seem to have a plan to use the water for agriculture in the context of 1,250 ha of rain-fed agricultural land. Currently planned water allocation for agriculture is 3.5 MCM.

The amount of inflow to the dam is 70 MCM in the study; however, the observed one is approximately 31 MCM. This is because of the low estimation accuracy of precipitation caused by insufficient observation density. There is no rainfall gauging station upstream of the dam, which induces low accuracy of spatial interpolation. Although the estimated average precipitation for 45 years is 337mm, it is possibly less. Volume for water supply to Bukan Dam was 12 MCM in 2016, although approximately 27 MCM was expected.

RWC is eager to increase agricultural water to satisfy the needs of the farmers who want to increase their income. On the other hand, the governor has accepted the increase in discharge to the downstream for environmental preservation. But residents show opposition to the discharge, because they have a perception that discharge from such a small dam does not contribute to the conservation of Urmia Lake. Each position has each opinion.

Figure 2.2.4 Saruq Dam

(4) Irrigated Area Located Upstream of Bukan Dam (No. 4 in Figure 2.2.1)

According to the RWC, 3.5-4MCM is pumped annually from the pumping station installed at the lakeshore of Bukan Dam (600L/s x 8 pumps) whose water is used for sprinkler and drip irrigation.

In the upstream area of Bukan Dam, 1,100ha is irrigated by water up-taken from wells. It still has 15,000-20,000ha of potential irrigated area (currently rain-fed agricultural land), which will double agricultural production by conversion from the rain-fed to irrigation.

In fact, 85-90% of inflow to Bukan Dam is derived from Kurdistan Province. However, in the context that the Bukan Dam is administered by West Azerbaijan Province, its utilization by Kurdistan Province has not been arranged. Kurdistan Province had requested West Azerbaijan Province for 87MCM of surface water for additional use.

Figure 2.2.5 Irrigated Area Located Upstream of Bukan Dam

(5) Adinan and Sonate Hydrological Stations

The Adinan Hydrological Station (No. 5 in Figure 2.2.1) normally performs twice a day manual observation (8AM and 16PM) besides once every two hours during flood. Peak flood was observed to be 176m^3/s in March 2017.

Sonate Hydrological Station (No. 6 in Figure 2.2.1) has been manually operated as the Adinan Hydrological Station. The data logger has commenced manual hourly observation, owing to the budget of ULRP in April 2017.

Adinan Hydrological Station

Well located nearby Adinan Hydrological Station

Sonate Hydrological Station

Logger Installed in Sonate Hydrological Station

Figure 2.2.6 Hydrological Stations Located Upstream of Bukan Dam

(6) Irrigation Channels between Bukan Dam and Noruzlu Diversion Dam

There are six (6) irrigation channels between the Bukan Dam and the Noruzlu Diversion Dam. The Sardar Channel (No. 7 in Figure 2.2.1) is one of them. The main use is agricultural water supply to 588ha of irrigation area.

Two polyethylene pipes with ø70cm have been installed along the bank of the Zarine Rud River, and an open earth channel has been excavated with 4-5m in width and 80km in length. Although closing of these two pipes are manually operated by soil backfilling, there is no function for intake flow adjustment.

According to the RWC staff, discharge observation at this waterway is regularly conducted (document with table to water level flow). Although intake discharge in the irrigation period is 8-10MCM with 3 m^3/s at intake point, it decreases to 0.5 m^3/s at the end. The intake points are fully opened 20 days per month from April to September and 10-15 days in October and November.

Besides Sardar Channel, there are five (5) primary irrigation channels located between the Bukan Dam and the Noruzlu Diversion Dam, namely; Achtappeh (337.5ha), Dasheskan (108ha), Hajiabad (600ha), Gojali (400ha) and Aghchelu (107ha). These channels have large loss due to the earth channel. It seems that RWC has a plan to convert these irrigation systems into pumping from wells.

Inlet with concrete pipes

Excavated channel

Figure 2.2.7 Sardar Channel

Aghchelu Channel is an excavated channel 10m in width and 1m in depth. Although sufficient flow has been confirmed at the inlet from Zarine Rud River, no flow exists at the gate of irrigation channel located 2km away from inlet due to insufficient hydraulic slope.

Aghchelu Channel (About 2km downstream after the river branches)

Aghchelu Channel (Just behind the river branches)

Figure 2.2.8 Aghchelu Channel (No. 8 in Figure 2.2.1)

Conflicts on daily operation between upstream and downstream are serious in these channels. In the future, the planned construction of pumping stations is expected to help solve these conflicts.

According to the RWC, approximately 500 pumps have been illegally installed between Bukan Dam and Noruzlu Diversion Dam aside from these six main irrigation channels. In addition, about 1,000 wells have been excavated along the river to intake from shallow underground water and 670 of which are illegal.

(7) Noruzlu Diversion Dam

Noruzlu Diversion Dam (No. 9 in Figure 2.2.1), the largest diversion weir in Urmia Lake Basin, has been designed and constructed by an Austrian company. Width of the dam, which supplies irrigation water to downstream and drinking water to Tabriz from the right bank waterway, is 330m.

Water allocation of Noruzlu Dam is governed by discharged water from the Bukan Dam which is upstream of Noruzlu Dam. The allocation includes irrigation water and drinking water to Tabriz City. Minimum release of 5m^3/s is always secured at the downstream of the weir, but it is not clear whether the river flow reaches Urmia Lake.

Operation schedule of Noruzlu Diversion Dam is linked with Bukan Dam. Peak flow discharge of 40m^3/s from Bukan Dam is released from July to August in the irrigation period (from March to September). During the non-irrigation period, both the drinking water to Tabriz and the water for Urmia Lake conservation is released to the downstream.

Weir Body of Dam

Overflow from weir (a view from the right bank)

Overflow from weir
(a view from the left bank)

Accessway inside weir body

Figure 2.2.9 Noruzlu Diversion Dam

(8) Illegal Intake of Noruzlu Diversion Dam Right Bank Waterway (for Drinking Water to Tabriz)

There are some illegal pumps installed along the waterways which intake water to the pipeline for drinking water supply to Tabriz.

According to the ULRP, although the installed pumps are illegal, the local government has encouraged water intake both from rivers and waterways because it was thought that plenty of water existed in the river in the past.

Installation condition of underwater pump for intake

Operation condition of underwater pump for intake

Figure 2.2.10 Illegal Intake Pumps

(9) Facilities Located Downstream of Noruzlu Diversion Dam

(a) Nezami Abad Hydrological Station (No. 11 in Figure 2.2.1)

Nezami Abad Hydrological Station which conducts online monitoring is located at the lowest point of the Zarine Rud River.

Nezami Abad Hydrological Station

Figure 2.2.11 Facilities Downstream of Zarine Rud River

(b) Connecting Waterway between Zarine Rud and Simine Rud

There is a connecting waterway (14m^3/s) from Zarine Rud River (MC channel) to Simine Rud River before water is distributed to the left bank irrigation area of the Noruzlu Diversion Dam via LP Channel (No. 12 in Figure 2.2.1). Purposes of this waterway are irrigation water and sediment removal, and the waterway was expanded by ULRP for the preservation of Urmia Lake by two years.

Irrigated land of 14,000ha exists along the downstream area of Simine Rud River and the whole area adopts the traditional irrigation method. There are pumps up-taking water from Simine Rud River with rights for utilization of water for irrigation subject to a certain fee.

Main Irrigation Channel for Left Noruzlu Irrigation Network

Outlet to Simine Rud River

Figure 2.2.12 Connecting Waterway Between Zarine Rud and Simine Rud

2.2.2 Simine Rud River Basin

(1) Simine Rud Dam

Simine Rud Dam (No. 13 in Figure 2.2.1) is under construction but stopped due to lack of budget, according to RWC. Simine Rud River is regarded as a "Seasonal River" and so river flow has completely dried up.

Simine Rud Dam (Inlet)

Simine Rud Dam (Dam Site)

Figure 2.2.13 Simine Rud Dam (Construction has been Stopped)

(2) Simine Rud Hydrological Station

As of September 2017, the Simine Rud Hydrological Station (No. 14 in Figure 2.2.1) has no facilities. According to WA, the equipment has been stolen and this station is not currently in use. Dashabad is now used as alternate point.

In summer season, as in the upstream, the downstream of Simine Rud River is completely dry. Currently, there is no dam in the upstream and hence there is no supply from upstream after flood discharge is induced by snowmelt.

Wells exist nearby river with 16m in depth (based on interview with a local farmer) and groundwater depth is 10m. Comparing altitudes with a GPS camera, it is assumed that the groundwater table exists 7-8m below the riverbed. Diameter of pump is three inches. Groundwater is pumped for irrigation twice a week, five hours a day, during the irrigation season.

Simine Rud Hydrological Station

Well installed nearby Simine Rud Hydrological Station

Figure 2.2.14 Simine Rud Hydrological Station

2.2.3 Mahabad River Basin

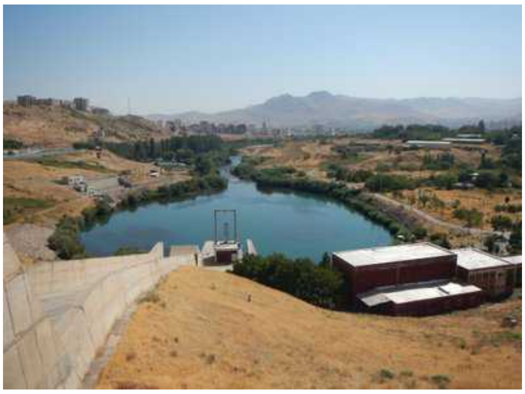
(1) Mahabad Dam

Mahabad Dam (No. 15 in Figure 2.2.1) has been constructed with 44.5 m of flatwater level and 197MCM of dam storage. Its operation commenced in 1969.

Out of 140MCM discharged into the Yusef Kandi Diversion Dam in 2017, 95MCM (88MCM as of August) was utilized for agriculture and 16MCM (total 36MCM: reserved for the following year) for drinking. Discharge for environmental requirement calculated by the DOE is under examination. Originally required agricultural demand was 135MCM (18,200ha of irrigated area), but it was decreased to 95MCM (potential irrigated Area 12,000ha) in the regulation of ULRP. There was a complaint from the farmers.

Inflow discharge into the dam is predicted based on the precipitation from November to February of the previous year. One (1) m^3/s of minimum discharge is secured between October and March, which consists of drinking, industrial and evaporation. If requested from the DOE for environmental sustainability discharge for Urmia Lake, additional discharge is added to it.

Mahabad Dam (Dam Lake)



Mahabad Dam (Downstream of Weir)

Figure 2.2.15 Mahabad Dam

(2) Yusef Kandi Diversion Dam

Yusef Kandy Diversion Dam (No. 16 in Figure 2.2.1) has been planned to intake 45MCM to irrigated fields at the left bank (5,800ha) and 50MCM to those at the right bank (6,200ha). Inflow to the dam was 95MCM in 2017. Agricultural water and irrigated area have been decreased from 140MCM as planned; 146.5 MCM (17,700ha) before 2013, 139MCM in 2013, 113MCM in 2014, 106MCM in 2015 and 95MCM (12,000ha) in 2016, due to the policy on reduction of agricultural water by 8% per year (up to 40%) since 2013. According to the RWC, farmers show objection to this policy.

More than 15 years ago, the percentages of agricultural area was 5% for orchards and 95% for farmlands. However, the orchard area has increased to 35%, and farmland has decreased to 65%. Irrigation efficiency is 38%. (Loss of primary and secondary channels is 92%, those of tertiary and quaternary channels is 78-80%, and that at agricultural field is 50%).

As of August 2017, no discharge to downstream of this dam was confirmed, and that all the inflow from upstream was spent for agriculture. Basically, water is supplied to downstream in high-water season and when the DOE requests water supply for the purpose of river restoration.

During irrigation period from April to September, 16m^3/s of discharge is released for 5 days to start the water distribution from the bottom-flow irrigation block. As the water distribution approaches the upstream, it is gradually reduced (12, 10, 6 and 3m^3/s). Drainage to one irrigation block is about 25 to 30 days, and the discharge pattern is almost unchanged for 37 years.

The Water Allocation Plan has been elaborated for each watershed and dam at the upstream based on precipitation and their demands. According to the RWC and ULRP, the planning process is: (1) the

Ministry of Agriculture - Jihad (MOJA) grasps the irrigation area in the command area; (2) MOJA requests the precipitation forecast to IRIMO, calculates the effective rainfall and calculates the necessary flow rate for irrigation; (3) RWC certifies their estimated water demand through WA; and (4) ULRP is supposed to limit the amount of certification and supply (joined from 2013).

Yusef Kandy Diversion Dam

Irrigation Channel Nearby Inlet

Figure 2.2.16 Yusef Kandi Diversion Dam

(3) Mahabad Irrigation Network

In the Mahabad Irrigation Network (No. 17 in Figure 2.2.1), the traditional irrigated area at the upstream has been converted into the modern system (drip and sprinkler with high irrigation efficiency). The drainage channel finally returns to Mahabad River, the main river.

Irrigation channels consist of 1st to 4th channels and are owned and controlled by WA. MOJA can operate tertiary and quaternary channels whose capacities are 200L/s for tertiary and 70L/s for quaternary. Some 25-30ha lie adjacent to quaternary channels and their inlets located at only one side, so that infiltration and evaporation losses seem large.

In the irrigation plan, one crop type is planted at one tertiary channel, but in fact 15 types are planted in some plots. This complicated planting causes complicated water distribution.

Mahabad Irrigation Network

Mahabad Irrigation Network

Figure 2.2.17 Mahabad Irrigation Network

2.2.4 Gadar Chay River Basin

On Gadar Chay River, a flood occurred in winter of 2016 causing casualties. The peak flow rate at that time was 300 m^3/s upstream of Naqade. In Gadar Chay River, according to the ULRP staff, sedimentation appeared, but it did not become a serious issue.

Main Channel of Gadar Chay River

Checkdam

Figure 2.2.18 Main River of Gadar Chay and its Check Dam

(1) Chapar Abad Dam (Under Construction)

As of August 2017, Chapar Abad Dam (No. 18 in Figure 2.2.1), whose storage capacity is 46MCM, was under construction with expected completion in March 2018, Although this dam was planned with 127MCM of storage capacity in the last survey, dam height was lowered because of the policy on 8% reduction (up to 40%) in 2013. In the context that pipes with ø50 cm × 2 were installed as the temporary drainage channel to downstream whose water level was at half of these pipes, current discharge (regarded as base flow) seems to be less than 1m^3/s.

A transboundary diversion channel, Jaldian Channel (16m^3/s of discharge capacity) is currently under construction to convey 88MCM of water annually from Silve Dam (Lavin Chay) located at the west side of Urmia Lake Basin.

Planned water allocation are 12.5% for drinking, 4.5% for environment, 8% for lake evaporation and the remaining 75%, for release and for conservation of Urmia Lake, respectively.

Chapar Abad Dam (Under Construction)

Jaldian Channel (Under Construction)

Figure 2.2.19 Chapar Abad Dam and Transboundary Channel

(2) Naqade and Bahramlu Hydrological Stations

Naqade Hydrological Station (No. 19 in Figure 2.2.1) with gauge and water level recorder is installed in Naqade City. Equipment for discharge observation is also installed and discharge measurement is carried out. The HQ rating curve is calibrated once a month, according to the RWC.

Bahramlu Hydrological Station (No. 20 in Figure 2.2.1) is a candidate as calibration point for the hydrological cycle model. In the survey, it was found that the location of this hydrological station provided by IWRM Co. is different from the actual situation and so it was corrected based on handy GPS.

Naqade Hydrological Station

Bahramlu Hydrological Station

Figure 2.2.20 Hydrological Stations on Gadar Chay

(3) Hasanlu Dam

Hasanlu Dam (No. 21 in Figure 2.2.1) with 94MCM of storage capacity has the purpose of water use, of which 95% is for agriculture, 2-3% for industrial use, and the remaining for tourism and environment. Though the amount of agricultural water in 2017 decreased to 65MCM due to the agricultural water reduction policy, the irrigated area has not changed at the range of 5300 ± 40ha per year. Water source of the dam is the Gadar Chay, 12 km away. Gates are closed when the water reservoir reaches 94MCM.

Along the dam lake, there are three primary pumping stations and, currently, two of them (3.2 m^3/s, 1.9 m^3/s of pumping capacity) are in operation. The remaining one (3.5 m^3/s) was built, but was not operated due to the agricultural water reduction policy. There are also 32 secondary pumping stations, according to the RWC.

Figure 2.2.21 Hasanlu Dam

2.2.5 Discussion with Relevant Organizations

The Survey Team visited Tabriz University, Urmia University, and IRIMO to discuss and exchange opinions on the Project outline and approaches.

(1) Visit to Tabriz University

The Survey Team explained the outline of the Survey, hydrological cycle model and the methodology of evapotranspiration estimation. Opinion exchange was conducted between the Survey Team and the researchers of remote sensing, meteorology and agriculture in Tabriz University. There were a number of participants from Tabriz University and the ULRP regional office.

Regarding the hydrological cycle model, calibration period was discussed and the provision of hydrological data was requested from the Survey Team.

As for the estimation of evapotranspiration, there were various questions on the METRIC (Mapping Evapotranspiration at High Resolution with Internalized Calibration) method since there were a number of participants involved in remote sensing technology for evapotranspiration estimation.

Figure 2.2.22 Meeting in Tabriz University

(2) Visit to Urmia University

The Survey Team explained the outline of the Survey, the hydrological cycle model and the methodology of evapotranspiration estimation. Opinion exchange was conducted between the Survey Team and the researchers of remote sensing, meteorology and hydrology in Urmia University. There were a number of participants from Urmia University and the regional office.

Regarding the evapotranspiration estimation, calculation procedure and accuracy of the evapotranspiration estimation in the METRIC method were discussed, and it was agreed the method is applied in the Survey.

Figure 2.2.23 Meeting in Urmia University

(3) Visit to the IRIMO Weather Station

The Survey Team visited IRIMO Meteorological Station in Tabriz to confirm the observation condition. The equipment for observation is properly operated.

Pan Evaporation Gauge

Anemometer (2m and10m)

Sunshine Hour Observation Instrument

Rain Gauge (Manual)

Rain Gauge (Online)

Radiometer (Lower Part is Reflection Measurement)

Figure 2.2.24 Facilities of IRIMO Tabriz

2.2.6 Other Information

(1) IWRM Principle among Relevant Provinces

In 2008, an agreement on IWRM (IWRM Principle) was made between relevant provinces: Kurdistan, East and West Azerbaijan. In the agreement, out of 6.8BCM of annual available water, 3.1BCM is utilized for the conservation of Urmia Lake (60% from West Azerbaijan, 8.7% from East Azerbaijan and 30.9% from Kurdistan), and the 3.7BCM remaining is used for own purposes of provinces (2.8BCM for West Azerbaijan, 1.1BCM for East Azerbaijan and 0.6BCM for Kurdistan). This distribution amount and rate were determined based on population, available water, RGDP, and agricultural area.

2.3 Western Area of the Basin

The locations of field investigation and interview in the southern area are as indicated in Figure 2.3.1.The numbers in the figure indicate site visited areas and are referred to descriptions in the subsections of 2.3. The schematic diagram of western river system is shown in Figure 2.3.2 with major hydrological observation stations and river structures.

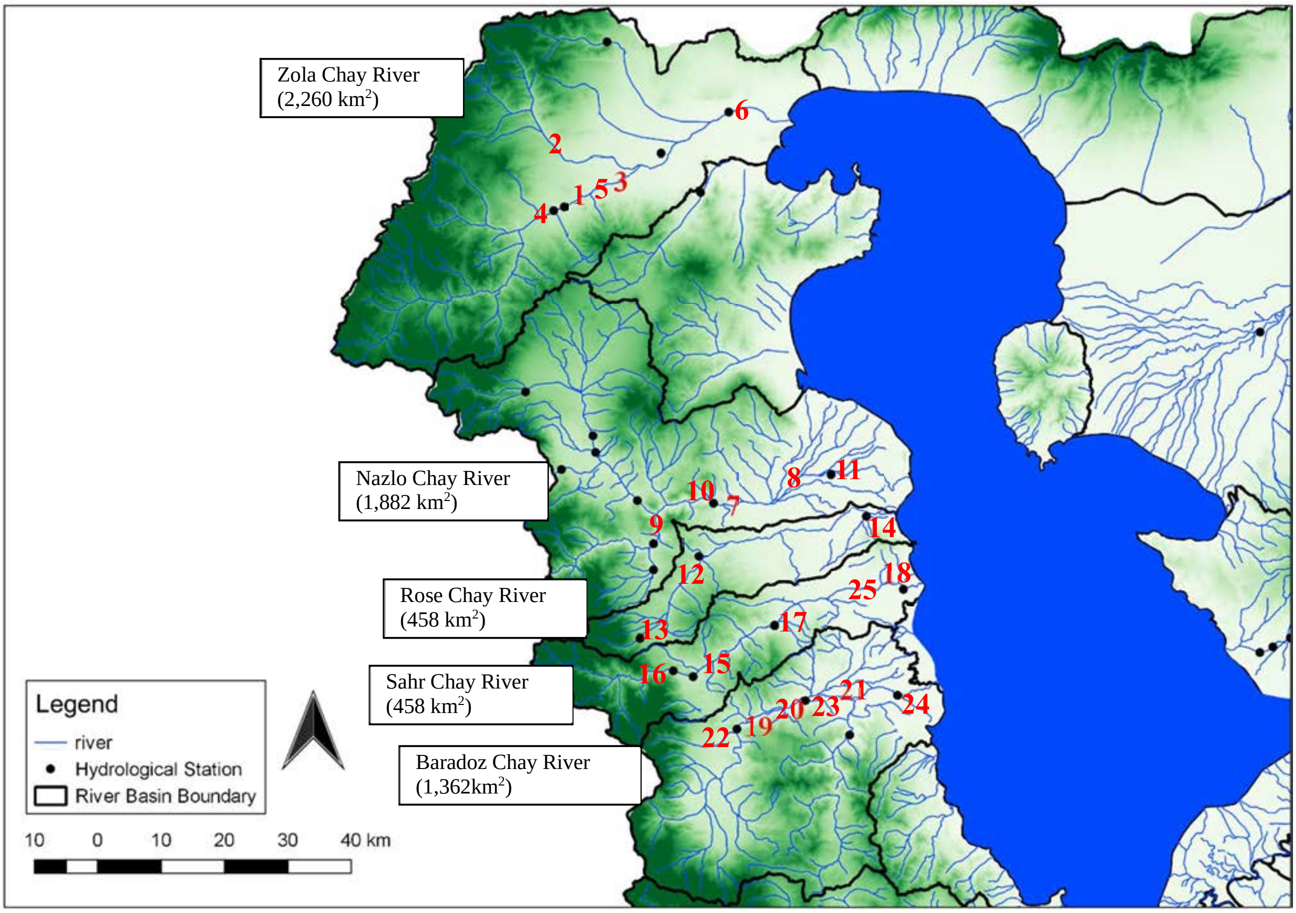


Figure 2.3.1 Main Places Visited for Field Investigation (Western Area)

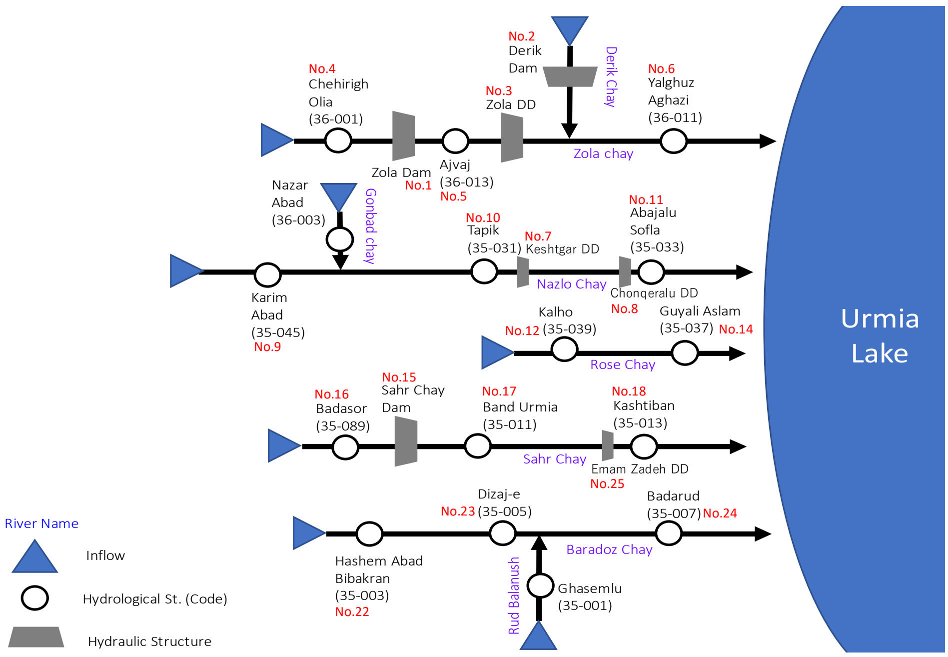


Figure 2.3.2 Main Hydrological Stations and Hydraulic Structure for Western Part

2.3.1 Zola Chay River Basin

(1) Key Hydraulic Structures along Zola Chay River

(a) Zola Dam

Zola Dam (No. 1 in Figure 2.3.1) is the largest water jar in Zola Chay River Basin which has 72MCM of storage capacity and 162MCM of designed inflow from upstream. According to WA staff, actual precipitation is less than the designed one based on observation record. WA is subject to change water allocation for downstream.

Most of the water storage in Zola Chay Dam is utilized for agriculture (56MCM), 10MCM for drinking water in Salmas City and 2MCM for industry. Besides, 30MCM of water is secured for environment, which is released and reaches the Urmia Lake during winter season. However, in fact, due to the change in precipitation trend, less water has been released (e.g. 17MCM in 2018).

No. 1 Dam Lake

No. 1 Release of Water from Gate

Figure 2.3.3 Zola Dam (No. 1 in Figure 2.3.1)

(b) Derik Dam

Derik Dam (No. 2 in Figure 2.3.1) is constructed along the branch of Zola Chay River, Derik Chay River. Designed storage capacity is 22MCM only for 4,500ha of irrigated area. However, at this moment, uninstallation of radial gate at spillway has decreased actual capacity by 10.5MCM, which satisfies 2,000ha of irrigated area. Although two pipelines [left bank: dia. 1,400mm (3.15 m^3/s), right bank: dia. 700mm (1.88m^3/s)] will be installed in future, at this moment, only one at left bank is installed and working. Currently, 0.97m^3/s of outflow is released from dam for agricultural water use.

In spite of little precipitation (250mm), approx. 0.4m^3/s of inflow has been generated, which sometimes can be zero due to water withdrawal at upstream. Some 300mm of precipitation took place last year.

No. 2 Dam Lake

Figure 2.3.4 Derik Dam (No. 2 in Figure 2.3.1)

(c) Diversion Dam along Zola Chay River

Zola Chay River Basin has approximately 8,400 ha of irrigated area. Zola Diversion Dam (No. 3 in Figure 2.3.1) is constructed between Zola Chay Dam and the confluence with Derik Chay River, which controls the water released from Zola Dam to supply irrigation water to both sides along Zola Chay River.

Zola Irrigation Scheme consists of Zola River Basin with 6,348ha and Darik River Basin (branch of Zola River) with 2,000ha, respectively. Main crop is apple, and wheat is cropped to some extent area. Total agricultural water demand in this area is approximately 132MCM, consisting of 100MCM for river water and 32MCM for groundwater.

During most of the irrigation season, the flood gate is closed, and no water goes down to the downstream, All water is utilized for irrigation and no water goes to the lake. Even if the water can go down to downstream, e.g., Yalghuz Aghazi Hydrological Station, according to WA staff, no water would show up on the river because of infiltration to riverbed. For the irrigation area downstream, groundwater is the only the source of irrigation extracted by pump.

Flood Gate

Zola Diversion Dam

Left Channel

Figure 2.3.5 Zola Diversion Dam (No. 3 in Figure 2.3.1)

(2) Key Hydrological Stations along Zola Chay River

(a) Chehirigh Olia (36-001), Ajvaj (36-013) and Yalghuz Aghazi (36-011)

The Chehirigh Olia Hydrological Station (No. 4 in Figure 2.3.1) is located at the most upstream of Zola Chay River. Even during the middle of summer season, there appears to be abundant base flow (1-2m^3/s, visually). According to WA, 185 m^3/s of peak discharge was recorded.

The Ajvaj Hydrological Station (No. 5 in Figure 2.3.1) is located at the closest downstream of Zola Dam, which was installed 45 years ago. There is no automatic observation system but only staff gauge.

The Yalghuz Aghazi Hydrological Station (No. 6 in Figure 2.3.1) is located at the most downstream of Zola Chay River. Water comes from upstream in quite a limited time, only for 10 days between April and May. The water during this period can reach to the Urmia Lake. In most of the period, as described above, water has diminished without reaching this station due to infiltration. Aside from less water from upstream, severe sedimentation on riverbed could be a reason for the diminishment of water, which also causes inaccuracy of water level observation. In near future, this station is to be restored with riverbed works.

No. 4 Chehirigh Olia Hydrological Station

No. 5 Ajvaj Hydrological Station

No. 6 Yalghuz Aghazi Hydrological Station

Figure 2.3.6 Main Hydrological Stations Located on Zola Chay River (No. 4, No. 5 and No. 6 in Figure 2.3.1)

2.3.2 Nazlo Chay River Basin

(1) Key Hydraulic Structures along Nazlo Chay River

(a) Keshtgar Diversion Dam

Keshtgar Diversion Dam (No. 7 in Figure 2.3.1) is the primary hydraulic structure to control the water in the Nazlo Chay River, which does not have a dam. During irrigation season, at this diversion dam, most of the water is allocated to several irrigation schemes and the remaining few amount of water is occasionally released to downstream through the flood gate. There are four main irrigation schemes, Balo (1,200ha, 12MCM) and Havnag (1,715ha) irrigation schemes along the right side of Nazlo Chay

River, and Dalmag (717ha, 8MCM) and Nozlu (1,252ha) along the left side. Balo and Dalmag irrigation schemes utilize the water channel designated as "Permanent" in which the water use is allowed throughout the irrigation season, and Havnag and Nozlu as "Seasonal" in which the water use is allowed in a limited time even during the irrigation season. As for the seasonal channel, groundwater is utilized for irrigation as supplement.

Currently, less water reaches this diversion dam due to decrement of river flow from upstream (Barduk River). According to WA, the upstream of Nazlo Chay River Basin is partly within the administrative boundary of Turkey and a certain amount of river water is extracted there.

Flood Gate

Main Channel for Dalmag Irrigation Sheme

Main Channel for Balo Irrigation Sheme

Figure 2.3.7 Keshtgar Diversion Dam (No. 7 in Figure 2.3.1)

(b) Chonqeralu Diversion Dam

Chonqeralu Diversion Dam (No. 8 in Figure 2.3.1) is located at approximately 15 km downstream from Keshtgar Diversion Dam. Currently, only during the period when water comes from upstream in spring, this diversion dam supplements the water supply to 3,000 ha of the irrigated area along the left bank. In this irrigated area, groundwater is utilized as the main source. According to the WA, this diversion dam was planned to be constructed to make water available even during the irrigation season. However, less water comes to this diversion dam due to the decrement of inflow from the Barduk River.

Although the main crop around the Keshtgar Diversion Dam is dominantly orchard which contains abundant water, percentage of orchard and other crops around Chonqeralu Diversion Dam (e.g. wheat, sugar beet, potato) is 50%, respectively.

No. 8 Chonqeralu Diversion Dam

Figure 2.3.8 Chonqeralu Diversion Dam (No. 8 in Figure 2.3.1)

(2) Key Hydrological Stations along Nazlo Chay River

(a) Karim Abad (35-045), Tapik (35-031) and Abajalu Sofla (35-033)

The Karim Abad Hydrological Station (No. 9 in Figure 2.3.1) with 506km^2 of catchment area, is located at the most upstream of Zola Chay River. This hydrological station was established in 1980. Maximum river discharge on record is 122m^3/s. Because of no hydraulic structure for water use and less extraction of surface water upstream, abundant water can be kept throughout the year. According to WA, although 5m^3/s of river flow exists on average, as of August 2018, it appeared as 2-3m^3/s. In the modeling, at this moment, the basin boundary is delineated with the mountainous area as the national border between Iran and Turkey, which causes underestimation of catchment area. In the modeling, this should be considered especially for the western part of the lake basin, because the actual river basin includes the mountainous area of the Turkish side.

At the Tapik Hydrological Station (No. 10 in Figure 2.3.1), discharge seems the same as that at Karim Abad, because of less inflow from the branch of Nazlo Chay River (Barduk River). According to the WA, inflow from Baduk River has decreased by one-fourth due to high water use in the catchment area partly located in Turkey.

The Abajalu Sofla Hydrological Station (No. 11 in Figure 2.3.1) is located at the most downstream of Nazlo Chay River. According to the WA, the equipment is periodically maintained. However, there appears to be conveyance loss due to sedimentation and vegetation in the channel, which can be mentioned for every station installed downstream of sub-river basins of the Urmia Lake Basin.

No. 9 Karim Abad Hydrological Station

No. 10 Tapik Hydrological Station

No. 11 Abajalu Sofla Hydrological Station

Figure 2.3.9 Hydrological Stations Located along Nazlo Chay River (No. 9, No. 10 and No. 11 in Figure 2.3.1)

2.3.3 Rose Chay River Basin

(1) Key Hydrological Stations along Rose Chay River

(a) Kalho (35-039) and Guyali Aslam (35-037)

The Kalho Hydrological Station (No. 12 in Figure 2.3.1) is located upstream of the Rose Chay River. Currently, although Rose Chay River is adjacent to Sahar Chay River with abundant river flow (e.g. at Badasor Hydrological Station), there is no water although river-bed water may exist. This indicates different distribution of aquifer with sub-river basins, which should be considered in the modeling. Water level is observed by float-type water level gauge and manually recorded twice a day. During flood season (March-April), overflow sometimes occur with approx. $20m^3/s$ from the rivers.

Upstream of Kalho, in Sirvara (No. 13 in Figure 2.3.1), springs of drinkable water take place, and it is purchased as packed as mineral water. This indicates productive aquifer is distributed although its distribution is unknown.

The Guvali Aslam Hydrological Station (No. 14 in Figure 2.3.1) is located at the most downstream of Rose Chay River. There is a possibility of conveyance loss due to sedimentation and inaccurate estimation of river discharge due to severe scouring in the channel. Water level is observed by float-type water level gauge. This station has plan to be reconstructed in near future.

No. 12 Kalho Hydrological Station

No. 13 Spring in Sirvara

No. 14 Gulayi Aslam Hydrlorogical Station

Figure 2.3.10 Hydrological Stations and Spring Located along Rose Chay River (No. 12, No. 13 and No. 14 in Figure 2.3.1)

2.3.4 Sahr Chay River Basin

(1) Key Hydraulic Structures along Sahr Chay River

(a) Sahr Chay Dam

Sahr Chay Dam (No. 15 in Figure 2.3.1) was constructed in 2009. This dam has 210MCM of storage volume and 220MCM of annual inflow from upstream which is derived from 330km^2 of catchment area and approximately 500mm of annual precipitation. According to the WA, 0.4 of annual runoff ratio is applied for the estimation of annual inflow.

Due to the difficulty of observing in the mountainous area, meteorological data, especially precipitation data was insufficient. Therefore, the precipitation data for upstream of dam was corrected with regression between precipitation and elevation which was applied for dam planning. The Survey Team requested the WA for information on the regression.

Out of 220MCM of annual inflow, 135MCM is utilized for irrigation (12,000ha of irrigated area), 56MCM for drinking in Urmia City, and 12MCM for environmental flow (500 l/s is released for the irrigation season which lasts between April and September), respectively.

No. 15 Dam Lake

Figure 2.3.11 Sahr Chy Dam (No. 15 in Figure 2.3.1)

(b) Diversion Dams along Sahr Chay River

There are 16 diversion dams on the Sahr Chay River. There used to be 7,000ha of irrigated area along the river, but due to change in flow regime control by dams and deterioration of facilities by sedimentation and lack of maintenance, 3,000ha of the irrigated area has resorted to groundwater as water source. Basically, water withdrawal from river for irrigation is banned starting in October, and all water goes to the lake although illegal water uptake by pumps remained.

Figure 2.3.12 Emam Zadeh Diverion Dam (No. 25 in Figure 2.3.1)

(2) Key Hydrological Stations along Sahr Chay River

(a) Badasor (35-089), Band Urmia (35-011) and Kashtiban (35-013)

The Badasor Hydrological Station (No. 16 in Figure 2.3.1) is located at the most upstream of Sahr Chay River. According to ULRP, due to the construction of Sahr Chay Dam, the hydrological station named “Mir abad (35-002)” was submerged under the reservoir. After construction of the dam, the hydrological station named “Badasor (35-089)” was newly installed upstream of Sahr Chay Dam in 2004. Currently, approximately 1-2m^3/s of minimum river flow takes place. Maximum flow is approximately 30-40 m^3/s. According to the WA, Sahar Chay River is categorized as a “permanent river” with river flow throughout the year even in summer season.

At the Band Urmia Hydrological Station (No. 17 in Figure 2.3.1), as of August 2018, 10-15m^3/s of discharge is released from Sahr Chay Dam for irrigation at downstream. Water level is observed with float-type water level gauge and auto-logger at 8am and 4pm every day. River cross section is surveyed every six months.

The Kashtiban Hydrological Station (No. 18 in Figure 2.3.1) is located at the most downstream of Sahr Chay River. Due to severe sedimentation, the station will be transferred 200m downstream in October 2020

There are three main diversion channels between Sahr Chay Dam and this station. Similar to the other stations, water level is observed by float-type water level gauge and manually recorded twice a day. Due to limitation of budget, maintenance of river (e.g. excavation) has not been conducted for a long time, which is the reason for transfer of the hydrological station.

No. 16 Badasor Hydrological Station

No. 17 Band Urmia Hydrological Station

No. 18(1) Kashtiban Hydrological Station

No. 18(2) New Construction Site of Kashtiban Hydro Station.

Figure 2.3.13 Hydrological Stations Located along Safr Chay River (No. 16, No. 17 and No. 18 in Figure 2.3.1)

2.3.5 Baradoz Chay River Basin

(1) Key Hydraulic Structures along Baradoz Chay River

(a) Irrigation System along Baradoz Chay River

Six diversion dams have been constructed along Baradoz Chay River with approximately 8,200ha of irrigated area. Figure 2.3.14 show schematic diagrams of irrigation schemes along Baradoz Chay River. Out of the irrigated area, approximately 3,000ha have water-rights, which permit farmers to withdraw water from the river periodically.

Basically, the gates are controlled with a certain pattern during irrigation season (repeatedly opened for 15 days and closed for 3 days). The remaining irrigation schemes without water-right withdraw water from the river only when the water comes from upstream. In these areas, water shortage constantly takes place and the farmers utilize groundwater for agriculture as supplement.

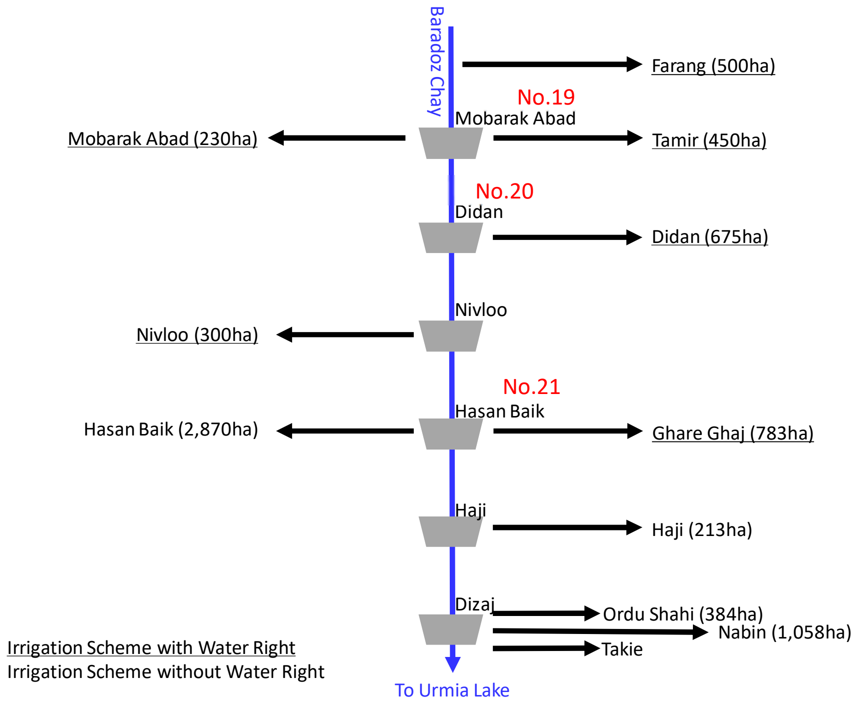


Figure 2.3.14 Schematic Diagram of Irrigation System along Baradoz Chay River

(b) Key Diversion Dams along Baradoz Chay River

Mobarak Abad Diversion Dam (No. 19 in Figure 2.3.1) is provided with two channels, the Mobarakan Channel on the right (230ha, 230L/s) and the Tamir Channel on the left (450ha, 450L/s). Irrigation type in both are traditional irrigation (flood irrigation), and the main crop is apple.

Both irrigated fields have water-rights. It seems that they do not have specific water withdrawal amounts, but the right to open the gates to withdraw water for a certain period. In the irrigation season (June to August), the gates of both channels are controlled repeatedly, i.e., 15 days for opening and three days for closing.

In the case of Mobarakabad irrigated area, it is assumed that 230 L/s of water (approx. 4MCM) is taken for three months. By dividing this amount with the irrigated area (230ha), 1700mm plus 400mm of precipitation depth is given to the fields. Considering the water requirement for apples (approx. 1,500mm) and the irrigation efficiency of flood irrigation (about 60%), this value seems adequate.

Didan Diversion Dam (No. 20 in Figure 2.3.1) has been newly constructed for irrigation water supply to the Didan Irrigation Scheme. Basically, the same concept of gate control as the Mubarak Abad Diversion Dam is applied.

Hasan Baik Diversion Dam (No. 21 in Figure 2.3.1) is located lowest with water-right for the Ghareghaj irrigation scheme. At this moment (basically during irrigation season), all river water goes to the irrigation channel and not to the downstream of Baradoz Chay River. Discharge in the irrigation channel appears approximately 0.1m^3/s, which does not satisfy the irrigation water demand, according to the WA staff. For supplement, groundwater ,including illegal intake, is used for irrigation.

No. 19 Mobarak Abad Diversion Dam

No. 20 Didan Diversion Dam

No. 21 Hasan Baik Diversion Dam

Figure 2.3.15 Diversion Dams along Baradoz Chay River
(No. 19, No. 20 and No. 21 in Figure 2.3.1)

(2) Key Hydrological Stations along Baradoz Chay River

(a) Hashem Abad Bibakran (35-003), Dizaj-e (35-005) and Badarud (35-007)

The Hashem Abad Bibakran Hydrological Station (No. 22 in Figure 2.3.1) is located at the most upstream of the Baradoz Chay River. This river is categorized as a “permanent river” in a mountainous area west of the Urmia Lake Basin with streamflow throughout the year.

It appears that $1m^3/s$ of base flow can be kept during the summer season. According to the WA, in the area surrounding of this station, 1m deep of snow is observed during the winter season. Although snow depth in the mountainous area is unknown, the depth could be high.

The Dizaj-e Hydrological Station (No. 23 in Figure 2.3.1) is located downstream of Didan Diversion Dam. Due to water withdrawal upstream, the velocity of approx. 0.5m/s appears slower than that at Bibrakan Hydrological Station. Discharge seems to be about 0.5m^3/s.

In the flood season, water depth reaches 2m. Considering river width (20m) and flow velocity (2m/s), average discharge is roughly 80m^3/s. In 2017, according to the WA, flood with 25-year return period (250m^3/s) was observed, which caused overflow to the surrounding area and breakdown of embankment.

The Badarud Hydrological Station (No. 24 in Figure 2.3.1) is located at the most downstream of Baradoz Chay River. No water comes during irrigation season due to water uptake at upstream and river stream appears from October to May. Sedimentation obstructs observation especially of low water level. In case difficulty in observation of low water, staff gauge is used twice a day observation for normal and hourly for flood events.

No. 22 Hashem Abad Bibrakran Hydrological Station

No. 23 Dizaj-e Hydrological Station

No. 24 Badarud Hydrological Station

Figure 2.3.16 Hydrological Stations Located along Baradoz Chay River

(b) Workshop

A workshop organized by ULRP was held at Sharif University on August 2018 and a lecture was given by a team member of the Survey Team. Approximately 50 to 60 people including Sharif University students and faculty members participated. In the lecture, "(1) Outline of estimation of evapotranspiration using satellite images" and "(2) Calculation method" were explained. After the workshop, the outline was posted on the ULRP website.

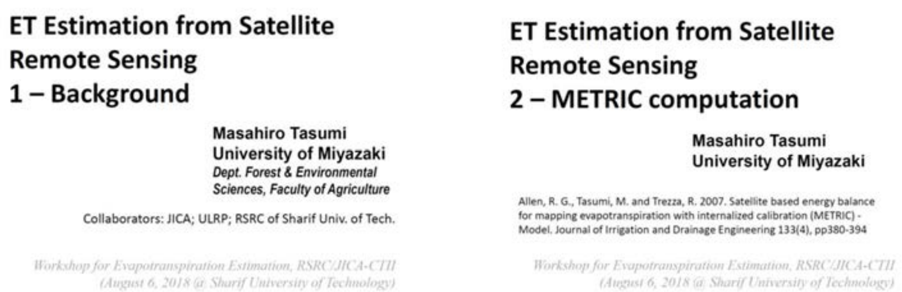


Figure 2.3.17 Document Explanation

Figure 2.3.18 ULRP Website

Figure 2.3.19 Venue of Workshop

2.4 Eastern Area of the Basin

The Survey Team had conducted field investigations to confirm the status of water cycle modeling of Urmia Lake Basin. Since modeling in the eastern part was scheduled during the 3rd Year of the Survey, the eastern part of Urmia Lake Basin was targeted mainly in the investigation. During the field investigation, interview surveys, were also conducted with the accompanying staff of RWC East Azerbaijan. The visited sites are as indicated in Figure 2.4.1 and Figure 2.4.3, respectively, and the overview of investigations are described as follows.

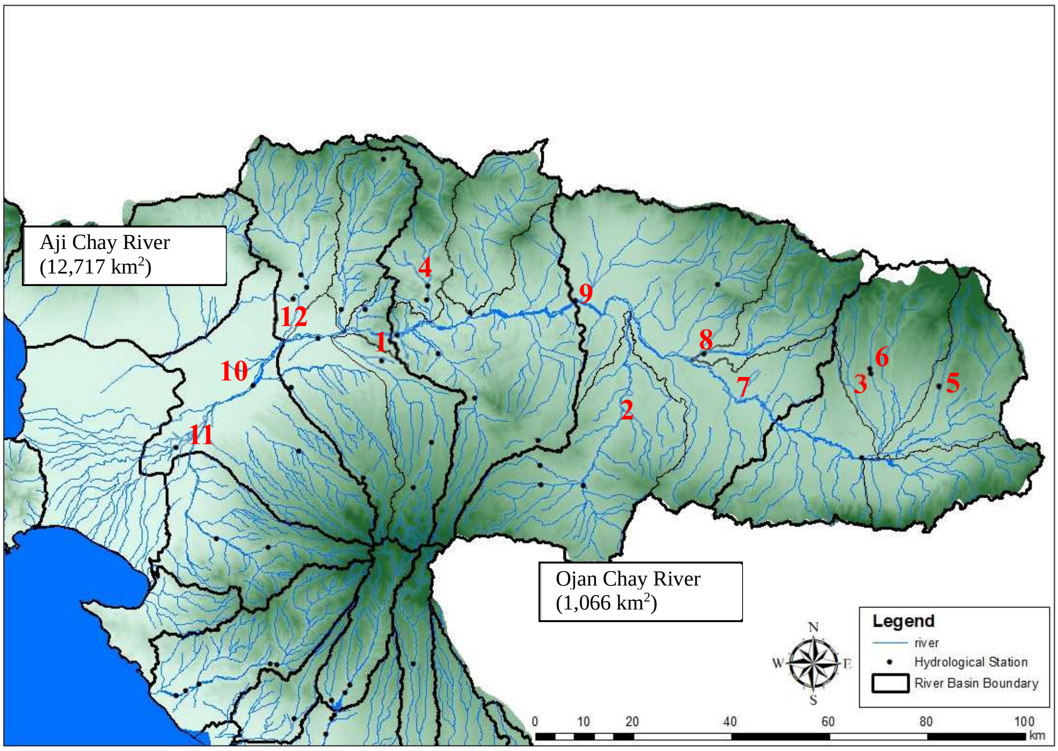
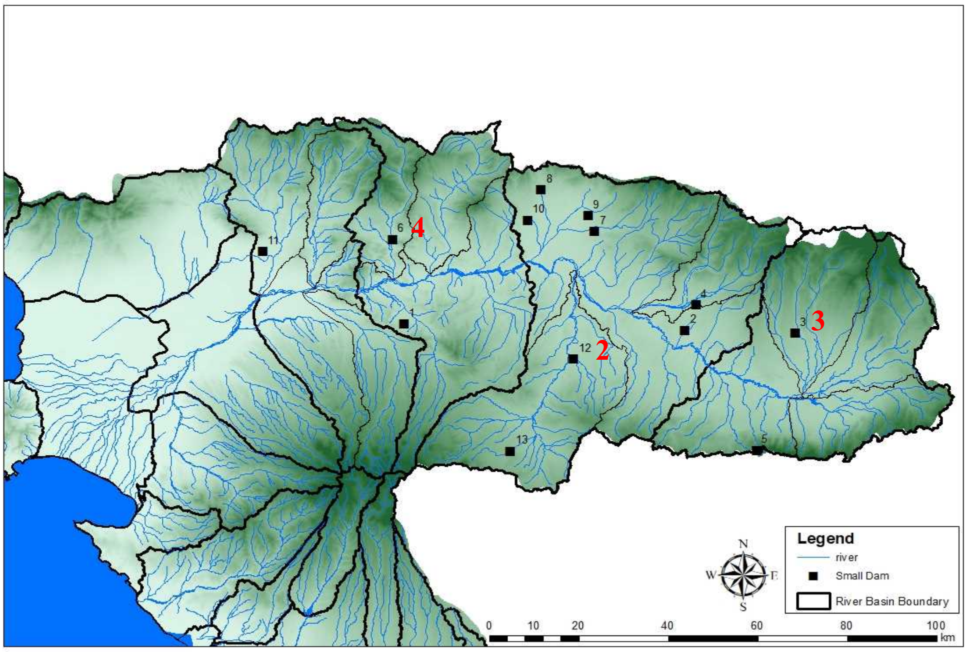


Figure 2.4.1 Main Places Visited for Field Investigation in the Eastern Area



*Numbers refer to those indicated in Table 2.4.1, Red letters indicate dams confirmed by the Survey Team.

Figure 2.4.2 Location of Small Dams in Aji Chay River Basin

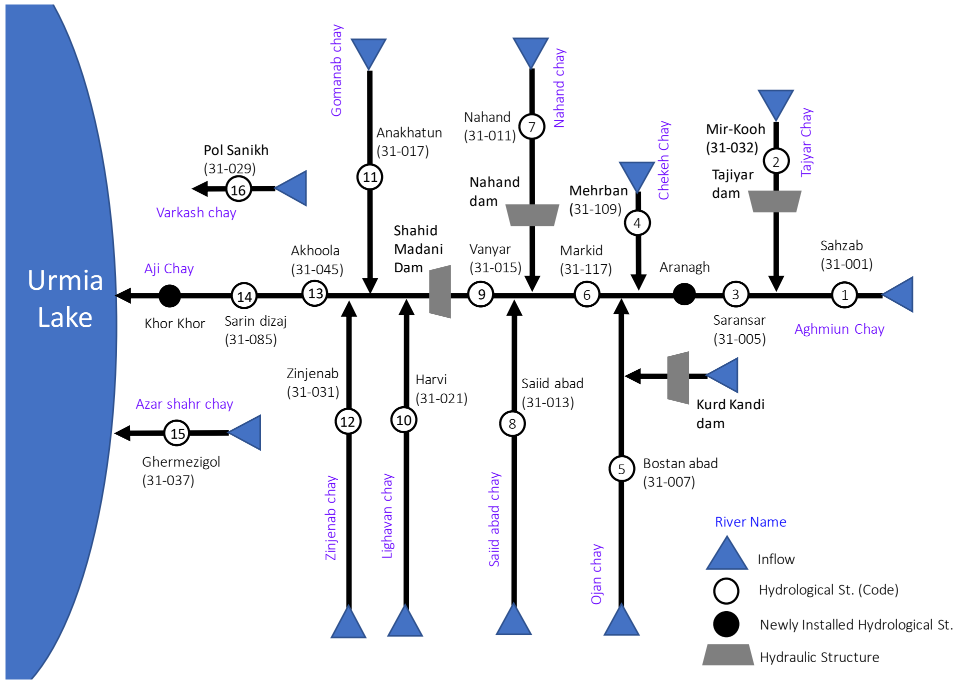


Figure 2.4.3 Main Hydrological Stations and Hydraulic Structure for Eastern Part

2.4.1 Key Hydraulic Structures along Aji Chay River

(1) Shahid Madani Dam

Shahid Madani Dam, commonly named as Vanyar Dam (No. 1 in Figure 2.4.1), which has 280 MCM of storage capacity, is the largest water jar in Aji Chay River Basin. Construction of the dam has already been completed. However, since the route of drinking water pipeline from Nahand Dam to Tabriz is located on this dam, the operation of the dam cannot be commenced until the alignment of the pipeline and the road are relocated.

This dam was constructed for the purpose of water supply mainly for agriculture. Since brackish water comes from some branches to this dam, ULRP decided to release water stored during the non-irrigation period (from autumn to winter) for Urmia Lake restoration. During summer season, since farmers downstream need water for irrigation, water is not stored in dam reservoir, but released downstream for withdrawal.


Figure 2.4.4 Shahid Madani Dam (No. 1 in Figure 2.4.1)

(2) Small Dams (Reservoirs) for Water Use

Aside from the Nahand Dam for domestic water supply to Tabriz, 13 small dams (reservoirs) have been constructed for the main purpose of agricultural water use.

(a) Kordikandi Dam (No. 2 in Figure 2.4.1 and No. 12 in Figure 2.4.2)

Located in Sarab, this dam (reservoir) was built for the water source of 600ha of irrigated area in two villages (5.6MCM/year). Main crops of the area are barley, wheat, fodder crop and potato. Irrigation season is between end of May and end of September, in which water is allocated in every 7 days mainly for potato. Operation of outlet (bulb gate with φ600 mm) is based on farmer's and Water Authority's experience.

There is only one inflow channel to the dam with $0.4m^3/s$ of water diverted from Ojan Chay. Maximum is $1m^3/s$. Ojan Chay is a seasonal river with $25m^3/s$ maximum and 0.5-1 m^3/s average flows. Wheat is grown in rainfed area, with water fed from groundwater when necessary. Wheat seeding is in October and cultivation is at the end of August. (Currently, growth is not confirmed.)

(b) Tajiyar Dam (No.3 in Figure 2.4.1 and No.3 in Figure 2.4.2)

Located in Sarab, this dam (reservoir) was constructed for water source of 340ha of irrigated area in two villages (4.3MCM/year). Currently, this dam is fully-stored.

Main crops of are wheat, alfalfa and canola. Pressurized irrigation (tape irrigation) is introduced in cultivated area. Irrigation schedule is the same as that of Kurdikandi Dam. Tajiyar Chay is a seasonal river.

(c) Nahand Dam (No. 4 in Figure 2.4.1 and No.6 in Figure 2.4.2)

Nahan Dam provides 26MCM/year only for drinking water. Constructed in 1996 and provided with φ800mm pipes with water allocation of $0.8m^3/s$ from Tabriz, no water shortage takes place.

Table 2.4.1 Summary of Small Dams in Aji Chay River Basin

No.	Name	UTM_x (m)	UTM_y (m)	Height (m)	Length (m)	Storage Capacity (MCM)	Operation Year	Cultivated Area (ha)
1	Malek Kian	632307	4211829	33	223	8.80	1993	0
2	Ardalan	695135	4210361	12	600	6.57	1985	1,080
3	Tajyar	719674	4209626	34	403	3.50	2003	635
4	Gheisaragh	697640	4216296	21	970	2.80	1990	520
5	Fazel Goli	711054	4182132	14	64	2.13	1985	850
6	Nahand	629724	4231719	35	730	21.57	1996	0
7	Param	674930	4233620	17	420	3.37	1997	825
8	Yengje	663008	4243345	8	230	0.50	1984	100
9	Minagh Khaki	673477	4237334	10	520	0.30	1984	80
10	Khormalou	659875	4236185	4	140	0.33	1984	65
11	Amand	600752	4228837	19	211	2.00	1995	117
12	Kordkandi (Vahdat)	670171	4203609	15	2,500	5.40	2004	614
13	Joghan	655993	4181943	38	180	3.00	2011	362
Total						**60.27**		**5,248**

*Provided by ULRP

Kordikandi Dam (No. 2 in Figure 2.4.1 and No. 12 in Figure 2.4.2)

Tajiyar Dam (No. 3 in Figure 2.4.1 and No. 3 in Figure 2.4.2)

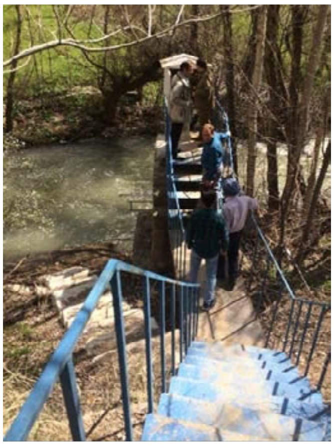
Nahand Dam (No. 4 in Figure 2.4.1 and No. 6 in Figure 2.4.2)

Figure 2.4.5 Small Dams Visited by the Survey Team

2.4.2 Visited Hydrological Stations along in Aji Chay River Basin

(1) Upstream (Sahzab (31-001), Mirkuh Haji (31-032))

Sahzab Hydrological Station (No. 5 in Figure 2.4.1)



Mirkuh Haji Hydrological Station (No. 6 in Figure 2.4.1)

Figure 2.4.6 Hydrological Stations in Upper Aji Chay River Basin

(2) Midstream (Aranagh, Mehrban (31-109) and Markid (31-117))

Aranagh Hydrological Station (No. 7 in Figure 2.4.1)

Mehraban Hydrological Station (No. 8 in Figure 2.4.1)

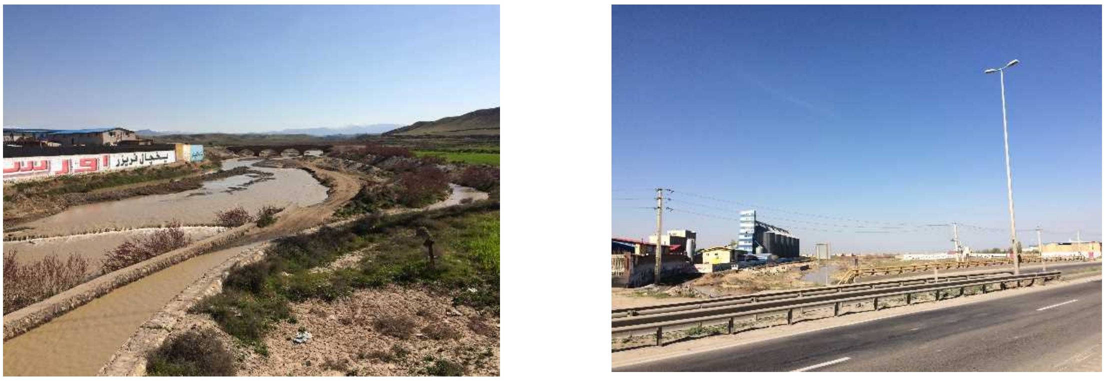
Markid Hydrological Station (No.9 in Figure 2.4.1)

Figure 2.4.7 Hydrological Stations in Middle Aji Chay River Basin

(3) Downstream (Akhola (31-045), Khor Khor and Pol Sanikh (31-029))

Akhola Hydrological Station (No. 10 in Figure 2.4.1)

Khor Khor Hydrological Station (No. 11 in Figure 2.4.1)



Pol Sanikh Hydrological Station (No.12 in Figure 2.4.1)

Figure 2.4.8 Hydrological Stations in Lower Aji Chay River Basin

2.5 Contributions of Field Surveys for the Hydrological Cycle Model

The results of field survey described in Section 2.1 to 2.4 contribute to the establishment of hydrological cycle model. The key points of contribution are explained as follows:

(1) Existence of Large Amount of Unauthorized Water Users

ULRP and the related agencies explained and showed that unauthorized water users are existing in the Basin. Since regional ULRP mentioned in the field survey and the technical steering committee meetings that the unauthorized water amount is several times higher than that of authorized water and the unauthorized intake points are scattered along channels and dam lakes. Although the information of unauthorized water is very limed in terms of intake locations with its quantities and intake patterns, the unauthorized water use amount cannot be ignored for hydrological cycle modeling. Therefore, the Survey Team and ULRP decided to solve this situation through hydrological cycle modeling, e.g. constructing some mechanism in hydrological cycle model and establishing appropriate water intake data based on evapotranspiration estimated from satellite images.

(2) Assuring Conditions of Irrigation Canals

The major irrigation canals can be seen in the downstream of dams and weirs. Although the clear schematic diagrams have not provided to the Survey Team, the Survey Team obtained the information during the field survey and discussed with ULRP and IWRM Co. to correct the information. The information is very important to set major water intake points from the mainstream of rivers in the hydrological cycle model.

(3) Situation of Dam Operation During Simulation Period

ULRP provided the Survey Team with a list of dams with associated information to put dam modules in the hydrological cycle model. The exact conditions such as stating year of operation and operation rules during the simulation period are additionally confirmed in the field survey. The interbasin water transfer from dams to cities in another river basin also confirmed to keep hydrological balance in the whole basin.

(4) Existing Countermeasures

Some of countermeasures proposed in the previous survey already implemented in the basin. During the filed survey, the Survey Team and ULRP visited the site of implemented countermeasures in order to confirm the operating conditions and embed the conditions into the model as existing measures.

(5) Confirmation on Condition of Reafference Hydrological Stations and Agricultural Areas

The Survey Team and ULRP confirmed the situation for almost all discharge gauging stations decided as reference stations for the model calibration on site. The obtained information was effectively used to determine the quality and accuracy of the observed discharge data. Also, local information such as situations of agricultural land and meteorological observation which are contribute to estimation of evapotranspiration was confirmed directly in the field.