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The Water-Saving Strategies Assessment (WSSA) Framework: An Application for the Urmia Lake Restoration Program

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Abstract: Increases in water demand often result in unsustainable water use, leaving insufficient amounts of water for the environment. Therefore, water-saving strategies have been introduced to the environmental policy agenda in many (semi)-arid regions. As many such interventions failed to reach their objectives, a comprehensive tool is needed to assess them. We introduced a constructive framework to assess the proposed strategies by estimating five key components of the water balance in an area: (1) *Demand*; (2) *Availability*; (3) *Withdrawal*; (4) *Depletion* and (5) *Outflow*. The framework was applied to assess the Urmia Lake Restoration Program (ULRP) which aimed to increase the basin outflow to the lake to reach 3.1×10^9 m^3 yr^{-1}. Results suggested that ULRP could help to increase the *Outflow* by up to 57%. However, successful implementation of the ULRP was foreseen to be impeded because of three main reasons: (i) decreasing return flows; (ii) increased *Depletion*; (iii) the impact of climate change. Decreasing return flows and increasing *Depletion* were expected due to the introduction of technologies that increase irrigation efficiency, while climate change could decrease future water availability by an estimated 3–15%. We suggest that to reach the intervention target, strategies need to focus on reducing water depletion rather than water withdrawals. The framework can be used to comprehensively assess water-saving strategies, particularly in water-stressed basins.

Keywords: water-saving strategies assessment framework; climate change; rebound effect; Urmia Lake; water resources management; water governance

1. Introduction

During the last century, water management policies have mainly focused on developing water resources to secure food and energy for a growing population. This has led to an increasing number of reservoirs, wells and irrigated areas [1]. Climate change has also had a significant impact on water scarcity in (semi)-arid regions [2]. Water demand has thus approached, or is approaching, the limit of water availability in many basins, also referred to as basin closure [3,4]. This leaves limited volumes of water available for the natural environment [5]. The Colorado River in the United States, for instance, no longer reaches the Gulf of California [6], the Aral Sea has desiccated due to a decline in inflows to the Amu Darya and Sir Darya rivers [7] and Bolivia's second largest lake, Lake Poopó, has already dried up [8]. To prevent further environmental degradation and to promote resilience to drought, water-saving interventions (solutions) have been introduced to the environmental policy agenda in many (semi)-arid regions [9]. However, many of these policies have not only failed to reach their goal of saving water for the environment, but have also weakened basin resilience through loss of flexibility and redundancy [10]. Water-saving policies in southern Spain, for instance, have increased (rather than decreased) water depletion by 20%, along with a fourfold increase in costs of management and operation [11]. This calls for a better understanding of the complex impacts of water-saving interventions on the water balance of basins.

The key to understanding a water-saving policy is to distinguish between water withdrawal and water depletion. Water withdrawal refers to the total amount of water extracted from a basin for different uses, while water depletion is the fraction of water withdrawal not returning to the water system. Water depletion can be divided into beneficial and non-beneficial consumption [12]. Beneficial depletion occurs when water is depleted to produce goods such as agricultural products. Non-beneficial depletion occurs when no benefit (or a negative benefit) is derived from the depletion of water [13]. Without a clear distinction between withdrawal and depletion, misconceptions and misinterpretations of performance indicators for water-saving policies can occur [12,14]. Many efforts to improve water-use efficiency, especially in agriculture, focus on reducing withdrawals with sometimes little impact on water depletion [15,16]. Increased efficiency in resource use can lead to increased total resource use [17]. This is known as the rebound effect and has been reported in many water-saving investments [18–23]. Promoting irrigation efficiency often not only reduces withdrawals, but also decreases return flows. Changes in return flows link field hydrology to basin hydrology [24–27]. Therefore, it is important to undertake a basin-wide approach when it comes to increasing water-use efficiency. If surface irrigation systems are replaced by sprinkler or drip systems, the return flow decreases, which in turn reduces downstream water availability [10,28] and can amount to up to 60% (77% in rice fields) of the water applied for irrigation [27]. Cai et al. [29] used an integrated modeling approach which included hydrologic and agronomic models for the evaluation of basin management scenarios in the Maipo River Basin in Chile. They showed that increased irrigation efficiency in agricultural areas can negatively affect river flow, as water depletion increases even if water withdrawals decline.

Existing water policies often ignore the possible changes in future water availability and demand. In (semi)-arid regions, rainfall is often unpredictable, while there are also large annual and seasonal differences in terms of water availability. This variability may further increase, and in many semi-arid regions, water availability is projected to decrease due to climate change [30]. Moreover, water demand, especially for irrigation, often increases in these areas and will become even more pronounced with increasing global warming [31]. Water demand is also likely to increase in the domestic and industrial sectors due to population growth, socioeconomic development and land use change [32].

Although well-described in literature, the dynamic effect of these complexities is often not adequately addressed by water-saving policies. In the absence of an adequate basin-wide assessment tool, water-saving strategies may even aggravate water scarcity and put more pressure on natural resources [16,33,34]. In this study we introduce a comprehensive water-saving strategies assessment (WSSA) framework to assess the water resources' status "ex-ante" and "ex-post" of the interventions. The framework highlights real water saving by distinguishing between *Demand, Availability, Withdrawal, Depletion* and *Outflow* in the context of possible changes in future demand and availability. To demonstrate the WSSA framework, we applied it to evaluate a set of proposed water-saving strategies in the Urmia Lake Restoration Program (ULRP) which aims to restore the Urmia Lake in northwestern Iran. Applying existing ground and modeled data, the WSSA framework depicts the situations ex-ante and ex-post of the intervention while accounting for different climate change and socioeconomic scenarios. The study aims to raise awareness among policy makers who are aiming to save water for alternative uses—in particular, for the environment.

2. Materials and Methods

2.1. Study Area

Lake Urmia located in northwestern Iran (Figure 1), was once the largest lake in the Middle East and one of the largest permanent hypersaline lakes in the world. Its basin area is around 51,000 km^2, some 5000 km^2 of which was covered by the lake [35]. The Urmia Basin has a total population of 6.5 million and is an important agricultural region. The average annual precipitation ranges between 200 and 300 mm, with air temperatures between 0 and −20 °C in winter and up to 40 °C in summer. The basin's climate is classified as arid to semi-arid, causing the agriculture to be highly dependent on irrigation [36]. The total irrigated area in the basin is 5119 km^2, with 89% of available water used for irrigation (*Withdrawals*). The main crops are wheat, barley, alfalfa, potato, tomato, sugar beet and apple.

An assessment of the lake's water surface level over a hundred-year span shows a sharp, unusual decline after 1995 [37]. By 2016, the surface area of Lake Urmia was found to have decreased by 90% (Figure 1). As a result, the salinity of the lake has also increased sharply, disturbing ecosystems, local agriculture and livelihoods, regional health and tourism [38].

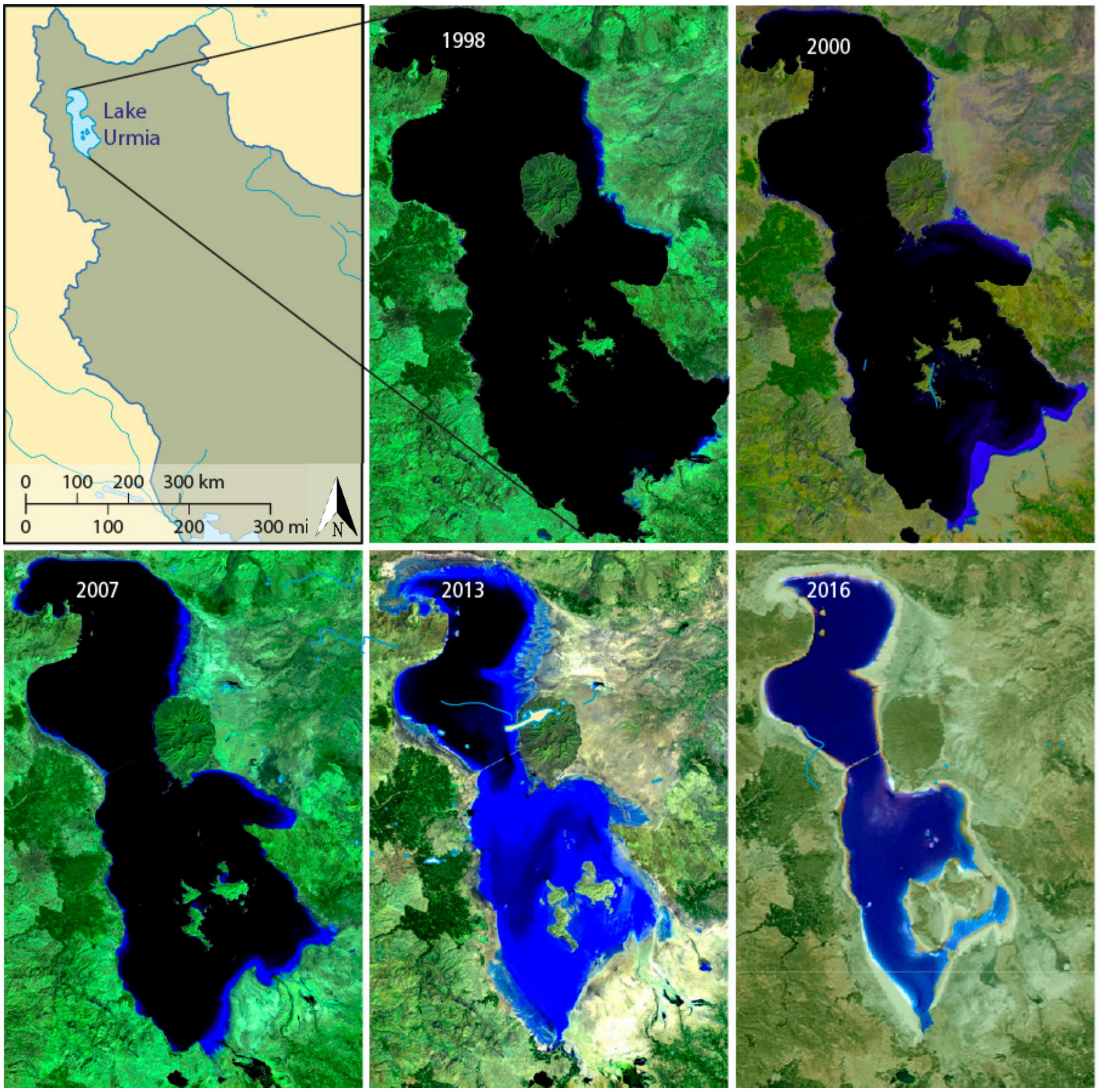

Figure 1. Lake Urmia location in the northwest of Iran and the desiccation trend between August 1998 and August 2016 [39].

2.2. Urmia Lake Restoration Program (ULRP)

To address the unsustainable situation, the government of Iran announced a national ten-year program, the "Urmia Lake Restoration Program" (ULRP), in July 2013 (Supplementary Materials (1)). The government committed a budget of USD 5 billion to the program [40], the main goal of which is the revival of the life cycle of the lake within 10 years. The plan also aims to promote the development of sustainable agriculture.

The ULRP uses six categories of strategies. For this study, we assumed successful ULRP implementation, namely that withdrawals in the basin will be successfully controlled or that structural strategies will be able to direct the surface flow available in the basin to the lake [41]. While the quantitative effects of strategies that aim directly to increase the basin *Outflow* are unclear, those having a direct impact on *Outflow* are:

Strategy #1. Reduction of 40% of ground and surface water allocated to the farmers through a direct purchasing system run by the Ministry of Energy.
Strategy #2. Planning by the Ministry of Jihad-e-Agriculture to enhance the productivity of 60% of the remaining water volume still used for irrigation.

(2-a). Deficit irrigation for wheat.
(2-b). Deficit irrigation for barley.
(2-c). Replacing barley with alfalfa.
(2-d). Using greenhouse cultivation for vegetables.

Strategy #3. Allocation of funds and supply of the required technologies by the government to increase the efficiency of usage of the remaining water.

(3-a). Increasing application efficiency by applying micro-irrigation alternatives.
(3-b). Increasing distribution efficiency by using pipes for water distribution to the fields.
(3-c). Increasing conveyance efficiency by lining canals.

Strategy #4. Appropriation of the required funds and accelerated transfer of water from the Zaab and Silveh rivers to the Urmia Lake Basin.
Strategy #5. Transfer of treated wastewater from the Urmia Lake Basin into Lake Urmia.

2.3. The Water-Saving Intervention Assessment Framework

Water accounting refers to approaches that present information on water resources, supply and use [42]. This involves a water-balance approach where the sum of outflows equals the sum of outflows plus storage [13]. Thus, water accounting is the key to understanding water inflows and outflows at the basin scale, which is essential for assessing water-saving strategies [16]. Water accounting covers a range of methods of reporting water information [43]. Building on the water accounting approach, we propose a framework that provides a simple overview of the status of the water resources of a basin (WSSA; Figure 2). By comparing the situations ex-ante and ex-post of the interventions, the WSSA framework can evaluate the effectiveness of water-saving strategies. The WSSA framework serves three main purposes. Firstly, it allows for considering possible future changes in water availability and demand due to climate change and socioeconomic scenarios. Secondly, the difference between water demand and withdrawal is clearly shown. This highlights shortages and overuse that could affect the efficacy of a water-saving intervention. Thirdly, depletion and return flows (to surface water and groundwater) are included separately; this serves to avoid overlooking the potential rebound effect. The WSSA framework comprises five main components to evaluate water-saving strategies under different socioeconomic and climate change scenarios. As follows, we present each component and the possible methods to estimate them ex-ante and ex-post of the intervention:

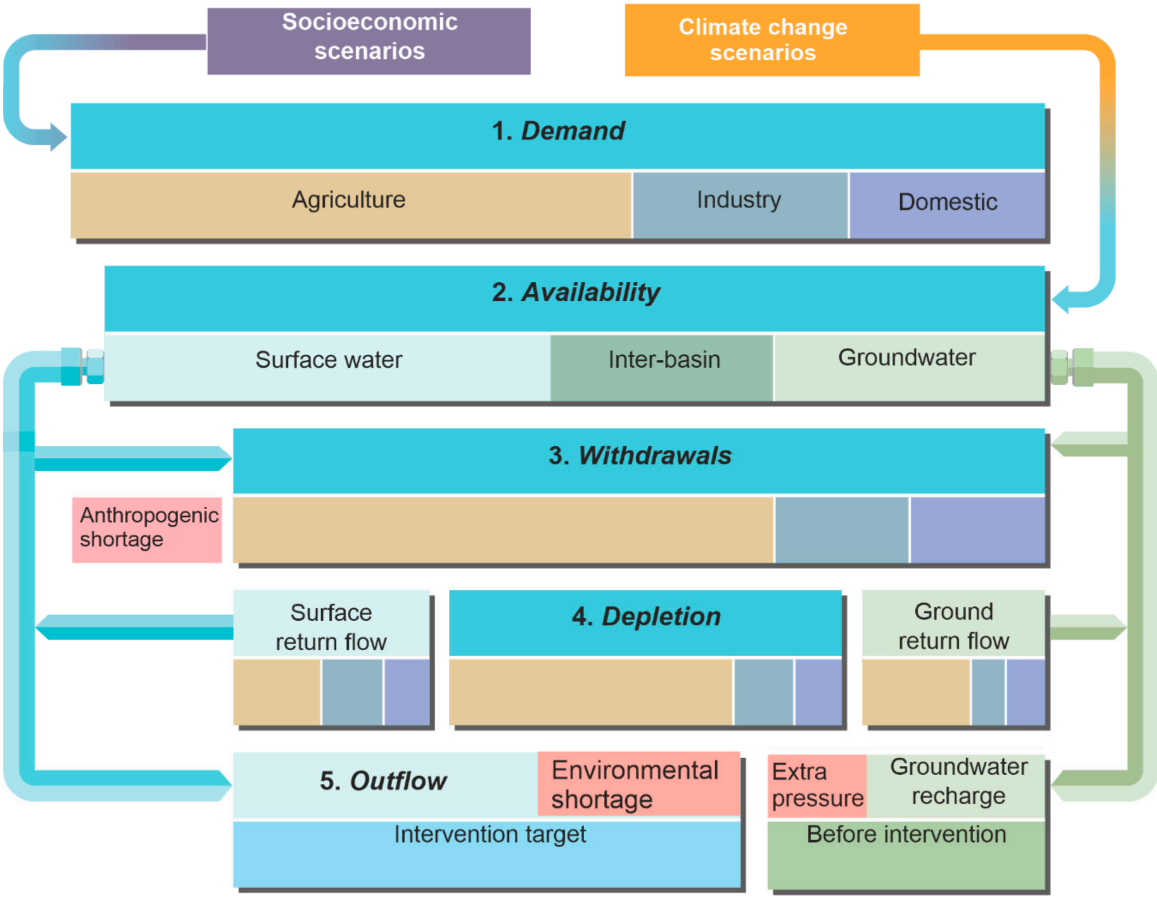

Figure 2. The water-saving strategies assessment (WSSA) framework with the five key components relating to the water balance of the entire river basin. Water-saving strategies can affect all five components directly or indirectly. Therefore, to assess the impact of water-saving strategies on the basin, the five components should be estimated ex-ante and ex-post of an intervention.

1. *(Gross) Demand* (for simplicity, we refer to this as *Demand* in this paper) should be estimated for specific water uses (agriculture, industry and domestic) under different socioeconomic scenarios. *Demand* is equal to:

$$Demand = \text{net water demand/total efficiency}$$

Ex-ante *Demand* can be obtained from empirical data for different sectors. Ex-post *Demand* should be calculated considering population growth and future development in the industrial and agricultural sectors. If *Demand* is not met in a basin, then a shortage occurs.

In the Urmia case, the ex-ante *Demand* for the agricultural sector was obtained from the official report by the Iran Ministry of Energy [44]. They calculated the Urmia basin *Demand* based on the cultivated area of the basin, cropping patterns, planting and harvesting dates, irrigation management and efficiency. To estimate the ex-post *Demand* for the agricultural sector, firstly the net demand was estimated by applying the proposed headlines for Strategy #2. Secondly, the total irrigation efficiency E_{Total} equals conveyance efficiency (E_c) × distribution efficiency (E_d) × application efficiency (E_a)); the explanation of each term is in the Appendix A) was estimated by applying the proposed headlines for Strategy #3. Finally, the *Demand* was estimated by dividing the net demand by total efficiency.

The estimation of the ex-ante *Demand* for industry and domestic use was reported by the Iranian Ministry of Energy [45]. The ex-post *Demand* for industry and domestic use was estimated for two senarios: "business-as-usual" (applying the current water distribution system) and the "business-as-planned" (applying improvements in the water distribution system), considering a growing popluation and industrial development [45].

2. *Availability* is the amount of water in the basin which is exploitable; this includes naturalized surface flow, extracted groundwater and any water added to the basin water resources by being transferred from outside the basin or by desalination. This is equal to:

$$Availability = naturalized\ surface\ flow + renewable\ groundwater + additional\ sources$$

Naturalized surface flow: The naturalized surface flow (the surface flow without considering any anthropogenic impact) can be estimated through a simulation approach for both ex-ante and ex-post by applying a hydrological model. The ex-post naturalized flow can be simulated for different climate change scenarios.

The naturalized surface flow for the Urmia case was estimated by using the Variable Infiltration Capacity (VIC) hydrological model. We manually calibrated the VIC model for the Urmia basin in a systematic way, using seven runoff-related model parameters (including the infiltration parameter) and three soil-layer thicknesses for the Urmia Basin; for more information, please refer to Shadkam et al. [46]. We forced the calibrated VIC for the Urmia Basin using bias-corrected daily climate model output, as developed within the Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP [47–49]). In order to cover the whole range of future greenhouse gas emissions, we used the Representative Concentration Pathways (RCPSs), selecting the highest (8.5) and the lowest (2.6) [50]; for more details, please refer to [51]. To cover decadal variabilities, we used a 10-year moving average for 2005 and the projected outflow for 2025.

Renewable groundwater: The ex-ante groundwater extraction data can be obtained from data measured on the ground or from satellite data. Ex-post groundwater *Withdrawals* can be estimated based on future water demand and groundwater extraction regulations. Groundwater use requires careful consideration. Groundwater *Withdrawal* should, essentially, return back to groundwater. If groundwater volumes reduce, then this should also be accounted for in the WSSA framework. This is particularly important for an area where groundwater volumes are under pressure. The framework does not assess the interaction between surface water and groundwater.

There are around 88,000 wells in the Urmia Lake Basin, of which an estimated 40,000 are unauthorized. The *Withdrawals* from groundwater, including wells and qanats, were reported by the ULRP [52]. These *Withdrawals* represent groundwater supply for the historic period 2000–2010. Based on the ULRP, there needs to be a 40% decrease in *Withdrawals* in agriculture, of which $0.5 \times 10^9\ m^3\ yr^{-1}$ would be deducted from groundwater abstraction [53]. However, a substantial portion of industrial and domestic *Demand* will still be met from groundwater resources. This means that groundwater extraction will increase in the industrial and domestic sectors. Therefore, the groundwater extraction for ex-ante was estimated considering the ULRP plan, the population growth and the industrial development under both the business-as-planned and business-as-usual scenarios.

Additional sources: These may include water transfers or abstractions from non-renewable (fossil) groundwater sources. In the Urmia basin, $0.7 \times 10^9\ m^3\ yr^{-1}$ of inter-basin transfer water from the Zaab Basin has been considered as an additional source.

3. *Withdrawals* (also referred to as water extractions in the literature) refers to abstractions by all users (agriculture, industry and domestic) and can be estimated for current and possible future developments by using observations and model simulations. Ex-post *Withdrawals* should also include those that result from proposed interventions. The amount of *Withdrawals* depends on how much water is available. If the *Availability* is more than the *Demand*, then the *Withdrawals* are equal to the *Demand*.

For the Urmia basin, the ex-ante *Withdrawals* for agricultural sector were reported by the Iran Ministry of Energy [44]. The ULRP aims for the reduction of 40% of allocated water to the farmers (Strategy #1), which can be translated to a 40% reduction in the ex-post *Withdrawals*. Up to now, the domestic and industrial demands have always been met in the basin; the ex-ante *Withdrawals* have been equal to the *Demand*. For ex-post, the domestic and industrial *Demands* will continue to be fully met; *Withdrawals* will, thus, be the same as *Demand* in these two sectors.

4. *Depletion* (also referred to as consumption) is equal to:

$$Depletion = Withdrawals - \text{return flow}$$

Thus, to calculate water depletion, one needs to understand what proportion of the *Withdrawals* will return to the system. In an endorheic basin, a change in the depletion will show the real water saved through the intervention [54].

To determine the ex-ante return flow in the Urmia basin, we used simulation studies which have estimated the current total return flow into the basin [55,56]. To estimate the proportions of return flow to groundwater and to surface water, we used reports by the Iran Ministry of Energy [57] which estimated the surface return flows from irrigation, based on field observations.

To determine ex-post return flow for the Urmia basin, we used Toloei's study [58], which assessed the effect of changing from gravity irrigation to pressurized systems by applying the Soil and Water Assessment Tool (SWAT) to the Urmia Basin.

5. *Outflow* is the streamflow at the outlet of a catchment area.

$$Outflow = Availability - Withdrawals + \text{surface return flow}$$

To evaluate whether there is enough *Outflow*, it should be compared to the Environmental Flow Requirement (EFR) or, in the case of the Urmia Lake Restoration Program, the intervention target.

3. Results

In what follows, we present the results of the estimation of the five components, both ex-ante and ex-post the ULRP, to assess if the ULRP is able to increase the basin outflow to the lake and reach its goal of a 3.1×10^9 m^3 yr^{-1} outflow to the lake.

3.1. Demand

3.1.1. Agricultural Sector's Demand

Ex-ante *Demand*: The Iran Ministry of Energy [44] reported that the net irrigation demand for water is around 2.6×10^9 m^3 yr^{-1}. The total irrigation efficiency E_{Total} was reported to be 34% and 42% for croplands and orchards, respectively. Consequently, the ex-ante *Demand* in the agricultural sector was estimated to be 6.7×10^9 m^3 yr^{-1} (around 2.3×10^9 m^3 yr^{-1} relates to orchards and 4.4×10^9 m^3 yr^{-1} to farmlands).

Ex-post *Demand*: Following this, we present the estimation of ex-post *Demand* by considering the application of proposed headlines for Strategy #2 (to estimate ex-post net demand) and Strategy #3 (to estimate ex-post efficiency).

The ex-post net water demand has been estimated based on the proposed headlines for Strategy #2 [53] (Table 1):

(2-a) Deficit irrigation for wheat: the Soil and Water Research Institute of Iran [59] estimated that by changing the current variety to the Pishgam variety for the Urmia Basin, deficit irrigation of up to 10% can be conducted without a significant reduction in productivity.

(2-b) Deficit irrigation for barley: the Bahman variety was applied, based on the Soil and Water Research Institute of Iran's [59] recommendation for the Urmia Basin.

(2-c) Replacing alfalfa with barley: the reported net irrigation demand of alfalfa is ~2300 m^3/ha lower than that of barley (Bahman variety). The initial investigation revealed that there is potential to replace 30% of alfalfa in the area with barley; this was applied in this study [41].

(2-d) Using greenhouse cultivation for vegetables: the Iran Ministry of Energy [60] reported that greenhouse cultivation can decrease the net irrigation demand by 25% in this area for vegetables. We considered that the ULRP will be able to transfer all vegetables to greenhouses by 2025.

Therefore, in total, if Strategy #2 (2-a to 2-d) is applied successfully, the net irrigation demand will decrease by 0.2×10^9 m^3 yr^{-1}—a 7% reduction. Table 1 shows the average net irrigation demands for the covered area ex-ante and ex-post of the individual strategies.

Table 1. The impact of the Urmia Lake Restoration Program (ULRP) Strategy #2 (enhancing crop water productivity) on the net irrigation demand. The average net irrigation demands for the covered area were estimated ex-ante (2000–2010) and ex-post (2020–2030) individually for Strategy #2 (2-a to 2-d).

Proposed Strategies	**Net Irrigation Demand ($\times 10^9$ m^3 yr^{-1})**	
	Ex-Ante ULRP	**Ex-Post ULRP**
(2-a) Deficit irrigation for wheat (164 ha)	0.448	0.389
(2-b) Deficit irrigation for barley (36 ha)	0.072	0.065
(2-c) Greenhouse cultivation for vegetables (4 ha)	0.019	0.014
(2-d) Replacing alfalfa with short growing season barley (121 ha)	0.872	0.760
Total	1.410	1.228

The ex-post irrigation efficiency was estimated based on the proposed headlines for Strategy #3 [53] (Table 2):

(3-a) Increasing irrigation efficiency by applying micro-irrigation alternatives: the current application efficiency is around 50%. For croplands (i.e., wheat, barley and sugar beet), we substituted sprinkler irrigation for furrow irrigation which has an efficiency in the basin of around 75%. For orchards (fruits and nut trees), the current reported efficiency is about 62%, which could increase to around 90% if the current furrow irrigation is replaced with drip irrigation [44].

(3-b) Increasing distribution efficiency by using pipes for water distribution to the fields: the average current distribution efficiency in the basin is around 85%, which could increase to around 95% when pipes are used [44].

(3-c) Increasing conveyance efficiency by lining canals: the average conveyance efficiency in the basin is around 80%, which could increase to around 90% if lining would be implemented [44].

Regarding the topography, soil type and water quality, up to 70% of the irrigated land could potentially be irrigated using pressurized irrigation. Therefore, it has been assumed that 70% of all irrigated land will be equipped with pressurized irrigation after full implementation of the ULRP [60]. Furthermore, by applying Strategy #3 (3-a to 3-c), the total irrigation efficiency is expected to increase to 77% for orchards and to 64% for croplands.

Thus, the *Demand* (net demand divided by total efficiency) in the agricultural sector could potentially decrease to an estimated 4.1×10^9 m^3 yr^{-1} (38%).

Table 2. The impact of the Urmia Lake Restoration Program (ULRP) Strategy #3 (increasing irrigation efficiency). The irrigation efficiencies were estimated ex-ante (2000–2010) and ex-post (2020–2030) individually for Strategy #3 (3-a to 3-c).

Application	**Ex-Ante ULRP**				**Ex-Post ULRP**			
	E_c	E_d	E_a	E_{Total}	E_c	E_d	E_a	E_{Total} *
Orchard	80%	85%	62%	42%	95%	90%	90%	77%
Cropland	80%	85%	50%	34%	95%	90%	75%	64%

* (E_c): Conveyance efficiency; (E_d): Distribution efficiency; (E_a): Application efficiency; $E_{Total} = Ec \times Ed \times Ea$.

3.1.2. Domestic and Industrial Sectors

Ex-ante *Demand*: In 2005, the population in the Urmia Basin was around 5 million, with 3.5 million people living in urban areas and 1.5 million in rural areas. Their water *Demand* was estimated by the Iranian Ministry of Energy [61]. This estimate considered 7100 firms in the basin, including textile, food, metal and steel, wood, mining and machinery manufacturing, for which the *Demand* was reported by the Iranian Ministry of Energy to be around 0.3×10^9 m^3 yr^{-1} [61].

Ex-post *Demand*: The population of the Urmia Basin is predicted to increase to around 6.5 million in 2025 [62]. The number of firms is also predicted to increase to 16,352 sites in the basin. The *Demand* will increase by 190% and 254% for the business-as-planned and business-as-usual scenarios, respectively (Figure 3). Detailed information can be found in the Supplementary Materials (2).

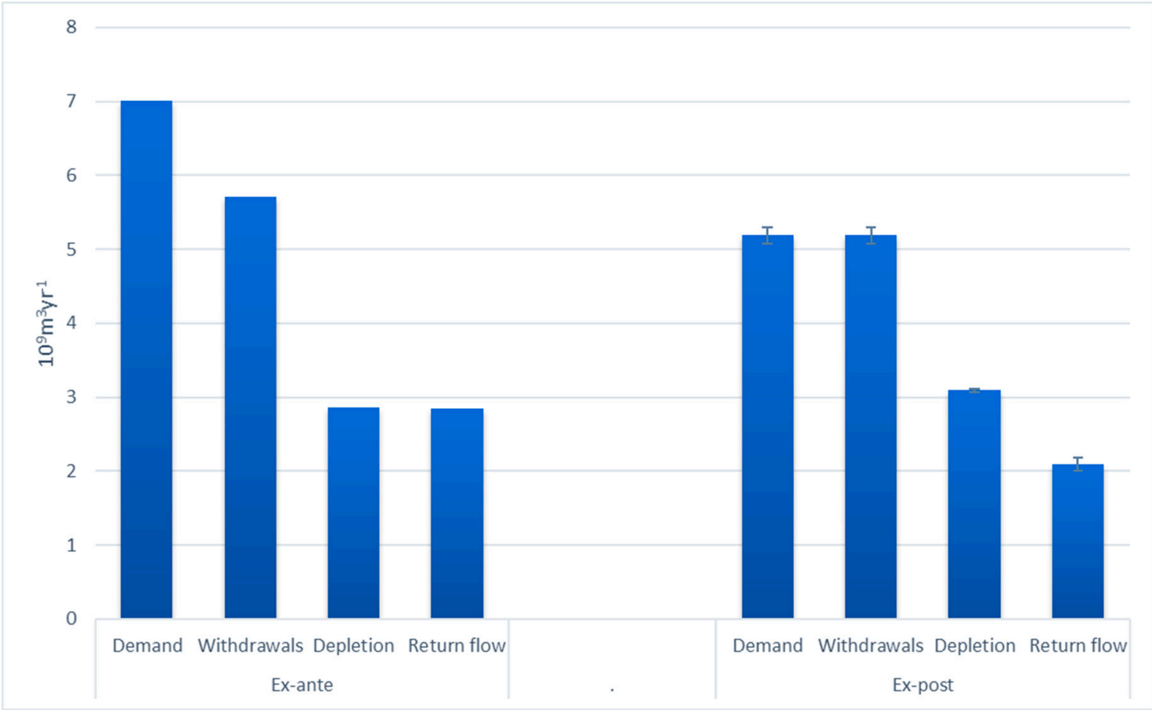

Figure 3. The Urmia Lake Basin ex-ante (2000–2010) and ex-post (2020–2030) *Demand*, *Withdrawals* from ground and surface water, *Depletion* and return flows to the surface and groundwater. The error bars represent the value ranges under the different climate change and socioeconomic.

3.2. *Availability*

Ex-ante *Availability:* Based on the simulated naturalized runoff (using the VIC model), the water availability is around 4.7×10^9 m^3 yr^{-1}. There are approximately 88,000 wells in the Urmia Lake Basin, of which an estimated 40,000 are unauthorized. The *Withdrawals* from groundwater, including wells and qanats, were reported by the ULRP [52] to be 2.4×10^9 m^3 yr^{-1}. These withdrawals represent the groundwater supply for the historic period 2000–2010. There was no inter-basin transfer in the Urmia Lake Basin over the ex-ante period.

Ex-post *Availability*: Based on the simulated naturalized results, naturalized runoff is expected to reduce in 2010–2030 by around 3% for the low climate change scenario (RCP2.6) and by 15% for the higher climate change scenario (RCP8.5).

Based on the ULRP, there needs to be a 0.5×10^9 m^3 yr^{-1} decrease in *Withdrawals* in agriculture from groundwater abstraction [53]. However, a substantial portion of the industrial and domestic *Demand* will still be met from groundwater resources. This means that groundwater extraction will increase by 0.5×10^9 m^3 yr^{-1} and 0.7×10^9 m^3 yr^{-1} under the business-as-planned and business-as-usual scenarios, respectively. Thus, after the ULRP, the total groundwater *Withdrawals* are expected to increase by ~1% and ~7% under the business-as-planned and business-as-usual socioeconomic development scenarios, respectively.

In addition, 0.7×10^9 m^3 yr^{-1} of inter-basin transfer water from the Zaab Basin has been added to the available water. The *Availability* for the ex-ante and ex-post periods are presented in Figure 4. For more detailed information, please refer to Supplementary Material (3).

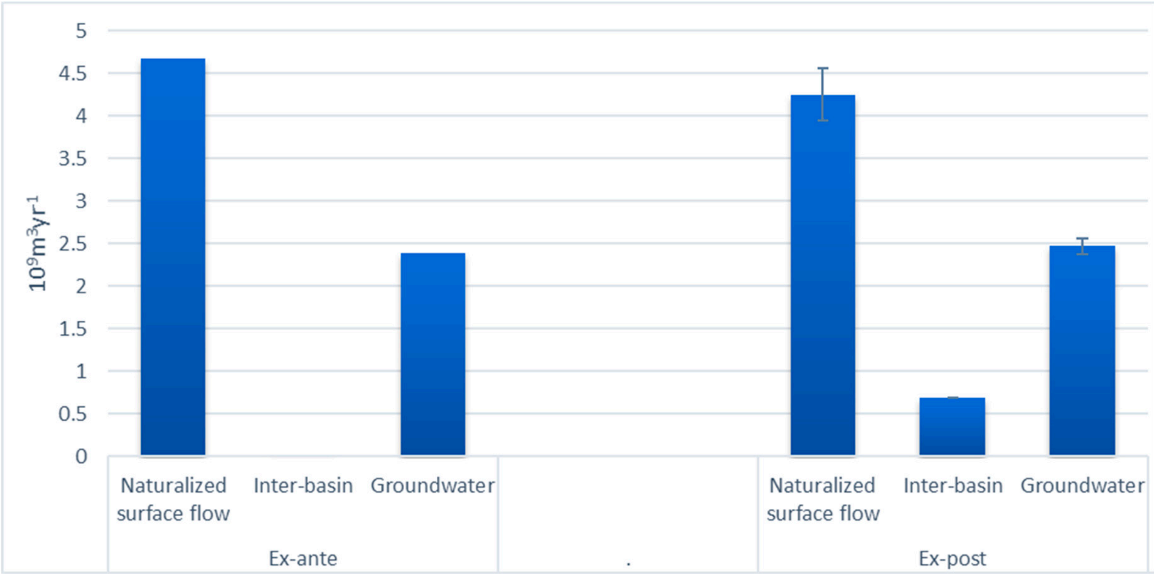

Figure 4. The Urmia Lake Basin ex-ante (2000–2010) and ex-post (2020–2030) *Availability* for the ex-ante and ex-post periods; the error bars represent the uncertainty range under the low climate change scenario (RCP2.6) and the higher climate change scenario (RCP8.5) (for naturalized surface flow) and the business-as-planned and business-as-usual scenarios (for groundwater).

3.3. *Withdrawal and Depletion*

3.3.1. Agricultural Sector's Withdrawal and Depletion

The amount of *Withdrawals* depends on water *Availability* for the agricultural sector. If the available water is less than *Demand*, then the *Withdrawals* will be the available water for agriculture; otherwise, *Withdrawals* are equal to *Demand*. The ex-ante *Withdrawal* for the agricultural sector was reported to be around 5.3×10^9 m^3 yr^{-1} [44], which is much less than the *Demand* (6.7×10^9 m^3 yr^{-1}). The ex-ante *Demand* is expected to decrease by 40% to 4.0×10^9 m^3 yr^{-1} which is less than the available basin water for the agricultural sector (5.3×10^9 m^3 yr^{-1}). Therefore, the *Withdrawals* equal the *Demand*.

Depletion equals *Withdrawals* minus return flow. We thus need to firstly estimate the return flow. Simulation studies have estimated the current total return flow (to surface and groundwater) in the basin to be, on average, 48% of irrigation *Withdrawals* [55,56]. However, the proportions of return flow to groundwater and to surface water were not determined in these studies. To estimate the proportions of return flow to groundwater and to surface water, we used reports by the Iran Ministry of Energy [57] which estimated surface return flows from irrigation to be ~18% of *Withdrawals*, based on field observations. The return flow to the groundwater should, thus, be around 30%. Therefore, the estimated return flows for the ex-ante period are 0.9×10^9 m^3 yr^{-1} and 1.6×10^9 m^3 yr^{-1} to surface and ground flow, respectively. *Depletion* equals *Withdrawals* − return flow. Therefore, the ex-ante *Depletion* is estimated to be 2.7×10^9 m^3 yr^{-1}.

Toloei [58] assessed the effect of changing from gravity irrigation to pressurized systems, applying the Soil and Water Assessment Tool (SWAT) to the Urmia Basin. In common with this study, they assumed the transformation of gravity irrigation to drip irrigation for orchards and to sprinkler irrigation for farmland. Their results showed a decrease of 60% in groundwater return flow. They also reported a negligible amount of surface return flow in the case of pressurized irrigation. Based on their results, the ULRP will decrease the return flow by 77% and 40% for surface and groundwater, respectively. Thus, *Depletion* is estimated to increase (rather than decrease) by ~5% to 2.9×10^9 m^3 yr^{-1} after the ULRP (Figure 3).

3.3.2. Domestic and Industrial Sectors

Up to the present time, domestic and industrial demands have always been met in the basin; the ex-ante *Withdrawals* have been equal to the *Demand*. Based on the reported domestic and industrial return flow [61,63], the ex-ante *Depletion* is estimated at around 0.07×10^9 m^3 yr^{-1} (Figure 3).

After implementation of the ULRP, the domestic and industrial demands will continue to be fully met; *Withdrawals* will, thus, be the same as *Demand* in these two sectors. Based on the predicted domestic and industrial return flow, *Depletion* would increase by around 81% and 87% for the business-as-planned and business-as-usual scenarios, respectively (Figure 3).

In addition, the ULRP aims to treat and direct all urban (not rural) and industrial wastewater to the lake. To estimate how much domestic and industrial water will return to surface and groundwater, we applied the ULRP strategy aimed at treating and directing all urban (not rural) and industrial wastewater to the lake. Therefore, following the ULRP, the estimated urban and industrial wastewater was added to the surface water flows.

3.4. Outflow under Different Climate Change and Socioeconomic Scenarios

Outflow equals *Availability* − *Withdrawals* + Surface return flows. Therefore, *Outflow* for the ex-ante period was equal to 2.3×10^9 m^3 yr^{-1}. This is within the range of the reported ex-ante outflow to the lake [53]. The results (Figure 5) show that if the ULRP succeeds in performing all strategies, it can increase outflow by 49%, 51%, 53% and 57%, under the RCP2.6 and business-as-planned socioeconomic, the RCP2.6 and business-as-usual socioeconomic, the RCP8.5 and business-as-planned socioeconomic and the RCP8.5 and business-as-usual socioeconomic scenarios, respectively. However, only under RCP2.6 and under both socioeconomic scenarios will the basin outflow reach the ULRP target of 3.1×10^9 m^3 yr^{-1}. This is not the case for the RCP8.5 scenario for either socioeconomic scenario. The results are compared with the Urmia Lake Environmental Flow Requirements (EFRs) estimated by Abbaspour and Nazaridoust [64], which is the Urmia Lake Restoration Program's (ULRP's) target.

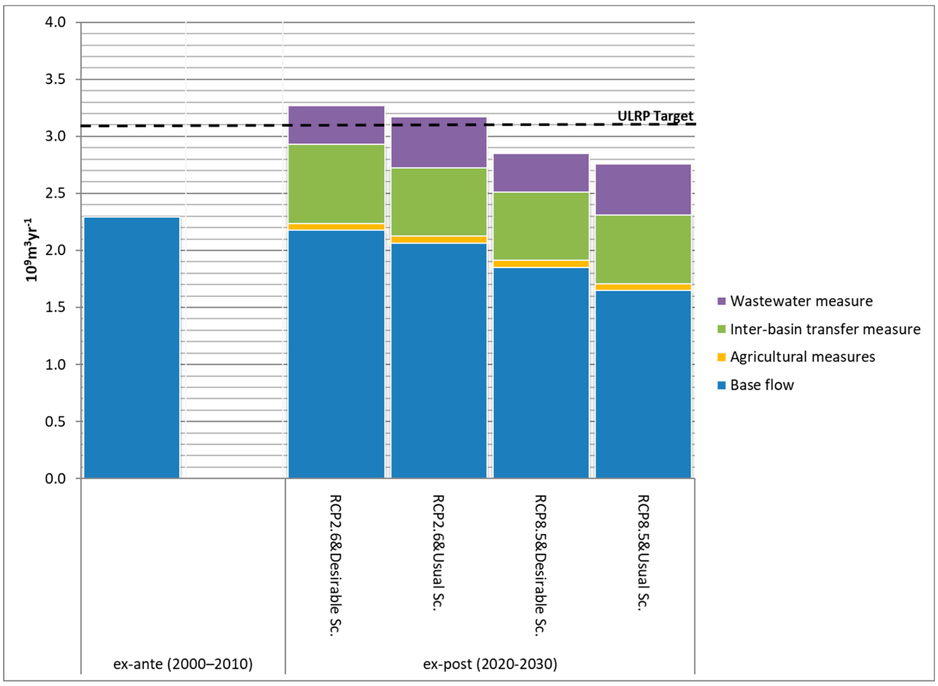

Figure 5. The ex-ante (2000–2010) and ex-post (2020–2030) outflows to the Urmia Lake under two different climate change scenarios (RCP2.6 and RCP8.5) and two different socioeconomic scenarios (business-as-planned and business-as-usual). The dashed line is the Urmia Lake Environmental Flow Requirements (EFRs) estimated by Abbaspour and Nazaridoust [64], which is the Urmia Lake Restoration Program's (ULRP's) target.

The effectiveness of each ULRP strategy in terms of changing *EF* (surface outflow) has also been estimated. The effectiveness of agricultural strategies in terms of *EF* can be estimated as the difference between *Withdrawals* for agriculture and surface return flow from agriculture before and after implementation of the ULRP. The effectiveness of wastewater strategies on *EF* is equal to the urban and industrial wastewater which would be conveyed to the lake under the ULRP. As shown in Figure 5, the most effective strategy is inter-basin transfer followed by the wastewater strategies. The agricultural strategy has little impact on the water flow.

Figure 6 shows the WSSA framework for the ULRP for ex-ante and ex-post of the interventions (a), the most optimistic climate change scenario for the future (RCP2.6) with the socioeconomic business-as-planned scenario (b) and the most pessimistic climate change scenario for the future (RCP8.5) with the socioeconomic business-as-usual scenario (c).

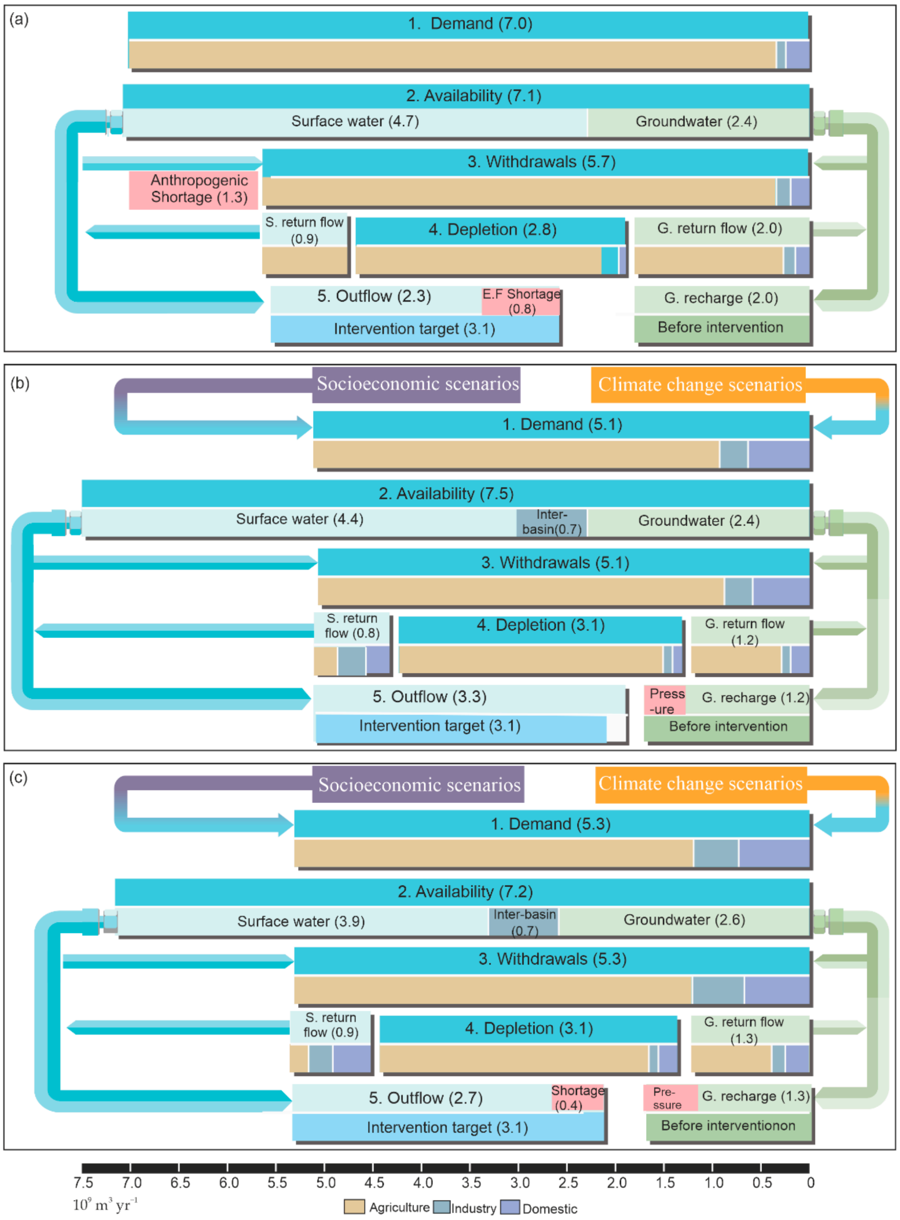

Figure 6. The water-saving strategies assessment (WSSA) framework for (**a**) ex-ante of the intervention (2000–2010) and ex-post of the intervention (2020–2030); (**b**) the RCP2.6 and business-as-planned socioeconomic scenarios and (**c**) the RCP8.5 and business-as-usual socioeconomic scenarios.

4. Discussion

To achieve a sustainable water balance for all water users in a basin, it is necessary to identify, quantify and report water-related information in a structured way. To achieve this, several national and international organizations have introduced different water-accounting frameworks. Some examples of water accounting systems are the System of Environmental–Economic Accounting for Water (SEEAW) [65], Water Footprint Accounting [66] and Water Accounting Plus (WA+) [5]. However, as none of the frameworks were specifically designed to assess a water-saving intervention, their results are not suited to adequately inform policy makers on the efficacy of water-saving interventions. The WSSA framework introduced in this study assists in generating a simple and informative overview that can be used to evaluate proposed interventions. Its benefits are threefold. Firstly, it considers uncertainties in water *Availability* and *Demand* by including climate change and socioeconomic scenarios. Secondly, the role of the rebound effect can be analyzed systematically by explicitly distinguishing between *Withdrawal* and *Depletion*, and thirdly, it discloses any possible shortages or over-exploitation in the basin by an explicit recognition of *Demand* and *Withdrawals*. The framework promotes an improved understanding of the current state of basin water resources, future uncertainties and barriers and provides opportunities for real water saving in a water-stressed basin. The framework can also be used to evaluate the impact of water-saving policies on groundwater resources.

4.1. Application of the WSSA Framework for the ULRP

As can be seen in Figure 6a, for the ex-ante period, the sectors' water *Demands* were almost equal to the *Availability* (~7×10^9 m^3 yr^{-1}). In terms of EFRs, this shows that the basin experiences water scarcity. It is, therefore, not surprising that the sectors' *Withdrawals*, 5.7×10^9 m^3 yr^{-1}, were lower than their *Demands*. The difference between the two has been expressed as representing the anthropogenic water shortage in the basin (Figure 6a). As domestic and industrial demands are fully met, this shortage is fully attributed to the agricultural sector. It means that there has already been a (gross) shortage of ~1.3×10^9 m^3 yr^{-1} (~20% of *Demand*) for the agricultural sector in the basin. This is confirmed by the Iran Ministry of Energy [44], particularly for the downstream part of the basin (near Lake Urmia). Regarding this shortage, proportionally, only 2.1×10^9 m^3 yr^{-1} of the 2.6×10^9 m^3 yr^{-1} net demand for water can be met. Thus, of the 2.7×10^9 m^3 yr^{-1} agricultural depletion, 2.1×10^9 m^3 yr^{-1} is beneficial and 0.7×10^9 m^3 yr^{-1} is non-beneficial ex-ante agricultural depletion. After the ULRP (Figure 6b,c), the *Demand* for water would be less than the *Availability* under all scenarios. This shows that there would be no anthropogenic water shortage in any of the sectors, including the agricultural sector. In other words, the ULRP would be able to fulfill the full irrigation demand for the farmers and, in that way, eliminate the earlier shortage. From the 2.9×10^9 m^3 yr^{-1} agricultural depletion after implementing the ULRP, 2.4×10^9 m^3 yr^{-1} (full net demand) would be beneficial and 0.5×10^9 m^3 yr^{-1} non-beneficial depletion of water.

Ex-ante *Depletion* for all sectors together has been estimated at 2.8×10^9 m^3 yr^{-1}. After implementation of the ULRP, *Depletion* is estimated to increase further, rather than decrease, by estimated amounts of ~8% and ~9% for the business-as-planned and business-as-usual scenarios, respectively. The increase in *Depletion* is caused by two factors; the first factor is the growth in population and industrial development, whilst the second factor, as explained above, is that the ULRP would provide enough water to overcome earlier shortages. This would mean that the entire agricultural net *Demand* would be met. Thus, although the ULRP agricultural strategies would decrease *Demand* by ~40% and *Withdrawals* by ~23%, *Depletion* would still increase by an estimated ~17%. This implies that the proposed interventions in agriculture will not lead to real water saving, but rather lead to increased water use in agriculture.

4.2. The ULRP Outcome under Different Scenarios

The basin *Outflow* to the lake was estimated for four different scenarios and the results indicate that the ULRP is likely to reach its goal only under limited climate change. As 60% of total *Withdrawals* by the agricultural sector are from surface water, if *Withdrawals* are decreased from 5.3×10^9 m^3 yr^{-1} to 4.1×10^9 m^3 yr^{-1}, the surface *Withdrawals* would decrease by approximately 0.8×10^9 m^3 yr^{-1}. On the other hand, the surface return flows would decrease sharply by 0.7×10^9 m^3 yr^{-1} due to the use of pressurized irrigation systems. Thus, in practice, the ULRP agricultural strategies would only help to save water at a volume of 0.06×10^9 m^3 yr^{-1}; this is far below the expected amount (1.34×10^9 m^3 yr^{-1}, [53]). These results are consistent with Saemian et al. [67] who evaluated the efficiency of the ULRP measures on the state of the lake up to 2019 using spaceborne observations along with ground-based measurements. Their results showed that the lake status stabilized between 2015 to 2019; however, the long-term trend (2003 to 2019) was still negative. They indicated that the stabilization was mostly due to a drought-free period from 2015 to 2019 and anomalous precipitation events in 2016 and early 2019 (rather than the ULRP measures).

The proposed policy will also lead to an increase in urban and industrial return flow from treated wastewater that would be conveyed to Lake Urmia. This will add around 0.5×10^9 m^3 yr^{-1} of water to surface return flows. Before the ULRP was implemented, the return flow went back to the groundwater; consequently, the proposed change will cause a considerable reduction in return flow to the groundwater. In addition, the groundwater return flows from the agricultural sector would decrease by 0.7×10^9 m^3 yr^{-1} after the implementation of the ULRP.

4.3. Reasons for the Possible Failure of the ULRP

The application of the framework to the Urmia Lake Basin revealed that under a limited climate change scenario (RCP 2.6), the policy could reach the water-saving target. This, however, assumes that the ULRP is fully implemented, which is actually unlikely. It is thus possible that the ULRP will not achieve its stated goal, despite the huge investment and the social and economic impacts of the proposed interventions. These results reflect those of Saemian et al. [67] who assessed the lake's status up to 2019 and reported that the water level is still far from its targeted level. The framework made clear a few reasons for the poor performance. The first reason is the rebound effect. However, as the ULRP decreases the gross surface *Withdrawals*, it will cause almost the same reduction in the surface return flow. This means that although average irrigation efficiency would improve from 38% to 84%, the ULRP's agricultural strategies would not lead to the expected change in the basin outflow to the lake. This can be explained by the concept of effective irrigation efficiency rather than classical irrigation efficiency. The ULRP aims to increase classical efficiency, which is *Depletion* divided by *Withdrawals*, whereas effective efficiency is the crop-effective use of applied irrigation water (*Depletion*) divided by the effective inflow less the effective outflow (*Withdrawals* − return flows) [54]. The effective irrigation efficiency for the Urmia Lake Basin is, thus, around 75% in the current situation. This relatively high effective efficiency for the basin shows that there is not much room to improve the efficiency. These results are consistent with those of Alizadeh and Keshavarz [68] who assessed the status of irrigation efficiency in Iran. They indicated that due to high effective efficiency in Iran, there is not much real water saving to be attained through irrigation efficiency improvement. However, having said that, in this study, it was assumed that the authorities are able to control water extraction and land expansion, which is highly unlikely. Berbel et al. [69] undertook a comprehensive literature review linking water savings with water diversion and depletion, including both theoretical models and empirical evidence. They concluded that if land expansion and water rights are not strictly controlled in a water-saving intervention, increasing rather than decreasing water depletion is to be expected. The results of this study also support the study by Ahmadzadeh and Morid [55]. Their simulation results showed that pressurized irrigation can reduce water uptake by about 0.16×10^9 m^3 yr^{-1} compared to current surface irrigation in the Zarrineh Rud Basin, which is the main sub-basin in the Urmia Basin. They also indicated that pressurized irrigation reduces the return flow by about the same amount, which results in no significant change in the total outflow to Urmia Lake. Farokhnia [56] simulated a transformation from furrow irrigation to drip irrigation (for orchards) and sprinkler irrigation (for farmland) for the Urmia basin, applying the SWAT model. Their results showed that improving irrigation efficiency in the Urmia basin would decrease *Withdrawals* by 45%. However, real water saving would only be around 13% if the farmers retain deficit irrigation, and otherwise, only 5%.

The second reason for the possible poor performance of the proposed interventions reveals the fact that the basin has already faced a water shortage of around 1.3×10^9 m^3 yr^{-1} in the agricultural sector. Therefore, the net demand will not be fully met, which means that farmers are already experiencing water shortages. Unwillingness to perform deficit irrigation and low productivity have been reported in many parts of the basin, particularly in the downstream parts around the lake [44]. By increasing irrigation efficiency, the *Demand* will be less than the *Availability*, implying that the farmers can withdraw the amount they need and meet the full irrigation demand. Therefore, the depletion increase will be ~17%. In other words, implementing the proposed interventions (ULRP) will compensate for the anthropogenic shortage which the basin population has already faced rather than save water for the environment. We named this effect as the *Shortage effect*. The *Shortage effect* occurs when water-saving strategies (e.g., increasing efficiency) provide results, thus reducing the *Demand*, which means reducing the shortage which had already been in place in the basin. It means that, unlike the ex-ante intervention, the plants can receive as much water as they need, resulting in increasing *Depletion* and decreasing *Available* water for the environment. Although this effect can play a serious role in interventions aimed at saving water for the environment, to the best of our knowledge, this has not been considered as such in the previous literature.

A third reason for the possible poor performance of the proposed interventions is that the ULRP ignores the impact of future changes. The naturalized surface water of the basin may decrease by around 3% to 15% under RCP2.6 and RCP8.5, respectively. This has not been considered in the policy. Ignoring the impact of climate change is an extremely critical issue, with most of the scenarios predicting a water availability decline in semi-arid areas [2]. Saemian and Elmi [67] demonstrated that the lake level stabilized from 2015 to 2019; however, they warned that due to the high correlation between the lake status and rainfall, the current situation may not continue in times of dry periods. Another relevant change is the possible increase in demand due to socioeconomic development. However, as the ULRP aims to convey the treated wastewater to the lake, socioeconomic development can also increase the amount of wastewater which will eventually add to the lake outflow. This is not a sustainable solution, however, because it decreases groundwater recharge and will thus increase pressure on groundwater resources which are already heavily utilized.

4.4. Limitations and Uncertainties

Our assessment is affected by different uncertainties and limitations. Firstly, we used model simulation results for water availability. For uncertainties in the modeling framework, refer to Shadkam 2016a, 2016b [46,51]. The rest of the data, including *Demand* and *Withdrawals,* are derived from ground-measured data. All data were taken from governmental reports, whilst the validity of the data was confirmed by the ULRP Committee. However, data are often uncertain and/or error-prone. This is especially the case for parameters that are difficult to plan strategically, such as return flows. The numbers used for the purpose of demonstrating the framework in this study should, thus, be revised when more accurate data become available.

Secondly, this study focused on annual outflow to the lake at the basin level. Therefore, the results of this study do not show distinctions between the dry and wet seasons. However, this approach can be used further at finer spatial and temporal resolutions. This would help to understand where the particular strategies are needed. For example, across the basin, potential evaporation varies strongly. This is likely to be reflected in other parameters, such as irrigation efficiency, depletion or return flow. Thus, in a next step, the framework can be applied for finer spatial resolutions (e.g., sub-basin) and finer temporal resolutions (e.g., seasonally, to assess the seasonal variations including dry and wet seasons). However, such an approach depends on data availability.

Thirdly, using the framework, assessments are made to explore the effects of interventions. These assessments are based on quantifiable parameters in the water domain only, while some interventions may have other effects. For example, the inter-basin transfer is ranked as the most effective strategy for increasing outflow but it may negatively affect social or ecological indicators in another basin. In such cases, an additional qualitative assessment would be required. Finally, this study does not include surface–groundwater interactions which are susceptible to changes in the water balance. Moreover, for this simple demonstration case, changes in agricultural demand due to climate change were ignored, as were many other factors.

5. Conclusions

Although the concepts of water-saving strategies have been well described in the literature, many failed examples around the world show that the dynamic effects of water-saving strategies are still quite complex to be evaluated flawlessly by policy makers. The water-saving strategies assessment (WSSA) framework introduced in this study provided policy makers with a simple and informative overview to be used for evaluating proposed interventions by comprising five components. The WSSA framework was built on existing concepts and knowledge and combines them into a new comprehensive tool for evaluating planned water-saving strategies. This framework can be distinguished from existing water accounting frameworks ([5,65,66]) as it allows policy makers to explore the potential effects of planned activities while also taking into account the future by including climate change and socioeconomic scenarios. Furthermore, by making a clear distinction between *Demand, Availability*, *Withdrawal, Depletion* and *Outflow,* the framework raised the awareness of the policy makers on the common mistakes made in water-saving policies. The framework is, therefore, a useful communication tool which differentiates between these terms. In addition, the framework introduces a conceptual notion that depicts the undesired impact of water-saving policies, referred to as the *Shortage effect* in this study. In basins that face water shortages, the *Shortage effect* occurs when water-saving strategies result in a reduced shortage (leading to more *Depletion*) rather than saving water for the environment. The WSSA framework also helps to highlight opportunities that lead to real water saving in a basin.

The application of the WSSA framework for the Urmia Lake Basin revealed that although the Urmia Lake Restoration Program helped to increase *Outflow* into the Urmia Lake, it was unlikely to meet its target, in particular for the agricultural sector. By generating a clear overview of the situation of *Demand* and *Withdrawals* in the basin, the WSSA framework showed that agricultural strategies would probably not have a noticeable impact on the *Outflow* to the lake. Therefore, water saving interventions focused on increasing irrigation efficiency in this basin would not lead to an increase in the basin *Outflow* to the lake. The results of this study showed that additional sources of water, namely inter-basin transfer and treated wastewater, were more effective strategies for increasing *Outflow*. However, these interventions are also accompanied by side-effects associated with environmentally unsustainable outcomes. The WSSA framework showed that the most secure approach to increase real water saving is by reducing *Depletion*, which is a clear indicator of water saving. The ULRP decreased only 6% of agricultural *Depletion* (mostly none-beneficial). It is thus recommended to focus more on reducing both beneficial and non-beneficial *Depletion* in the Urmia Basin. Another strategy which can be considered to reduce *Depletion* is through decreasing soil evaporation in agricultural areas, particularly in irrigated land. The results of this study also showed that the performance of the proposed interventions is more sensitive to changes in the climate compared to socioeconomic changes. This is for two reasons. Firstly, over 90% of the water is depleted by the agricultural sector, so changes in population size and industrial developments have a relatively low impact on *Demand* compared to the agricultural sector. Secondly, based on the ULRP, the domestic and industrial wastewater will be treated and added to the basin *Outflow* to the lake. Therefore, by increasing domestic and industrial withdrawal, this return flow will also increase.

An advantage of using the WSSA framework is to give a clear overview of the possible effects of a water-saving intervention on basin water resources and to prevent critical issues being overlooked. It is thus recommended that, even where data are limited, the framework should be applied to assess any proposed water-saving intervention before implementation. Using the WSSA framework to compare alternative interventions can highlight the potential pitfalls and may be used to facilitate the debates among stakeholders. Furthermore, any type of data can be used, including ground data, results from model simulations, estimations derived from remotely sensed data or even some best-guess estimations.

Supplementary Materials: The following are available online at http://www.mdpi.com/2073-4441/12/10/2789/s1. Table S1: Urmia Basin ex-ante (2000–2010) and ex-post (2020–2030) *Demand; Withdrawals* from ground and surface water, *Depletion* and return flows to surface and groundwater ($\times 10^9$ m^3 yr^{-1}) for different sectors under different socioeconomic scenarios, Table S2: Urmia basin water Availability (×109 m^3 yr^{-1}) for ex-ante period and ex-post under RCP2.6 and RCP8.5.

Author Contributions: Conceptualization, S.S., P.v.O. and F.L.; Methodology, S.S., P.v.O.; Software, S.S.; Validation, S.S., P.v.O. and A.R.; Formal Analysis, S.S.; Investigation, S.S. and A.R.; Resources, S.S. and A.R.; Data Curation, S.S. and A.R.; Writing-Original Draft Preparation, S.S.; Writing-Review & Editing, S.S., F.L., P.v.O. and P.K.; Visualization, X.X.; Supervision, F.L., P.v.O. and P.K. All authors have read and agreed to the published version of the manuscript.

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Appendix A

Table A1. Indicators definition.

Indicator	Calculation Used in This Paper	Definition
Availability	Naturalized surface flow + renewable groundwater + additional sources	Part of water in the basin which is exploitable
Demand	Net water demand/total efficiency	Total amount of water needed by different sectors (i.e., agriculture, industry and domestic)
Withdrawal	-	Total amount of water extracted from a basin for different sectors (i.e., agriculture, industry and domestic)
Depletion	*Withdrawals* − return flows	Fraction of water withdrawal not returning to the water system
Outflow	*Availability* − *Withdrawals* + surface return flow	Streamflow at the outlet of a catchment
Distribution efficiency (E_d)	-	Represents the efficiency of water transport to the field
Application efficiency (E_a)	-	Represents the efficiency of water application in the field
Conveyance efficiency (E_c)	-	Represents the efficiency of water transport in canals

Table A1. *Cont.*

Indicator	Calculation Used in This Paper	Definition
Total irrigation efficiency (E_{Total})	Application efficiency (E_a) × Distribution efficiency (E_d) × Conveyance efficiency (E_c)	Represents the total water efficiency
Non-beneficial *Depletion*	-	Occurs when no benefit (or a negative benefit) is derived from the *Depletion* of water
Beneficial *Depletion*	-	Occurs when water is depleted to produce goods such as agricultural products
Shortage effect	-	Occurs when water-saving strategies (e.g., increasing efficiency) result in reducing the *Demand*, which means reducing the shortage which was already in place in the basin. Therefore, the intervention causes the plants to receive as much water as they need, which will result in increasing *Depletion* and decreasing the available water for the environment

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