MINIMUM FLOWS FOR HYDROPOWER AND DAM PROJECTS

By

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1. INTRODUCTION

During the past century, human control of water resources has changed the course of development worldwide. In the year 2000, almost 47,000 large dams and 800,000 smaller dams existed, as reported by the World Commission on Dams (WCD, 2000); a result of the *hydrological alteration* of over half of the worlds' 292 large rivers. Such hydrological alteration, or change in flow regime, has allowed for the development of massive irrigation systems and subsequent food production, hydropower production and flood control. It has also allowed for ecological degradation, species extinction and human displacement.

In recognition of the growing environmental impacts of dams worldwide, recent attention in the past few decades has been given to addressing these concerns and calling for future dams to be built in a sustainable manner. One measure is to set a continuous minimum base flow from the dam at all times with the hope that integrating these flows into the design and operation of dams may minimize downstream impacts on river morphology and ecology. There is much research currently under way internationally in determining the 'adequate' minimum flow for ecological purposes. Such minimum flows are decided based on many holistically influenced factors, such as meeting crop water requirement, addressing concerns of local Water Users Association, and minimizing severe environmental impacts. The driving force for such studies into minimum flows is the concept of managing dam operations for the benefit of both humans and the environment.

A study on minimum flow was done during the design and construction of the Alborz Dam on Babol River in Iran of which National Engineering Services Pakistan (NESPAK) Pvt. Limited was one of the consultants. The design of the dam stipulated a minimum flow of 1 m^3 / sec to be continuously released from the dam at all times. This minimum flow was set to satisfy crop water requirements, and it was hoped that it would maintain some ecological integrity in the river. While the assessment of the ecological appropriateness of this 1 m^3 / sec flow was not within the scope of the study, NESPAK was tasked to study the impact of the proposed 1 m^3 / sec minimum flow on the depth, discharge and velocity of Babol River, as well as water quality parameter, Dissolved Oxygen (DO) downstream of the Alborz Dam. These parameters are some of the important parameters for sustaining riverine ecosystems.

2. DOWNSTREAM RIVER FLOWS AND DAMS & HYDROPOWER PROJECTS

In order to understand how the required 1 m^3 / sec minimum flow would affect downstream river channel depth, discharge, velocity and DO, it is important to

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understand how the naturally varying flow regime of river plays a role in sustaining ecological integrity in rivers and flood plains. This section therefore describes the natural flow regime of the river in the physical and ecological context followed by a brief description of the hydrologic alteration of such regimes through the construction of dams.

2.1 THE NATURAL FLOW REGIME

The natural flow regime of a river is generally variable and consists of a series of low flows, normal flows, high pulse flows and large flows known as floods. It is mainly important in defining the ecosystems within which biological communities flourish and develop as well as influencing primary and secondary production within the fluvial hydro system (Poff et al, 1997). Physically, a flow regime determines the channel and floodplain morphology, as well as the nature of vertical interactions between the river flow and groundwater. These characteristics of the natural flow regime of a river can be broadly classified as physical and ecological, described in detail below.

2.1.1 Physical : River Channel Morphology

The varying flows of a river are mainly responsible for transporting sediment downstream. During floods, when the flow is large and fast, a large amount of sediment is transported (Wolman and Miller, 1960). Basic river channel variables, such as width and depth vary with the change in flow and amount of sediment supply. Such processes are known as channel aggradation and scouring. When changes in discharge and sediment supply occur, the result is in a new transport capacity of the river. If this capacity is lesser than the sediment supply, then the river bed tends to aggrade. If the transport capacity is greater than the sediment supply, the river bed begins to scour (Clark and Wilcock, 2000). Such scouring and aggrading results in varying channel width and depth, i.e. morphological changes of the river channel. Many river channel features such as river bars and riffle-pool sequences are influenced by significant quantities of sediment transport in a river when the discharges in the river are dominant or ‘bank-full’. These discharges tend to occur frequently and leave the river channel is a state of dynamic equilibrium (Poff et al, 1997).

2.1.2 Ecological Functions

Poff et al (1997) has described stream flow as the ‘master variable’ that controls the distribution of riverine species and the integrity of the riverine ecosystem. As discussed earlier, the variable nature of flow regulates the transportation and size of sediment in the river channel. Sediment movement and the force of moving water also provide organic resources like algae and woody debris to the biological communities in a river channel which allow riverine habitat to flourish. The nature of the flows occurring in a river channels also influencesthe composition and abundance of species. High flows tend to release finer sediment from spaces that provide productive habitats to fish species while floods tend to transport woody debris to create other rich habitats for species (Poff et al, 1997). The table below (Table 2.1) summarizes the various ecological roles of the various types of flow.

Table-2.1: The Influence of Flow Levels on Ecology (Richter et al, 2006)

Flow Component	Ecological Roles
Low Flows	These flows (normal low levels) allow aquatic habitats for organisms, maintain normal levels of DO, water chemistry and temperatures and provide drinking water to terrestrial animals. They also allow for fish and amphibian eggs to be suspended. Drought levels, though usually perceived as detrimental, allow for the growth of floodplain plants, eliminate or limit the growth of invasive species, and in some cases allow predators easy access to prey.
High Pulse Flows	These flows create pools and riffles, and determine the size of sediment along river beds. They prevent riparian vegetation from growing into the river channel, flush away waste and pollutants to sometimes restore normal water quality conditions.
Floods	Floods help form new channels, replenish the flood plain with nutrients, provide a larger spawning ground to fish and aquatic organisms, eliminate invasive species, and recharge the groundwater table in the flood plain etc.

2.2 HYDROLOGICAL ALTERATION OF FLOW REGIMES

Human control of water resources, namely rivers and streams tends to disrupt the natural flow regime of a river, which is important both for river channel morphology and ecological integrity. Specifically, dams disrupt the dynamic equilibrium that is present between the flow of water and movement of sediment in a naturally flowing river (Poff et al, 1997).

Dams act by capturing downstream moving sediment in their reservoirs. Conditions of sediment-starved river then begin to persist downstream and result in downstream channel erosion and tributary head cutting. Controlled water releases (especially in this case of dams designed specifically for irrigation purposes) from the dam reduce the duration, frequency and magnitude of high flows and floods. This disruption in high flows tends to result in channel stabilization and narrowing, and a reduction in the formation of river features such as oxbow lakes and bars etc. (Poff et al, 1997).

Ecologically, the reduction in sediment downstream of the dam, results in the coarseness of the river bed which reduces the habitat of riverine species sensitive to sediment. The absence of high flows can cause sensitive species to have high mortality rates by preventing the formation of habitat that is required for spawning. Certain species tend to dominate other native and sensitive species, and creates an imbalance in the natural prey-predator relationship. The absence of floods downstream also affects the production of riparian species that are dependent on nutrient replenishment during floods (Poff et al, 1997).

3. ALBORZ INTEGRATED LAND AND WATER MANAGEMENT PROJECT

In order to provide a sustainable and reliable supply of water mainly for irrigation during the dry season between the Alborz Mountains and the Caspian Sea in Mazandaran Province in Iran, the Government of Islamic Republic of Iran (GOI) conceptualized and constructed the Alborz Dam on Babol River. Details of the Babol River Basin and project described ahead as well as the minimum flow study are adapted from the NESPAK-ATT report on 'Ecology, Monitoring & Management Plan of Babol River', Alborz Integrated Land and Water Management Project, World Bank Loan No. 4782-IRN (NESPAK-ATT, 2012).

Babol River is one of the major nine rivers in Iran with an average annual surface flow of 374 mcm. The other two rivers in the Albroz Basin are the Talar and Siah Rivers. The Alborz Basin covers an area of nearly 1,350 km^{2}and comprises of several sub-basins based on hydrological boundaries, irrigation and drainage characteristics, and pollution flows as shown in **Figure-1.1**. Each sub-basin has a variety of terrestrial and aquatic ecosystems dueto the variegated topographical position of the basins, extending from the West to the East, and from the southern flank of the Alborz Mountains to the coast of Caspian Sea in the North. The basin also includes numerous rivers and water bodies both lotic and lentic.

The main streams including Babol, Talar and Siah Rivers and their tributaries originally formed a complex of well-connected ecosystems consisting of rivers and stream beds, river bogs, ox-bows, filled-in abandoned river channel remnants, freshwater ponding areas, water swamps and riverine or riparian forests. As such, the river systems could be typified as rich green backbones running from the high snow-covered Alborz Mountain peaks to the Caspian Sea. The area was rich in wildlife and unique in the connectivity of natural ecosystems in a sub humid and humid environment that was relatively rich both in terms of species and ecological services. The original lateral linkages of the Alborz basin river system with its dependent ecosystems and nutrient flows in the flood plains were well maintained.

However, as the unfortunate fate of most ecological rich ecosystems, the Alborz basin and its river system including the Babol River sub-basin, an important food basket in the region, were subjected to human exploitation and development; a consequence of population pressure on natural resources and their indiscriminate use. The once highly resilient ecosystem dwindled and the ecological linkages weakened. Even though some of the linkages still exist, most have disappeared permanently without hope for restoration; while others dilapidated linkages can be rehabilitated and restored to some degree.

The construction of Alborz Dam in the Babol River sub-basin was no such exception either as a measure of human exploitation of natural resources. However, in an effort to adopt a holistic approach in the construction of the dam that not only benefited Babol River basin communities, but the other trans-basin (Talar & Siah River basins) communities, the GOI initiated the Alborz Integrated Land and Water Management Project (AILWMP) through World Bank (WB) financing. The development objective of the

AILWMP was aimed at piloting a basin-wide integrated water resources management (IWRM) program in Babol River Basin and to be replicated in other sub-basins within Alborz Basin, to protect their ecosystems, inter alia, Ab-Bandans (wetlands) and river ecology through equitable and ensured water supplies with the use of effective monitoring tools.

The AILWMP included five major components. The first related to watershed management in the upper watershed and the second to improvement in irrigation and agriculture in downstream areas of Alborz Dam. The other two covered IWRM Support System Development and Environmental Management Activities whereas the fifth component consisted of overall Project Management and Coordination. The Environmental Management components focused on the implementation of Environmental and Social Management Plan (ESMP) on the following subjects in compliance with seven WB safeguard policies triggered by AILWMP: i) water quality in rivers, irrigation and drainage networks, Ab-bandans and aquifers; ii) river ecology monitoring and mitigation; iii) forest monitoring and management; iv) an integrated pest management plan; v) resettlement instruments; vi) a dam safety plan; vii) physical cultural property; and viii) public participation and awareness raising.

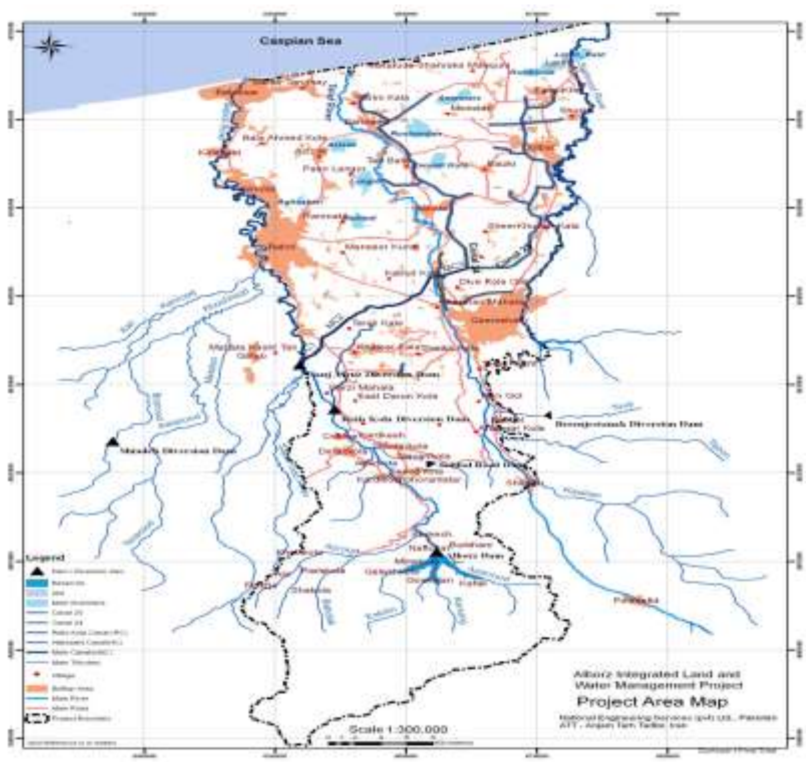

Figure-3.1: Project Area

(Source: Alborz Integrated Land and Water Management Project Report on 'Ecology, Monitoring and Management Plan of Babol River", October 2012.)

4. BABOL RIVER MORPHOLOGY

Based on topography and morphology, the Babol River sub-basin has been divided into three zones: (i) Upper; (ii) Middle; and (iii) Lower (**Figure-4.1**).Each zone is described below by its physical and biological environment and has been adapted from the NESPAK-ATT report on 'Ecology, Monitoring & Management Plan of Babol River', Alborz Integrated Land and Water Management Project, World Bank Loan No. 4782-IRN (NESPAK-ATT, 2012).

4.1 UPPER ZONE

This zone extends between elevations 8m and 150m above mean sea level (amsl), with the Persian Gulf as the southern boundary. It comprises of mountains with high relief altitude and steep to very steep dissected side slopes. In this zone, Babol River flows for a length of 45 km down a strong gradient in a deeply seated v-shaped valley with a high velocity, and in straight paths and semi-meander loops. The river bed in this reach is largely gravelly/stony and rocky, and locally also silty and clayey. Geological erosion on the mountain slopes without vegetative cover is high. At places, very deep gorges and ravines with gravelly fans on their mouths have been formed while at other locations sharp bluffs stand out. Colluvium is commonly found at the foot of the mountains. The mountain slopes in their upper parts are generally covered with natural forests while the lower slopes bear man-made plantations. Locally, they have been terraced for growing fruit trees. The average length of this zone is 30 km.

The riparian vegetation along the river bank is represented by rows/belts or groves of trees underlain by a thick cover of numerous woody and non-woody shrubs. Grassland patches are also a common feature of this landscape. The continuity of tree line along the banks is often broken by blank areas. The characteristic tree species of this zone are Alnus, Salix and Poplar. In the lower reaches of this zone, the plant species are the same but differ in cover which is sparse and the blank areas are more common.

Rainbow trout is a conspicuous species of this habitat. However in summer season, the species shift to the upper reaches whereas in winter season it is found throughout the length of the zone.

From the point of view of nutrient inputs, processing and flow, the Babol River may be viewed as a continuum from its source in the Alborz Mountains to its entry point (zero point) into the Caspian Sea. There is a succession of organisms along the continuum corresponding to the trophic context of any section of the river. Using this concept, the Babol River in its upper zone is the **production zone** and is the major source area tapping water, nutrients, solute, and sediment supplies from the mountain slopes.

River Water Quality : The Babol River in the upper zone is fed by three main tributaries including Azar, Eskelim and Karsang which join Babol River above the Alborz Dam site. Quality of surface water in these tributaries is reasonably good for domestic water supply, fishery and other aquatic life. The chemical and biological pollution is at its minimum in these rivers with reasonably high DO levels (in excess of 10 mg/l) and relatively low conductivity, nutrient and Biological Oxygen Demand (BOD_5) levels.

Water quality of the three main tributaries including Babol and Babolak in this zone is fairly good, and suitable for both water supply purposes and ecological habitats. Water quality monitoring data (1999-2003) collected from four (4) sites on these rivers indicate relatively low levels of Total Dissolved Solids (TDS) and major ions; however, Electrical Conductivity (EC) and acidity levels are slightly higher when compared with the zone above the Dam axis conditions indicating the presence of pollution in this part.

Climate : Climatically, most of the upper zone is sub-humid temperate with 600-700 mm annual rainfall, except alpine area which is semi-arid (annual rainfall 300 to 400 mm) and cold temperate, with summer temperatures rarely exceeding 25°C. Data on temperatures, potential evapo-transpiration and winds of the upper zone is lacking. The relative humidity is less as compared to middle and lower zones. Wind direction during the day in this zone is from the foothills to higher elevations and is reverse during the night

Erosion : The upper zone is highly susceptible to accelerated soil erosion attributed to high soil erodibility on steep to very steep slopes, and poor vegetative cover resulting from indiscriminate tree cutting/deforestation, overgrazing and trampling of soils by animals. Trampling causes surface sealing, which results into decreased infiltration rate, increased run off and accelerated soil erosion. In addition, construction of roads on fragile rock formations triggers landslides/landslips and breaking of poorly constructed and poorly managed terraces on sloping lands, contribute to sediment load substantially. Empirically calculated sediment load for some of the sub-catchments in the upper zone is 18.42 tons/ha/year, which is quite close to the internationally acceptable maximum critical limit of 20 tons/ha/year.

4.2 MIDDLE ZONE

This zone occurs between 8m amsland -15m Below Mean Sea Level (bmsl) and comprises old high-lying piedmont terraces (4 to 5 generations) and the low-lying Subrecent and Recent flood plains of the Babol River. The Babol River flows through its flood plains along a moderate slope making large meander loops of 10 to 15 times greater wave length than the river bed width. The length of the river in this segment is approximately 30 km. This zone is characterized by erosion and deposition cycles in the outer and inner sides of the meanders respectively. Meandering and soil erosion is particularly severe at points where construction material is excavated from the river-bed. The riparian vegetation comprises linear plantation of trees or groves of trees which are dominated by Poplar, Salix with a few Alnus. The ground cover is made up of shrubs and grasses. Narrow belts of grassland without trees and shrubs also occur separately along the stream banks in-between the segments of linear plantation.

The middle river zone is the **transfer zone**, and is characterized by high environmental heterogeneity and high species richness.

River Water Quality : Data of MRWC as well as ESMP studies show that water quality is poor in this zone. Conductivity readings are higher than in upper zone and together with higher levels of TDS and major ions. The data demonstrated significant levels of both heavy metal contamination and coliforms, suggesting that the water bodies suffer extensive pollution from a range of municipal, industrial and agriculture sources

Climate : The zone is characterized by humid (rainfall 1000-1100mm) subtropical climate. Maximum mean monthly air temperature in August is 31.7°C and minimum mean monthly temperature is 5.4°C in January. The mean annual evaporation is 750mm.The relative humidity is high due to vicinity of the sea. The common wind direction is from the sea to the land during the day when hot air over the land rises and is reversed at night time when the sea is relatively warm causing a breeze from the land to the sea.

4.3 LOWER ZONE

This zone lies between –15 m and –24 m elevation bmsl at the Persian Gulf level on the flat estuary plains made in deep mixed alluvium from the river and the sea. The Babol River flows here to a distance of about 14 km in a straight and semi-meandering channel made so due to forceful back lashing effect of the sea waves during high tides. The lower zone represents the deposition or storage zone.

River Water Quality : In this zone, the surface water quality is poor due to the effluents being discharged into the river from industrial, domestic and agricultural activities. No reliable water quality data is available in this zone. However, according to MDOE monitoring data, DO levels in this zone are low usually in the range of 3-5 mg/l. Data for Chemical Oxygen Demand (COD) and BOD_5 is not reliable, however, based on the anthropogenic activities in this zone, it seems that the surface water quality is deteriorating.

Soil Erosion : In this land system, the risk of soil erosion is very low in the Subrecent and Recent plains due to very low gradients, except on old and high terraces where the risk is moderate to high due to elevation.

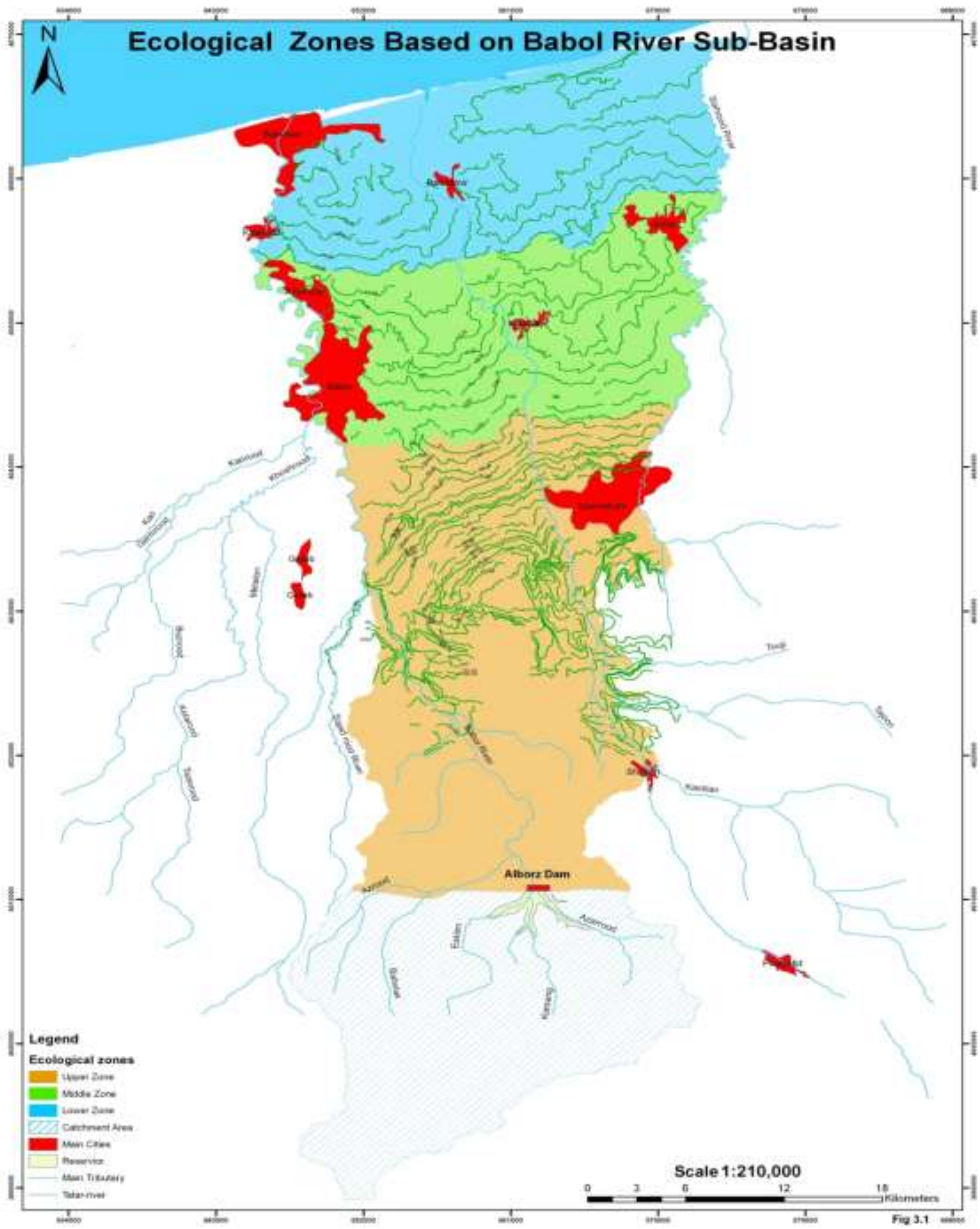

Figure-4.1: Ecological Zones Based on Babol River Sub-Basin

(Source: Alborz Integrated Land and Water Management Project Report on 'Ecology, Monitoring and Management Plan of Babol River", October 2012.)

5. RIVER FLOW MODELING

5.1 MODEL SETUP

The objective of river flow modeling of Babol River was to determine the river flow regime along the river from Alborz dam to Caspian Sea under varying river flows during a year under two conditions; (i) with Dam, and (ii) without Dam. In this regard one dimensional steady-state river-flow model of Babol River was set up to determine spatial and temporal variations of river flow hydraulics.

Babol River was modeled from Alborz Dam to Caspian Sea which is an 89 km long reach along the existing river meander. River cross sectional survey was carried out during the months of August to September 2008 (low flow period). Model has been run for two scenarios i.e. 'With-Dam' and 'Without-Dam' scenarios. Three typical flow years have been selected from the available stream gauging record on Babol River to simulate Dry, Average and Wet conditions in the river at various locations/reaches. Discharges for simulating the existing situation (present Without-Dam condition) and future condition (With-Dam) are derived from system operation simulation exercise carried out in December 2007. Monthly average of 10-daily data is used for all simulations.
Data requirements to develop one-dimensional river flow model are:

(i) River Geometry

(ii) Resistance to Flow

(iii) Magnitude of Flows

United States Army Corps of Engineers' well known and time tested one dimensional software 'Hydrologic Engineering Center River Analysis System' (HEC-RAS) version 4.0.0, released in March-2008, was used to carry out the one-dimensional steady state simulations.

River geometry is used to define river schematization by using the river cross sections and the reach lengths between the cross sections. 79 river cross sections have been used to cover 89 km long Babol River reach starting downstream of Alborz dam to Caspian Sea. Babol River is further split into six reaches which are defined in Table-5.1 below and in **Figure-5.1** which shows the slopes of the reaches.

Table-5.1: Babol River Reaches

	Reach			No. of Cross Sections	Slope
Sr. No.	Name	Description	Length (km)	(Nos.)	(%)
1	R-1	Alborz Dam to Babolak Confluence	4	2	1.3%
2	R-2	Babolak Confluence to Raeiskola	17	7	3.4%
3	R-3	Raeiskola to Ganjafroz	7	29	0.09%
4	R-4	Ganjafroz to Kharoon confluence	19	21	0.14%
5	R-5	Kharoon confluence to B1/1 area off take	22	9	0.082%
6	R-6	B1/1 area off take to Caspian Sea	20	11	0.049%

(Source: Alborz Integrated Land and Water Management Project Report on 'Ecology, Monitoring and Management Plan of Babol River", October 2012.)

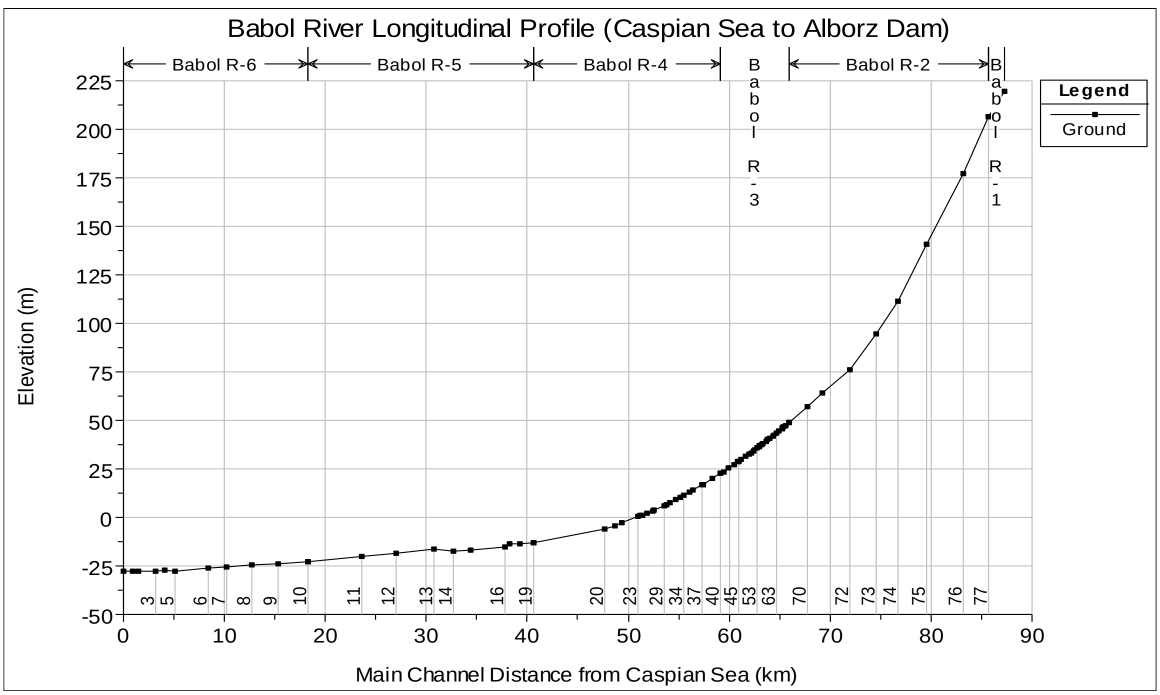

Figure-5.1: Babol River longitudinal profile from Alborz Dam to Caspian Sea

(Source: Alborz Integrated Land and Water Management Project Report on 'Ecology, Monitoring and Management Plan of Babol River", October 2012.)

5.2 RIVER FLOWS

Twenty-eight years of flow record (1977-78 to 2004-05) at various stream gauging stations has been examined for selecting three typical years to simulate the Dry, Average and Wet conditions in Babol River.1994-95 is selected as dry year, 2004-05 as average and 1991-92 as wet year. Seasonal and annual volumes for the mentioned years are given in **Table-5.2**.

Table-5.2: Water Volume at Ghorantalar for Three typical Dry, Average and Wet years

Year	Water Volume at Ghorantalar		
	Mehr-Esfand (September to March)	Farvardin-Shehrivar (April to August)	Annual
	(mcm)	(mcm)	(mcm)
Dry Year 1994-95	123	66	189
Average Year 2004-05	147	100	247
Wet Year 1991-92	192	338	530

(Source: Alborz Integrated Land and Water Management Project Report on 'Ecology, Monitoring and Management Plan of Babol River", October 2012.)

Moreover, the flows in each reach are calculated to account for the possible flow change due to either contribution of water through lateral tributaries/intermediate-basins or the diversion through traditional and new irrigation canals in "Without-Dam" and "With-Dam" scenarios, respectively.

5.3 RESULTS AND DISCUSSION

The results of the steady state simulation carried out determined basic hydraulic parameters like flow velocity, depth and width corresponding to the discharges for various reaches of Babol River mentioned in **Table-5.1**. Variation of flow velocity, depth and width corresponding to the dry, average and wet conditions in all six reaches of Babol River are compared for both "Without-Dam" scenario and "With-Dam" scenario.

Typical plot of discharge hydrographs for dry year in reach 1, 3 and 4 are shown in **Figure-5.2** through **Figure-5.4**. Comparison of these discharge hydrographs for "Without-Dam" and "With-Dam" scenarios show that discharges in "With-Dam" scenario remain always lower than the "No-Dam" condition during winter season[1] (Mehr to Esf and ; (September to March). This is due to filling of the reservoir during high flow season (which is the winter season) in "With-Dam" scenario.

It may be further noted that even during the reservoir filling period, a minimum amount of discharge i.e. 1.0 m^3 / s is released anyway in R-1 to preclude total drying of the reach. Furthermore, a sharp peak may also be noted during the month of Esf and (end February to Late March) in "With-Dam" scenario which corresponds to higher water requirements for preparing nursery of the forthcoming rice crop.

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1. Winter season is a high flow season in Mazandaran region.

Subsequently in the growing season, discharges in "Without-Dam" scenario remain lower than those in "With-Dam" scenario. The higher discharge is 'With-Dam" scenario is in fact the regulated water which was stored during high flow season and being released to fulfill the water requirements of the rice crop in the low flow season. Whereas, in "Without-Dam" scenario water could not be regulated from one season to the other and, therefore, remains on the lower side, in comparison of "With-Dam" situation. It may be noted that in No-Dam case the flow reduces to zero during the low flow and high water requirement period for a number of 10-day intervals.

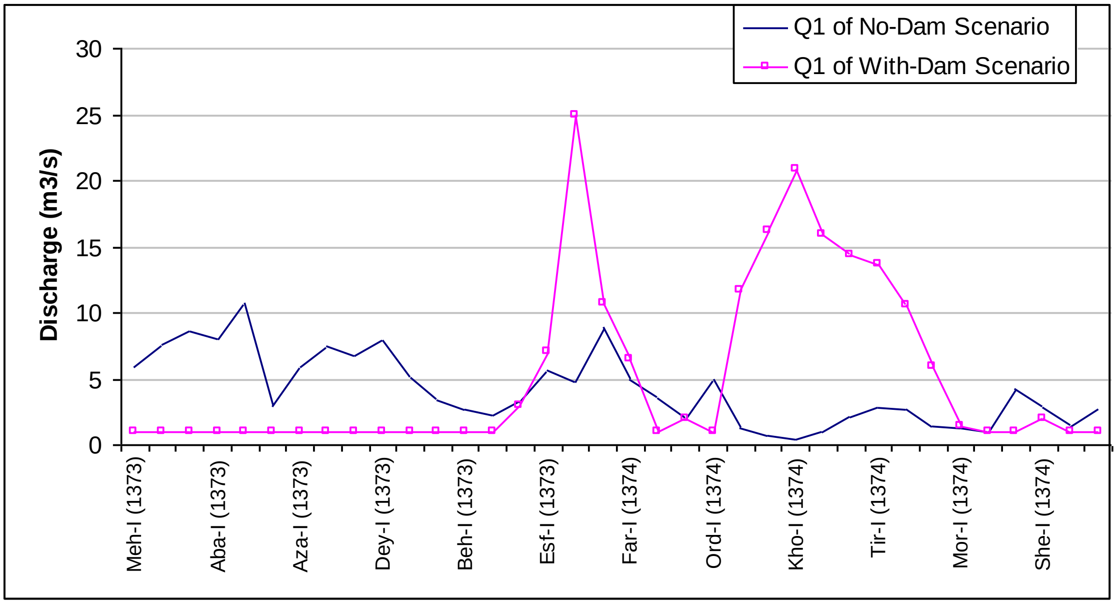

Figure-5.2 Comparison of dry year discharge for year 1994-95 in Reach-1 for "Without-Dam" and "With-Dam" scenarios[2].

(Source: Alborz Integrated Land and Water Management Project Report on 'Ecology, Monitoring and Management Plan of Babol River", October 2012.)

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2. Persian Calender Months: Meh (Sep-Oct), Aba (Oct-Nov), Aza (Nov-Dec), Day (Dec-Jan), Bah (Jan-Feb), Esf (Feb-Mar), Far (Mar-Apr), Ord (Apr-May), Kho (May-Jun), Tir (Jun-Jul), Mor (Jul-Aug), Sha (Aug-Sep)

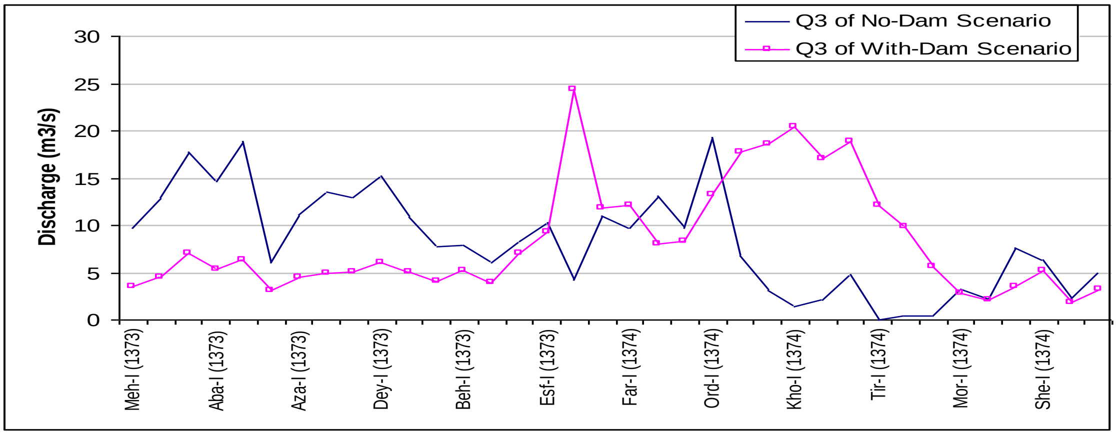

Figure-5.3 Comparison of dry year discharge for year 1994-95 in Reach-3 for "Without-Dam" and "With-Dam" scenarios

(Source: Alborz Integrated Land and Water Management Project Report on 'Ecology, Monitoring and Management Plan of Babol River", October 2012.)

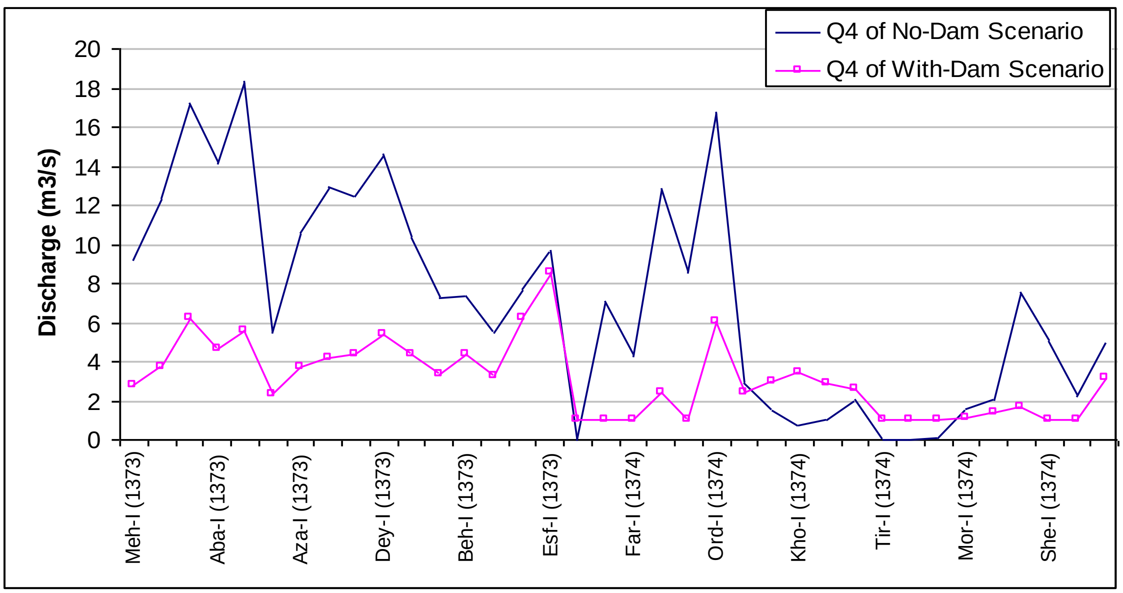

Figure-5.4 Comparison of dry year discharge for year 1994-95 in Reach-4 for "Without-Dam" and "With-Dam" scenarios

(Source: Alborz Integrated Land and Water Management Project Report on 'Ecology, Monitoring and Management Plan of Babol River", October 2012.)

The above analysis shows that generally river conditions would remain more conducive for aquatic life in "With-Dam" scenario as compared to "No-Dam" scenario. Reach-6 which is 20 km in length upstream of Caspian Sea is more critical during the dry year simulation. Comparison of flow velocity, depth and width for “Without-Dam” and “With-Dam” scenarios for Reach-6 is shown through **Figures-5.5** through **Figures-5.7**, respectively. The figures show that Ordebehesht (Late April to Late May), Khordad (Late May to Late June) and Tir (Late June to Late July) are the critical months in which discharges for “Without-Dam” scenarios becomes generally zero which causes drying of the reach during the drier years. On the other hand “With-Dam” scenario overcomes this problem by releasing flows from the dam to make the minimum flow of 1.0 m^3/s in any of the river reaches downstream. Therefore, the critical reach (R-6) can have minimum flow velocity of 0.3 m/s, 0.5 m depth and 25 m width even during the dry year.

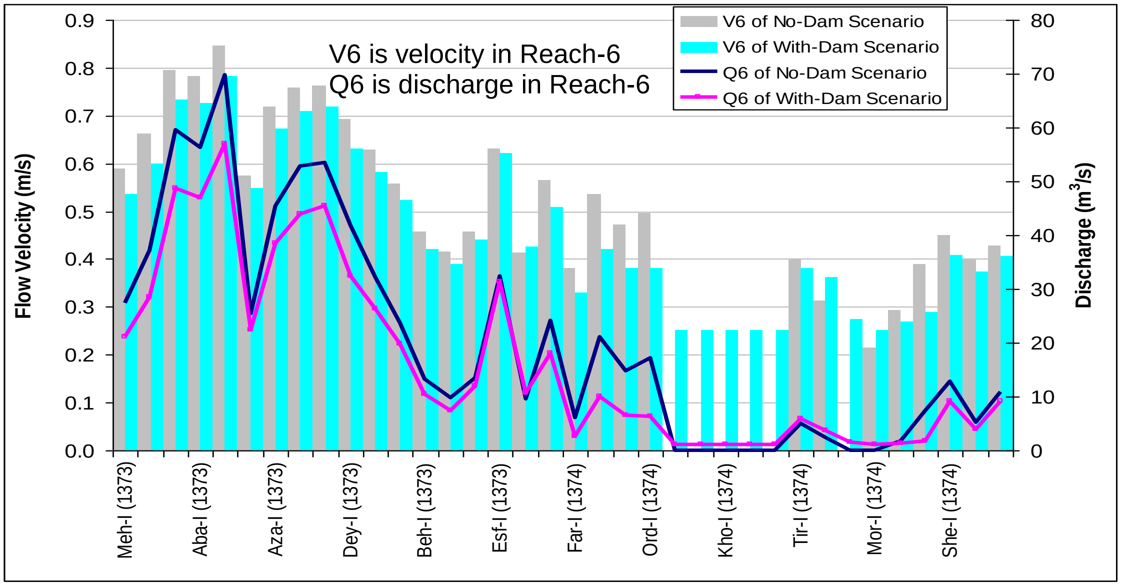

Figure-5.5 : Comparison of flow velocity for “Without-Dam” and “With-Dam” scenarios during a selected dry year 1994-95 in R-6

(Source: Alborz Integrated Land and Water Management Project Report on ‘Ecology, Monitoring and Management Plan of Babol River”, October 2012.)

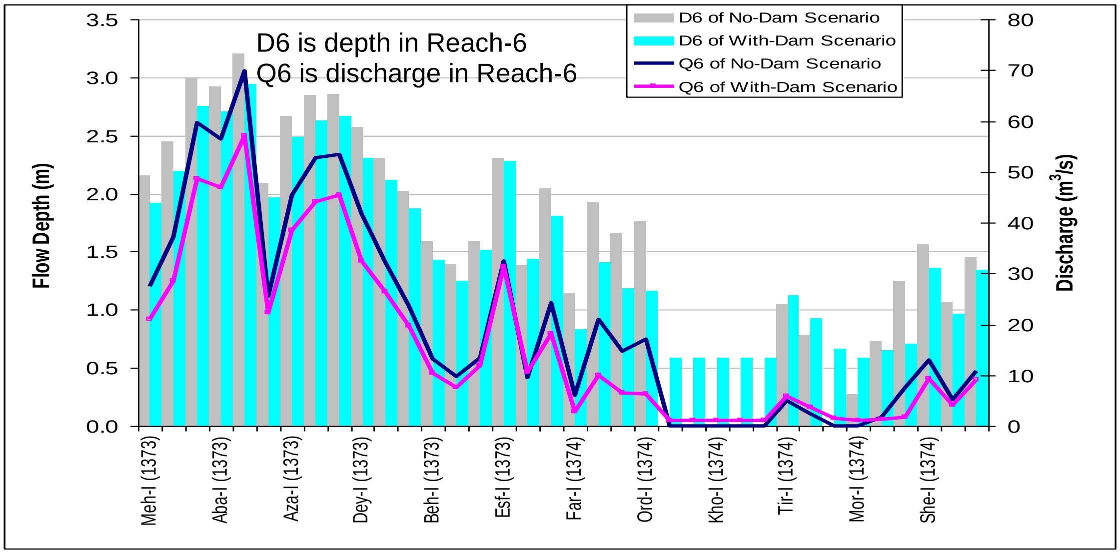

Figure-5.6 Comparison of flow depth for "Without-Dam" and "With-Dam" scenarios during a selected dry year 1994-95 in R-6

(Source: Alborz Integrated Land and Water Management Project Report on 'Ecology, Monitoring and Management Plan of Babol River", October 2012.)

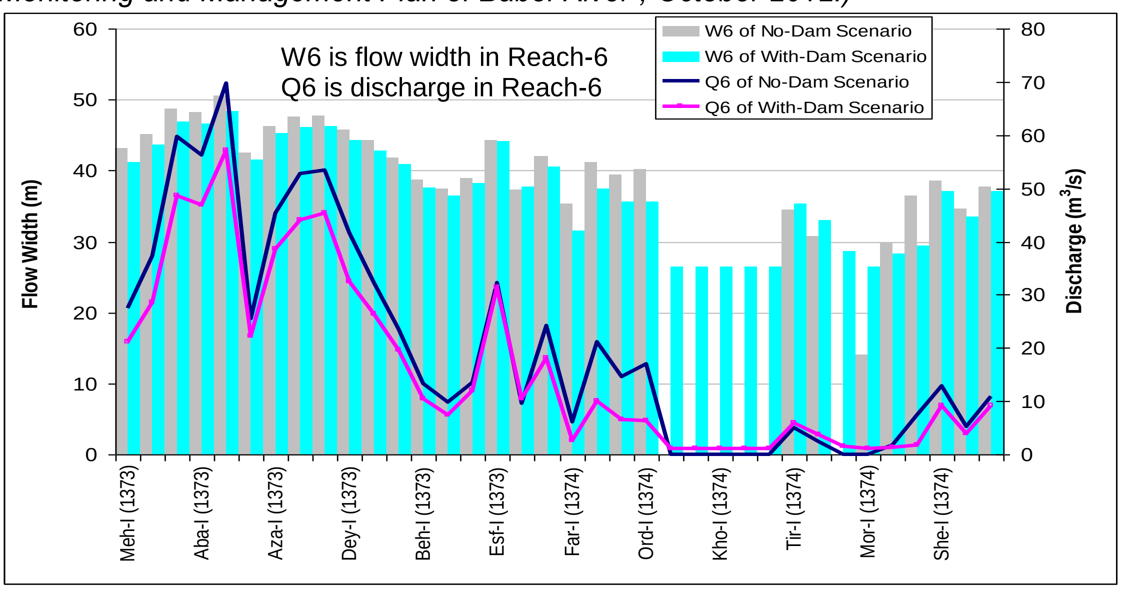

Figure-5.7 Comparison of flow width for "Without-Dam" and "With-Dam" scenarios during a selected dry year 1994-95 in R-6

(Source: Alborz Integrated Land and Water Management Project Report on 'Ecology, Monitoring and Management Plan of Babol River", October 2012.)

6. WATER QUALITY MODELING

A water modeling exercise was also carried out to determine the effects of Babol river flows on water quality in the six reaches of Babol river for both 'Without-Dam' and 'With-Dam' scenarios. Water quality modeling was carried out for the same three wet, average and dry years.

Above of Babol City upto Reach 4, there were no water quality problems. All tributaries bring fresh water of good quality to the Babol River. However, in lower reaches the situation changes for the worst due to municipal and industrial waste from Babol and Babolsar cities.

MIKE Basin Water Quality (WQ) model was used to model water quality in Babol River. Due to limitations in acquiring real time data most of the data was analytically derived. Pollution sources in Babol River and data, limitations are described below.

6.1 POLLUTION SOURCES

Sources of pollution were generally divided into point and non-point sources. Point sources typically represents pollutant sources with a well-defined outlet location such as industries, wastewater treatment plants, urban centers, individual households and other types of trunk sewer outlets.

Non-point sources usually contain fertilizer pollution, livestock pollution etc. Along the Babol River livestock was mostly situated in the upper watershed and middle and lower watershed almost have negligible number of livestock. Domestic and industrial pollution causes high Biological Oxygen Demand (BOD_5) and high nitrates and ammonia. Industrial pollution causes high COD, BOD_5 and TDS values and besides it also contributes other chemical pollutions and sometimes some most dangerous heavy metals like Hg, As and Cd etc. which are not detectable with simple laboratory equipment.

Fertilizer pollution was expected from agriculture areas along the Babol Farmers usually use nitrate, phosphate and potash fertilizers which due to rainfall / runoff or irrigation and drainage enters the river at various points. Load calculator was used in the Model to calculate the pollution loads for each catchment.

6.2 DATA LIMITATIONS / ASSUMPTIONS

Monthly River flows data for 2005 (average year) were used in the model. Monthly average of 10-daily data was selected so that river flow data and water quality data were for the same year.

Three main types of pollution were considered for Babol River modeling i.e. domestic, agricultural and industrial pollution. Domestic, agriculture pollution was automatically calculated by the software by giving the land use distribution along the river. For agricultural and domestic pollution, it was assumed that 2 km wide area from the center of river is contributing pollution in river. Industrial pollution data was not available. BOD_5 value and flow rates of only two or three industries were given, whereas total more than 50 industries are present at Babol River.

Slope of Babol River is divided into three categories. Slope is calculated from the surveyed cross sections along the Babol River. In lower watershed, rubber dam and sea backwater effect is not modeled easily.

6.3 MODEL SIMULATION AND RESULTS

Water quality of Babol River (with Dam) in its different reaches i.e. from Alborz Dam to Estuary against the hydraulic flows for minimum flow month (August) had been evaluated. Only one parameter for aquatic life of Babol River was considered, Dissolved Oxygen (DO). The modeling results are shown in **Figure-6.1** and **Figure-6.2.**

Computer model analysis revealed that the water quality of upper (Zone-1) and middle zones (Zone-2) had no serious concerns/issues. DO concentrations were well within the acceptable limits, however, modeled values of DO for the month of August (low flow season) showed lower ranges i.e. 2.3 to 4.5 mg / l for Zone-3 (lower zone). This is mainly due to inflow of industrial and domestic flow into the Babol River.

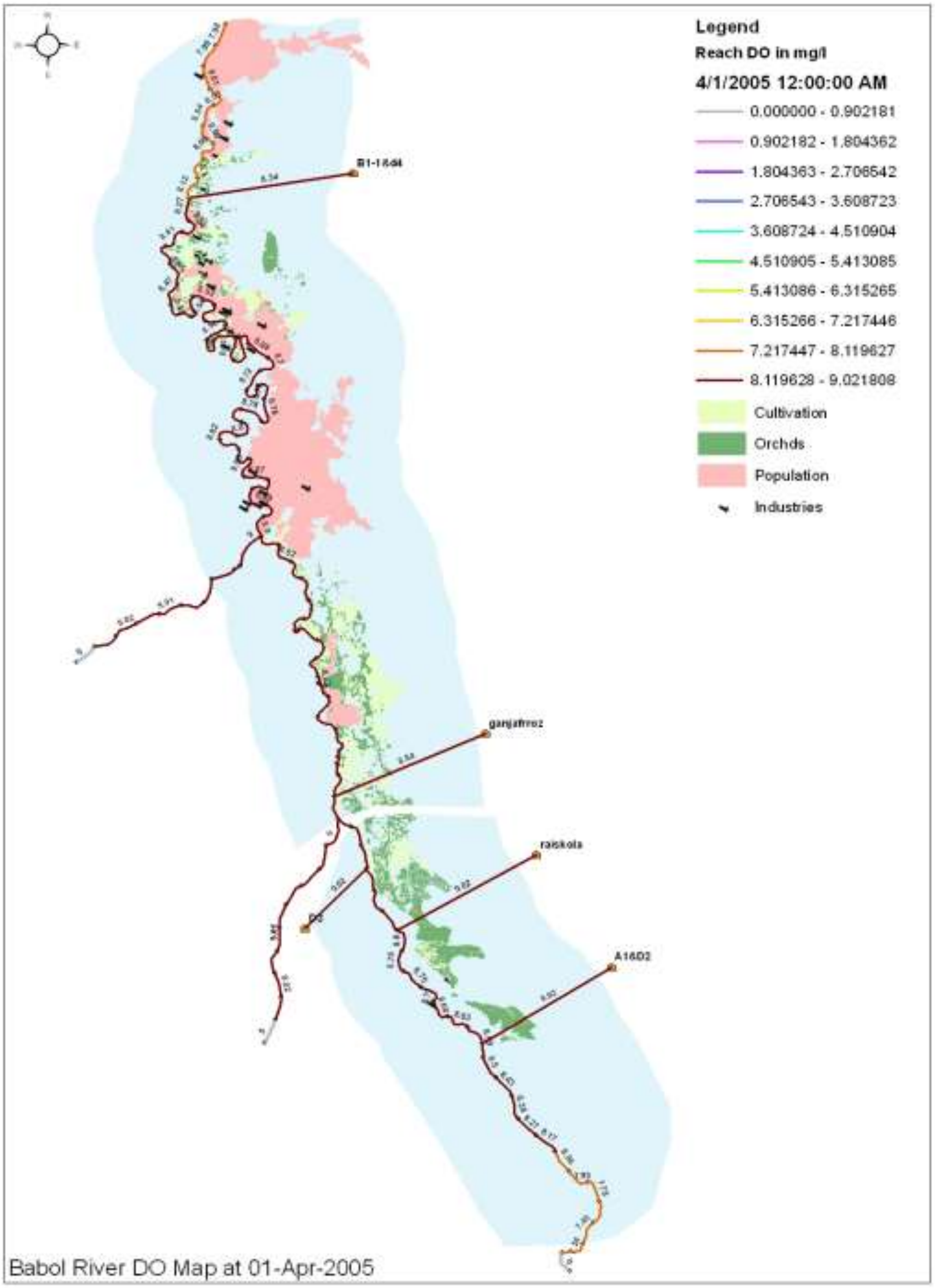

Figure-6.1 : Dissolved Oxygen (DO) April 2005

(Source: Alborz Integrated Land and Water Management Project Report on 'Ecology, Monitoring and Management Plan of Babol River", October 2012.)

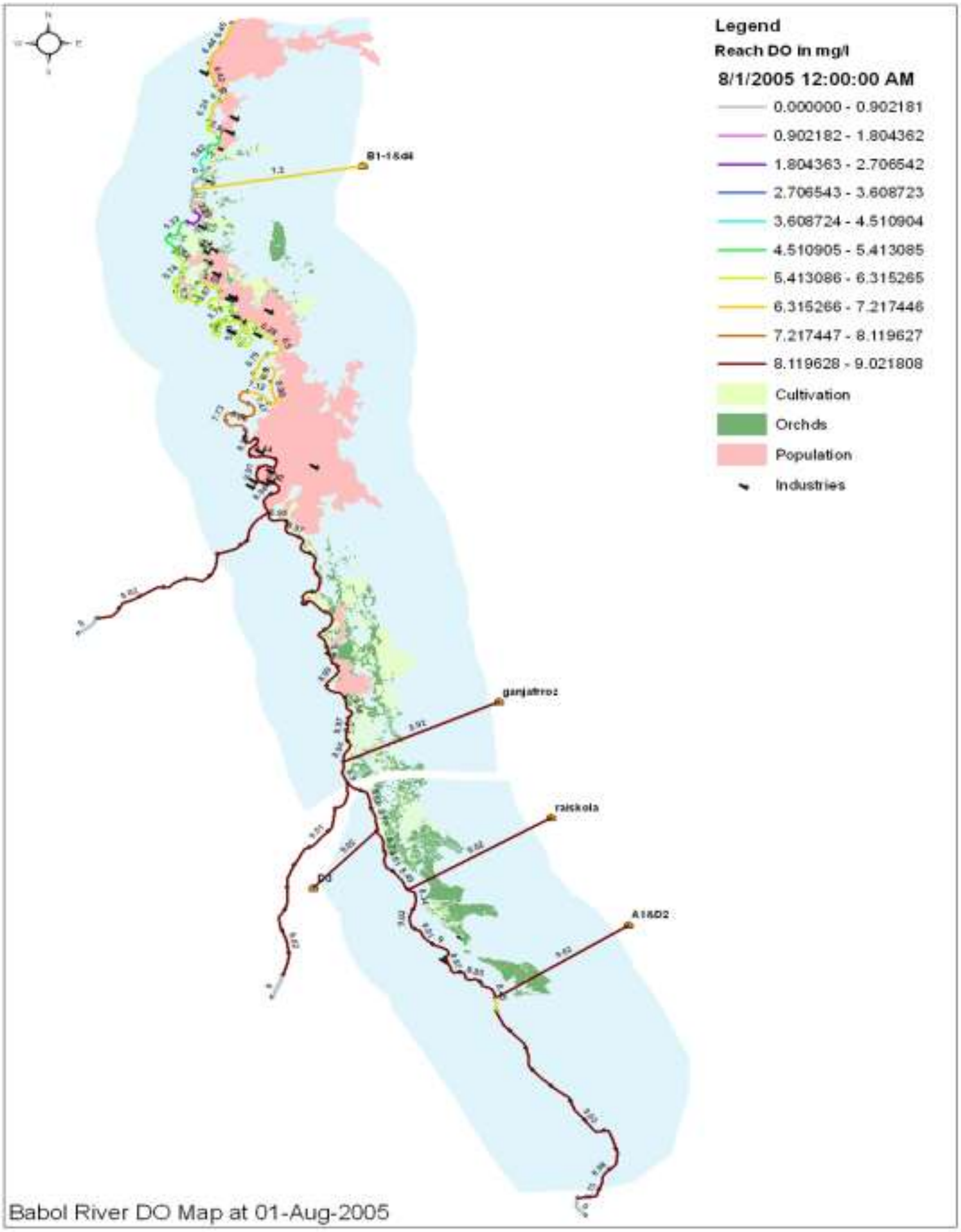

Figure-6.2: Dissolved Oxygen (DO) August 2005

(Source: Alborz Integrated Land and Water Management Project Report on 'Ecology, Monitoring and Management Plan of Babol River", October 2012.)

7. CONCLUSION

The Alborz dam will alter the natural flow regime of Babol River. One of the greatest benefits of the dam and the required 1m^3/sec minimum flow is that zero flow days or months will cease to exist, which were otherwise part of the natural flow regime of Babol River. Continuous flow of water will ensure that some measure of ecological integrity will remain downstream of the dam.

Water quality in the river is largely a function of human development in the Alborz Basin as the modeled results indicated. Even with the dam and its subsequent reduced flows, the model showed normal DO values except in the reach that is subjected to industrial effluents.

Modeling the impact of minimum flows in this study is a first step in the direction of sustainable engineering. While the larger question of whether this minimum flow is '*suitable'* for maintaining ecological integrity still remains to be studied, as a first step this study was imperative towards quantitatively understanding how changes in the natural flow regime affect river morphology and water quality. The next step would be to assess how the riverine and flood plain ecosystem would react and respond to such a minimum flow and subsequent changes in channel morphology and water quality.

8. REFERENCES

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