Evaluating the impacts of improving irrigation efficiency on water resources system reliability

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ABSTRACT

Climate change has caused numerous problems to management of water resources. Similar to many other countries Iran is also facing water crisis in most of its catchments. As one of the agricultural centers of this region, Dez basin may be affected by the impacts of this climate change. Approximately 4 billion cubic meters of water of this basin is consumed by the agriculture sector on a yearly basis, but the low efficiency of irrigation networks in this region leads to the loss of millions of cubic meters of water each year. Continuation of the current trend will evidently cause serious problems to the supply of water and agricultural future of this region. One of the actions for overcoming these problems involves increasing irrigation efficiency. In this paper, by simulating Dez basin, as an integrated water resource system, the effects of increasing the irrigation efficiency on the reliability of agricultural water from Dez basin were analyzed. The study scenarios consisted of short- and long-term changes of consumption level and management scenarios including a 10% and 20% increase in irrigation efficiency. The combination of these scenarios was simulated in WEAP. Results of the research have been discussed in both short- and long-term.

1. INTRODUCTION

The decrease in programmable water resources as a result of climate changes is one of the biggest challenges faced by the water resource management. One of the important and effective actions to be taken for addressing this crisis is correcting efficiency of the agriculture sector. Since management policies and planning in water resources engineering aim to reduce the impact of policies having negative effects on both the current and future status of water resources systems and to develop those policies and measures having positive effects on the system in socio-economic, environmental, political and legal aspects, there should be some parameters or indices to measure and assess the system efficiency in order for a water resources system to be evaluated and compared based on various management policies and programs (Safavi & Golmohammadi 2016). One of the most significant indices is reliability. Reliability as a substantial index is to assess the compatibility and flexibility of a system under hydrologic uncertainty conditions and water shortages (Fraga et al. 2017). Water supply reliability in the agriculture sector is highly dependent on agricultural irrigation efficiency. For this purpose, the first step toward improving irrigation efficiency and, consequently, promoting water resources and reservoirs management in a catchment is to evaluate different management policies and to adopt right decisions through integrated simulation in water resources engineering and planning. The integrated assessment and simulation are efficient since, in addition to providing a comprehensive view of a complex and dynamic system, they can assess different policies of decision-making and provide the grounds to choose the best approach possible. In this regard, the integrated models are used to thoroughly simulate and evaluate the effects of increased irrigation efficiency on reliability index.

Water scarcity is one of major concerns in different parts of the world, especially the Middle East. Likewise, Iran has recently faced a negative water balance and water shortages in its catchments. Iran's agriculture sector consumes more than 90% of water resources (Alizadeh & Keshavarz 2005) and its average irrigation efficiency is approximately 30% (Hesam & Keyani 2014), which is one of the major sources of water loss in this country. Considering the results of the studies conducted in Iran indicating that the agriculture sector is severely affected by the climate change (Gohari et al. 2013) (Rezaei et al. 2017), it seems obvious that the current trend would cause serious problems for the future of agriculture in this country. In order to remove this problem, the planning programs of Iran's stakeholders and government have recently shifted toward the use of modern applications and improving management conditions in catchments and reservoirs to achieve maximum use of available water resources. This study examined the issue at one of Iran's vital basins. Dez basin is located in South West of Iran and is one of the agriculture centers in this region and a significant number of people are involved in its agriculture sector. Water resources required for agricultural operations in the region are supplied by Dez reservoir dam at upstream of farmlands and about more than 4 billion cubic meters of water is annually used for the agriculture in this region. Furthermore, the low irrigation efficiency of irrigation networks available in the basin (Dez Irrigation Networks) annually cause million cubic meters of water to be lost (Navidi, 2016).

In previous research, the key role of reliability index was emphasized to ensure the sustainability of water resources systems and, consequently, compatibility with the water shortage crisis; the effects of increasing agricultural irrigation efficiency on water resource management of Sistan Basin in Iran was studied by Zamani et al. (2015); The research analyzed the scenario of increasing irrigation efficiency and declared irrigation efficiency of 34% in Sistan basin. The results of this research showed that if efficiency is improved using new irrigation methods in the region, water reserve grows and unmet demands in other sectors are considerably met. Abdolshahnejad et al. (2015) studied the challenges faced by the management of water resources systems in Hamidieh, Iran. The simulation results showed that the water resources shortages in the studied regions are aggravating over time. Hence, in order to improve the performance and to achieve the water resources reliability, the authors recommended some measures such as the improvement and modernization of the water supply system to be placed on the agenda. Psomas et al. (2016) investigated the effect of efficiency of agriculture irrigation on catchment management using Water Evaluation and Planning WEAP model for Ali Efenti Basin in Greece. The researchers claimed that the basin suffers from agricultural consumption unreliability in the summer and suggested that the effect of enhanced efficiency on drainage basin management should be considered in 2 scenarios: Deficit Irrigation (to achieve greater efficiency) and increased system efficiency by modernizing irrigation methods. The results showed that water would be saved by 23 and 7% through Deficit Irrigation rates and increased efficiency

resulting from modernizing and using modern irrigation methods to meet the needs in summer. Dehghan et al. (2015) studied planning for allocating water resources under different managerial scenarios in Gorganrood basin in Iran. In research, after basic studies and modeling the basin, the allocated percent of water volume for agricultural, industrial, aquaculture and environmental needs was obtained with regard to the intended goals of plans. The results showed that increasing irrigation efficiency can considerably preserve reliability of water supply in system and prevent its reduction. Santikayasa (2016) also developed a model to promote the integrated management in basins of Citarum River in Indonesia. In this study, the system reliability was assessed by comparing water demand and allocated irrigation water. The results showed that the reliability of the system would be reduced by 15%-26% because of climate change. In this regard, the researcher also added that the basin reliability significantly enhanced due to using improved irrigation methods and enhanced efficiency.

In line with previous research, the objective of this paper was to simulate and assess the effects of irrigation efficiency improvement management scenarios of the Dez Irrigation Network on the reliability index of the supply of agricultural water of Dez basin in Iran in the short- and long-term through integrated simulation of the Dez basin water resources system based on WEAP (Water Evaluation And Planning System) model (which functions based on the water balance equation).

2. MATERIALS AND METHODS

2.1 Study area

Dez basin is a subset of Great-Karun Watershed; this is an important basin in Iran located in the geographical coordinates 32°, 35´ to 34°, 07´ North latitude and 48°, 20´ to 50°, 20´ East longitude, Southwest of Iran. Dez River basin having the area of 23229 km^2 ends to Gharechai basin in the North, Karun Basin in the East and South and Karkhe Basin in the West (Rostami et al. 2009). The location of this basin is shown in Figure 1.

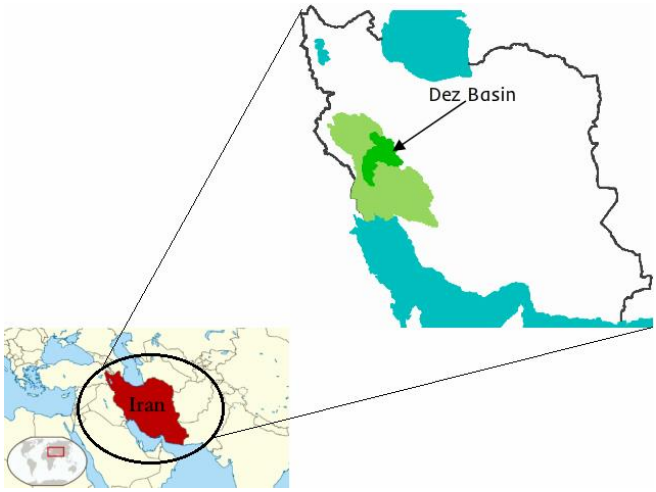

Figure 1. Study area

Resources and uses system of Dez basin is very complex and has various use and resource components. This basin supplies the required water of agricultural, aquaculture and drinking sectors of the area. One of the great water consumptions in this area is related to agricultural sector; such that agriculture is performed in this area in a wide extent. In order to supply the need of agricultural sector, more than 4 billion cubic meters of water is annually allocated from Dez storage dam to irrigation network of this basin (Navidi 2016). One of the biggest irrigation network of Dez basin is Dez Irrigation Network that having the net area of about 100000 hectares, and is one of the vastest irrigation networks in Iran (Navidi 2016). Dez Irrigation Network which is constructed by the aim of increasing water efficiency and irrigation optimization have high water wastes at the current time; such that irrigation efficiency in these networks is less than 33% averagely (Navidi 2016).

2.2 Crops water needs

Studies of monthly water needs for cultivated products in Dez Irrigation Network are computed using standard method suggested in Food and agricultural Organization (FAO) Irrigation and Drainage Paper no.56 (FAO-56). In these calculations, the values of evapotranspiration and effective monthly precipitation are obtained from meteorological studies. After calculating net irrigation need by considering cultivation pattern and cultivated area of different cultivated agricultural products, real demand of irrigation was estimated for the cultivated areas. Then total system irrigation efficiency was evaluated by comparing real demand of cultivation pattern and the allocated water level from Dez storage dam. This data is shown in Table 1.

Table 1. Allocated water, real demands and irrigation efficiency of Dez Irrigation Network

Year	Allocated water (MCM)	Real demands (MCM)	Irrigation efficiency (%)	Surpluses water (MCM)
2011	2135.99	697.73	32.66	1438.25
2012	1613.16	605.15	37.51	1008.01
2013	1953.54	633.81	32.44	1319.73
2014	2254.84	715.42	31.72	1539.41
2015	2147.44	683.62	31.83	1463.81

With regard to Table 1, it can be specified that the efficiency of Dez Irrigation Network is very low and at least 1 billion cubic meters of water is annually wasted. In the system of Dez basin resources, while water conveyance efficiency of Dez storage dam to agricultural lands is about 90% (Iran's ministry of energy 2014), but fatigue of tertiary and quaternary canals that cause great amount of water waste in agricultural lands, results in Dez basin irrigation and drainage networks that were built by the aim of increasing water efficiency in agricultural sector and preventing water loss, to be a pole of water loss in the area by their low efficiency.

2.3 Reliability index

In optimization methods, the influence of applying different policies on system performance of the intended water resources is evaluable with regard to goal functions and response set of points; while the results from applying different policies must be interpreted in simulation methods such that the possibility of selecting better policy is provided. One method which is proposed for evaluating the policies applied on a system of water resources is the use of operational indexes. Performance Indices (PI) are used for analyzing the efficiency and performance of different scenarios. These indices are divided into two general categories: Traditional Performance Indices (TPI) and Modern Performance Indices (MPI). TPI indeed include the statistics like mean, variance etc. while reliability is considered among MPI (Shafiee Jood et al. 2012). MPI contrary to TPI have direct attention to mobility of system performance under dangerous situations and hence are considered as a very safe option in evaluating water resource systems (Shafiee Jood et al. 2012). Hashimoto et al. (1982) introduced reliability as an important index in evaluating the performance of water resource systems which is used for evaluating different scenarios of management and exploitation from water resources. Reliability is the oldest and yet most usable index in water resource management issues and is equal to the possibility (P) that system situation (S) is in proper conditions (Hashimoto et al. 1982):

$$Reliability = P\{S \in NF\}$$

Equation 1

And when T is total time steps, j is failure counter, d_j is j_{th} failure period and M is number of failure events, reliability is estimating using the following relation:

$$Reliability = 1 - \frac{\sum_{j=1}^{M} d_j}{T}$$

Equation 2

Basically, reliability is a criterion of chance. The purpose of reliability is a standard output for exploitation. In irrigation, reliability is the level of trust that provides supply of crops water need (Hashimoto et al. 1982). Indeed, the water amount that is released for water needs of dam storage must be in a way that water needs of plan are supplied by high safety coefficient and in allowable risk for different goals such as drinking, agricultural, hydropower generation, etc. waters. Allowable reliability in required water supply for the projects of agricultural water supply is made standard in a way that the system is able to supply 95% of water needs of plan in 75% of the cases (Iran's ministry of energy 2004).

2.4 Scenarios

In this study, it was decided, with regard to very low irrigation efficiency in Dez Irrigation Network to use managerial scenarios of increasing irrigation efficiency by 10 and 20%. Water uses and demands in Dez basin can be divided into two categories of existing (in exploitation) demands and new (potential) demands. In the process of simulating scenarios, water resources and uses of Dez basin are used in 2 horizons. Short-term horizon is used for compiling existing demands. Water resource structures that are in study stage (potential) and have passed justification stage are also considered in long-term horizon. The simulated scenarios can be observed in the following table.

Table 2. Simulated Scenarios

Short term	Initial conditions	Evaluating reliability
	improving irrigation efficiency 10%	
	improving irrigation efficiency 20%	
Long term	Initial conditions	Evaluating reliability
	improving irrigation efficiency 10%	
	improving irrigation efficiency 20%	

2.5 Modeling and simulation of system

Simulation is the most applied method in evaluating different water resource systems. It is evident that simulation doesn't identify optimal design and policy, but is a rigorous tool for evaluating different plans and policies of exploitation that are identified by simpler optimizing models. In this research, integrated water resources management are selected for simulating water resource system of Dez basin. The possibility of system simulation towards various policies of water resources and performance union (due to considering a full range of options in exploitation, development and management of water resources management) is one main benefit of this method compared to other simulation methods. Ease of amending the model for the intended changes and the ability of performing analyze in each section has made this method more attraction among other different techniques for simulating water resource management systems. With regard to the information and considering the existing complexities in plan, in this study, Water Evaluation And Planning (WEAP) model is used for integrated simulation of Dez basin water resources system that is shown in Figure 2. WEAP model was developed by Stockholm Environment Institute and by specific support of U.S. Army Corps of hydrologic Engineers. This model provides a general flexible framework together with simple graphic user interface for policy analysis. This software is used for evaluating water projects in many countries.

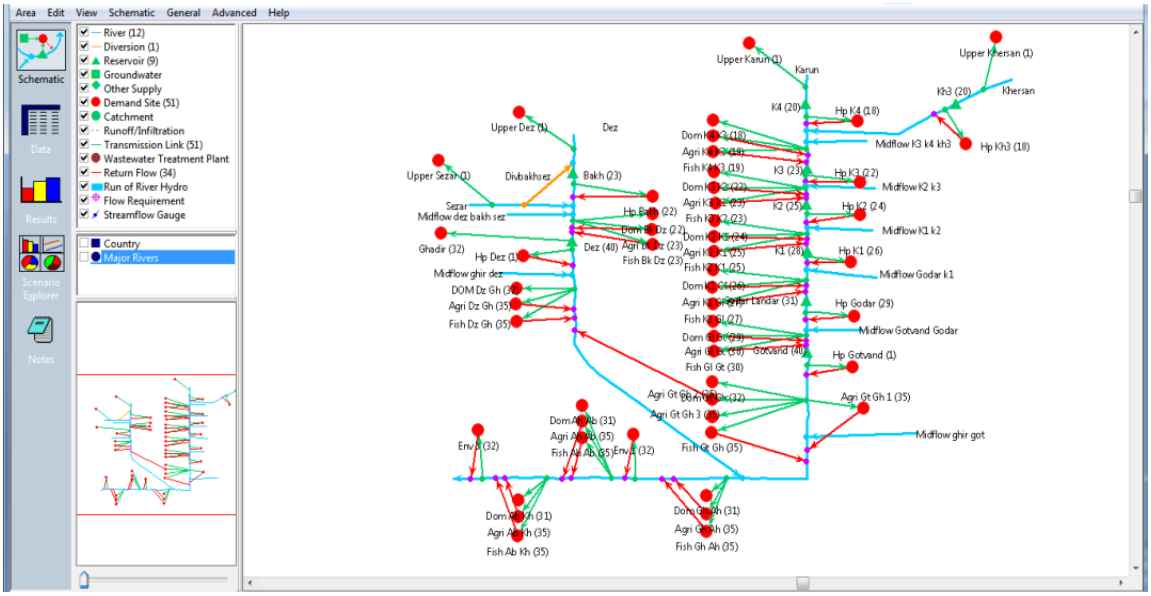

Figure 2. Configuration of water resource system in Dez basin

3. RESULTS

After complete simulation and entering the required data including time series of uses and resources in Dez Basin in each node, the model was implemented for different mentioned scenarios. With regard to the calculations, the level of water supply reliability in primary conditions was estimated equal to 71.69%. The results of simulation for efficiency increase that are performed in two horizons of short term and long term are presented in Table 3 and are compared in Figure 3.

Table 3. Results of simulated scenarios

Scenario	Condition	Improving irrigation efficiency levels	Reliability
First	Short term	10%	73.58%
		20%	75.47%
Second	Long term	10%	71.69%
		20%	73.58%

As it was mentioned, by the modeling and simulation performed for initial (current) conditions of Dez basin, the level of reliability index was estimated equal to 71.69%. Since in agricultural use, the acceptable level for reliability index of values is higher than 75%, it can be concluded that despite low efficiency of irrigation and allocating higher water than real need, agriculture in Dez basin is faced with shortage of water supply reliability.

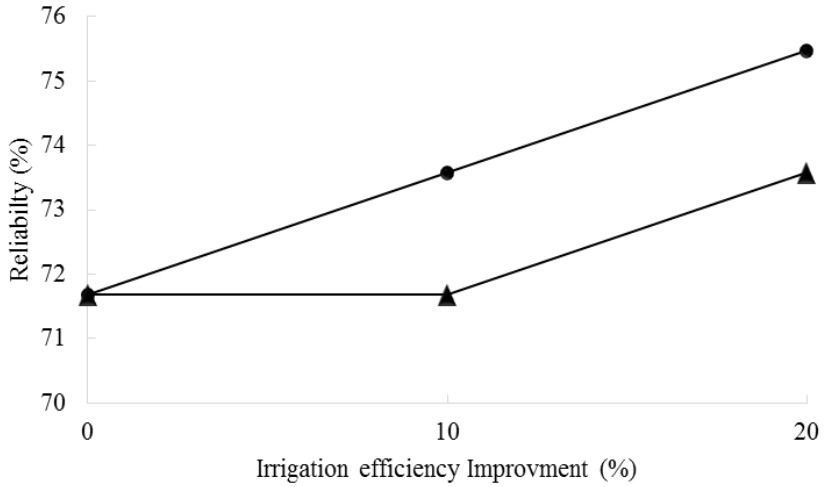

Figure 3. Comparing the influences of scenarios on reliability index; Short term (▲) and Long term (●)

With regard to the results of this research, managerial scenarios of increasing efficiency in short term (which system needs are in a state almost similar to current state and potential water structures and plans are not yet exploited) reliability is improved from 71.69% to 73.58% by 10% increase in irrigation efficiency; also the level of reliability is increased from 71.69% to 75.47% for 20% increase of irrigation efficiency. The considerable point is that even with this trivial increase of reliability, wide range of the years that have been with insufficient supply will be supplied. It is evident that in this way, the problems of water shortage in crops such as water stress or waste of product can be prevented and sensitive plants can be cultivated by more reliability and the area of cultivation can be extended. In these conditions, the farmers also perform with more relax.

In long term, downstream demands are also considerably increased (for example, the required drinking water of Ahvaz City -in downstream- is increased, also hydraulic structures of basin that are still in study are in exploitation step and are in working cycle using water). Therefore, it was observed that in these conditions, by increasing efficiency up to 10%, the existing reliability can only be hold but cannot be increased at all. Also, the results showed that by increasing 20% in irrigation efficiency, while reliability can be improved from 71.69% to 73.58%, but it is still lower than optimal value of 75%; this means that some years are still faced with possible lack of supply. It should be considered in the results that small values of increase in reliability index mean supply in many years that definitely leads to effective results.

Not a big influence by increasing irrigation efficiency of Dez Irrigation Network in some specific years on reliability index of Dez basin can be because of two reasons. First, in long term average of Dez River discharge, as the natural discharge and 5-Year moving average of Dez River discharge as shown in Figure 4, in some specific years, input of river was much lower than expected limit because of the big droughts, and therefore the increase of irrigation efficiency has no influence on reaching reliability to standard level and in every condition in those specific years the system was facing with failure and reliability wasn't achievable at all. The other reason is the dimension and the amount of used water in Dez Irrigation Network that is much lower than what is in cycle in all Dez basin; but with respect to the mentioned reasons, the positive influences of increasing network efficiency on basin reliability improvement cannot be ignored; because the small amount of increasing reliability will finally cause supply of the years that have had failure.

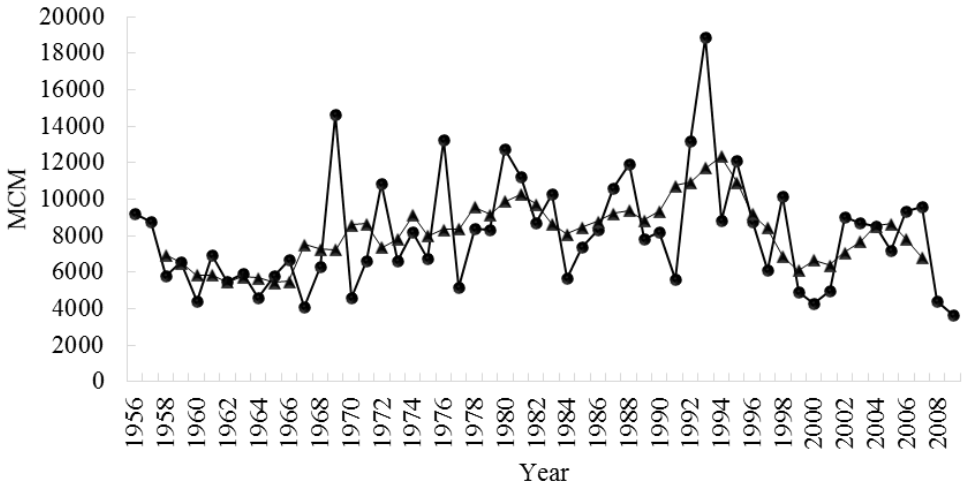

Figure 4. Changes in inputs of Dez River into Dez dam; natural discharge (●) and 5-Year moving average of inputs discharges (▲)

The results also show that, having the current irrigation efficiency, despite the waste of high amount of fresh water, system reliability is not also supplied and the possible lack of water supply exists in some months in year. Using the results of this research, it can be clear that achieving water supply reliability in all months of year in short-term needs 20% increase in the current irrigation efficiency of Dez Irrigation Network. It is also specified that in long-term conditions pursuant to demand increase, reliability is not completely supplied even with 20% efficiency increase. It is necessary in this case to act for increase of efficiency in this network with regard to the current low irrigation efficiency of Dez Irrigation Network. Since Iran is now faced with the signs of climate change and the predictions represent the increase of these signs and decrease of input from rivers, the supply of water for Dez basin agriculture faces with many problems in terms of water supply and reliability in the case of existing procedure; as with regard to the increase of demand in long-term conditions, even by assuming lack of change in hydrologic and climate parameters, system reliability cannot be ensured by 20% increase of efficiency.

4. CONCLUSION

The goal of the present research was to assess the effects of increased irrigation efficiency on water supply reliability index in Dez basin water resources system in the short- and long-term. For this purpose, first by considering Dez basin as an integrated system, managerial scenarios including 10% and 20% irrigation efficiency improvement for the two horizons in Dez Irrigation Network which is the biggest consumer of agricultural water in Dez basin were simulated. After performing the studies of water needs by the recommended method in FAO-56 and comparing the required water of cultivating pattern with the allocated water, total efficiency of irrigation in Dez Irrigation Network were obtained. The results represented that efficiency level in this network is very low, equal to 33% in average. Also, with regard to the results, the reliability of water supply for agriculture in the basin of Dez is now 71.69% which is lower than the recommended value. The results of this research for short-term conditions showed that 10% increase of efficiency can increase existing reliability and reach it to 73.58%; while it doesn't reach to the recommended level but helps the supply of reliability in various years. Also, by 20% increase of efficiency, the existing reliability can be increased and it can be reached to the recommended value i.e. 75%. Also, the results of this research for long-term conditions represented that in this condition because of the need of downstream and exploiting from new hydraulic structures, by 10% increase in irrigation efficiency of agricultural sector, only the current reliability can be preserved not to be worse. On contrary, 20% increase of efficiency helped system success in many years and therefore reliability index can be reached to 73.58%. While this value was lower than the recommended value, but considering long-term conditions and the costs of efficiency increase can be justifiable. It should be pointed in the investigation of results that the increase of values, even a little, in reliability index shows supplying a wide range of years that there was possibility of system failure and lack of supply in them. Results of this research were in line with results of similar studies (Zamani et al. 2015, Abdolshahnejad et al. 2015, Psomas et al. 2016, Dehghan et al. 2014 &

Santikayasa 2016) by stressing the vital role and necessity of improvement of irrigation efficiency in Dez Irrigation Network in the increase in reliability index, improvement of basin management, and conservation of the existing upstream dam water reserves (Dez dam) considering threats imposed by national and regional climatic changes on the decrease in programmable water resources..

5. ACKNOWLEDGEMENTS

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