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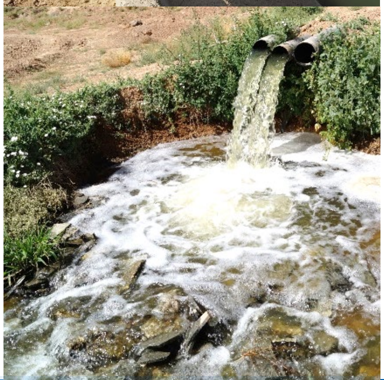



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Transformation Strategies in Agriculture

Project Report: Integrated Water Resource Management in the Zayandeh Rud River Basin

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مدیریت یکپارچه
رودخانه زاینده رود
IWRM
ZAYANDEH RUD

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Summary

Agriculture across the world is being transformed by the dynamic interaction of environmental and socio-economic factors such as the demand of global markets, urbanization, agricultural commercialization and intensification, climate change, concentration and vertical integration of food and bioenergy production. Innovation to adapt agricultural production to these challenges has to tackle the contemporary complexity of agricultural systems and its changing framework. The Zayandeh Rud river basin in Central Iran urgently needs forward-looking strategies for agricultural production in the midst of the acute problems of water scarcity and unequal water distribution between sectors and regions. The imbalance between water quantity and demand over the last two decades has motivated policy makers and managers to seek measures and strategies to reduce agricultural water use while minimizing losses in agricultural revenues. Addressing this complexity requires adaptation strategies in agriculture and rural development based on multi-stakeholder interaction.

The report at hand is one outcome of the project “Integrated Water Resources Management Zayandeh Rud” (3/2016 - 12/2018). It is an outcome of a strongly interactive process with local stakeholders designed and moderated in a cooperation between the German and Iranian project partners. The information gained in through the participatory process was synthesized into ten transformation strategies that are grouped into four focus areas (Capacity Development, Agricultural Management, Water Distribution, and Land Management and Soil Fertility). The participatory process and the resulting strategies with measures for their implementation are detailed in this report.

Important for the success of the agricultural transformation is the willingness of governments, farmers, donors, companies and civil society organizations to assume responsibilities, take risks and change behaviors at the level of individuals, organizations and society to pursue an accepted solution within the basin. The Iranian commitment to implementing IWRM in the Zayandeh Rud Basin and the two phases of the BMBF-funded project “IWRM” have been crucial steps towards the path to enhance the socio-economic and environmental situation in the Zayandeh Rud Basin. The comprehensive, deep and partially difficult but target-oriented discussions of the multi-stakeholders during the participatory workshops have been valuable contributions to improve communication and, therefore, the understanding of the diverse perspectives on the same challenging need for transformation.

Key to all the proposed transformation strategies in the report are activities to continue the development of a common knowledge base and set of tools, so that integrated resource management plans can be put forward and continually evaluated. Also emphasized is the need to involve all stakeholders to prevent fear of bias from hindering general acceptance of the tools. This is essential since none of the strategies can be expected to reduce basin-wide agricultural water use by themselves if the overall area of irrigated cultivated land area is not reduced.

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Abbreviations and symbols

Term	In AgroHyd Farmmodel/ IDM	Units	Description
AgTech			agricultural technology
apps			mobile apps (application)
ATB-CROPI			web-based program developed at ATB for crop water demand
BMBF			German Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung)
CWR	eAct+ tAct	mm	crop water requirement
DBV			National farmers' association of Germany (Deutsche Bauernverband)
DP	dp	mm	deep percolation of water through the soil
E_{act}	eAct	mm	actual evaporation from soil
E_{factor}	eFactor		factor to reduce evaporation due to mulching (1-eFactor = reduction)
EPO			Environmental Protection Organization
ERP			enterprise resources planning
ET_0	eto	mm	reference or potential evapotranspiration for a grass reference surface
ET_c	etc	mm	potential crop evapotranspiration
EWP			economic water productivity
FA			Focus areas
FAO			Food and Agriculture Organization
FMS			farm management system
FSA			farming systems impact analysis
f_w	fw	-	average fraction of soil surface wetted by irrigation or precipitation [0.01 - 1]
GIS			Geographical Information System
IC			irrigation controll
ICT			information and communication technologies
IDM			irrigation water demand module
Int	interception	mm	rainfall Interception by the plant above-ground biomass
IoT			internet of things
IPCC			Intergovernmental Panel on Climate Change
IPI			income protect insurance
IT			irrigation type
IWD	autoNetIrrigation	mm	Irrigation water demand
IWD_{min}		mm/year or MCM/ year	theoretical changes to IWD_{min} that can be expected from implementing technical measures
IWRM			Integrated water resource management
K_{cb}	kcb	-	plant-specific basal crop coefficient

K_s	ks	-	water stress coefficient
LBV			State farmers' association of Brandenburg (Landesbauernverband Brandenburg e.V.)
LST			land surface temperature
LWK			Lower Saxony Chamber of Agriculture (Landwirtschaftskammer Niedersachsen)
M			mulching
MCM			million cubic meters
n.a.			not applicable/not availible
NDVI			normalized vegetation index
NGO			non govermental organisations
NRW			North Rhine Westphalia, German state (Nordrhein-Westfalen)
OLI			Operational Land Imager
p_{adj}	pAdj	-	plant-specific-soil water depletion factor
PWP			physical water productivity
Q		MCM/year	discharge from dam
RBO			River Basin Organization
SAVI			soil-adjusted vegetation index
SC			single channel
SEBAL			Surface Energy Balance Algorithms for Land
SPA			Strategic Pathway Analysis
S_{sa}			soil saturation
SW			split windows
SWC			soil water moisture content
SWOT			strengths, weaknesses, opportunities and threats analysis
T_{act}	tAct	mm	actual crop transpiration
TAW			total available water in soil
TIRS			Thermal Infrared Sensor
TOWS			threats, opportunities, weaknesses and strengths analysis
USGS			US Geological Service
VI			vegetation index
WHO			World Health Organization
WMT			water management tool
WWTP			wastewater treatment plant
ZR			Zayandeh Rud

1 Introduction and Background

Innovation for agricultural development has to tackle the contemporary complexity of agricultural systems. Agriculture is transformed by the dynamic interaction of environmental and socio-economic factors such as the demand of global markets, urbanization, agricultural commercialization and intensification, climate change, concentration and vertical integration of food and bioenergy production (**Figure 1.1**). The specific challenges in the Zayandeh Rud Basin are the variability in water availability between years and high levels of salinity in soil and irrigation water in regions. Other factors which influence the development of strategies for innovative agriculture are the consumption pattern, the food safety standards and the need to ensure equitable benefits to the actors along the value-chains.

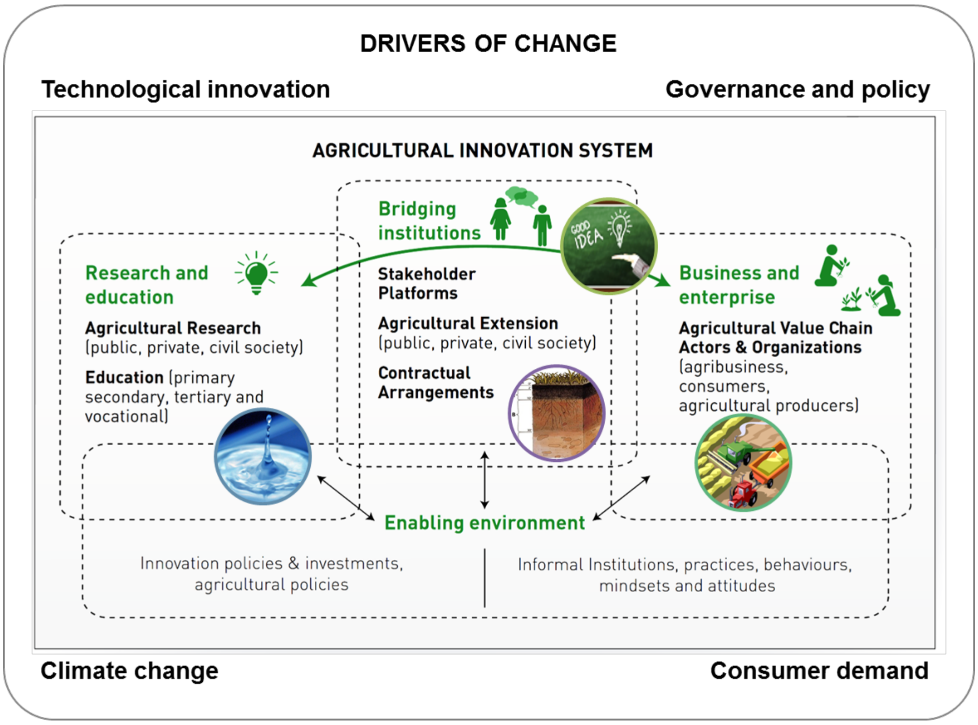


Figure 1.1: Agricultural innovation system (Source: adapted from AERNI et al., 2015.)

Addressing this complexity requires adaptation strategies in agriculture and rural development based on multi-stakeholder interaction. The report at hand is one outcome of the project "Integrated Water Resources Management Zayandeh Rud" (3/2016 - 12/2018). It is an outcome of a strongly interactive process with local stakeholders (e.g. farmer, farmer associations, Water Board Company, Non-governmental Organizations, governmental organizations, research centers) designed and moderated in a cooperation between the German and Iranian project partners (LIBRA et al., 2019). The development of the agricultural transformation strategies is based on two different methodological approaches:

The first approach was the ***agricultural and hydrological modeling*** of the effect of various measures on the agricultural water consumption using the site specific climate and soil data of the Zayandeh Rud Basin in combination with the plant specific information

(Gebel et al., 2017a). The modeling built on detailed analyses of the climate data (Gebel et al., 2017b, Faramarzi et al., 2017) and agricultural data (Raber et al., 2015) in the whole basin.

The second essential approach was the ***implementation of interactive multi-stakeholder workshops*** and expert interviews in the region. Workshops with farm advisers, experts from scientific institutions, governmental bodies, NGOs, local administrations and farmers were carried out: “Citizens´ Jury Workshop” (Horlemann et al., 2017a), “Strategy workshop for Agricultural Transformation in the Zayandeh Rud River Basin” (Horlemann et al., 2017b), “Expert workshop for the development of scenarios” (Zare, Libra, 2018). A strategy validation survey was conducted to develop an understanding of the implications connected with different measures and actions, and derive justified recommendations for the implementation of strategies. The participatory process is described in more detail in **Chapter 3**. The activities and their timing were chosen to progressively develop promising strategies for agricultural transformation in the basin with the stakeholders. First appropriate overall strategies were identified and prioritized, then their targeted impacts and desired outcomes were evaluated, and, lastly, pathways for their implementation were formulated, which included describing detailed measures and activities. The main outcomes have been extracted and expanded upon for the development of the transformation strategies. Four main focus areas to support a sustainable agricultural development in the basin were identified (**Figure 1.2**): **Capacity Development**, which includes the broad area of Agricultural extension, education and consulting**, Agricultural Management, Water Distribution, Land Management and Soil Fertility.**

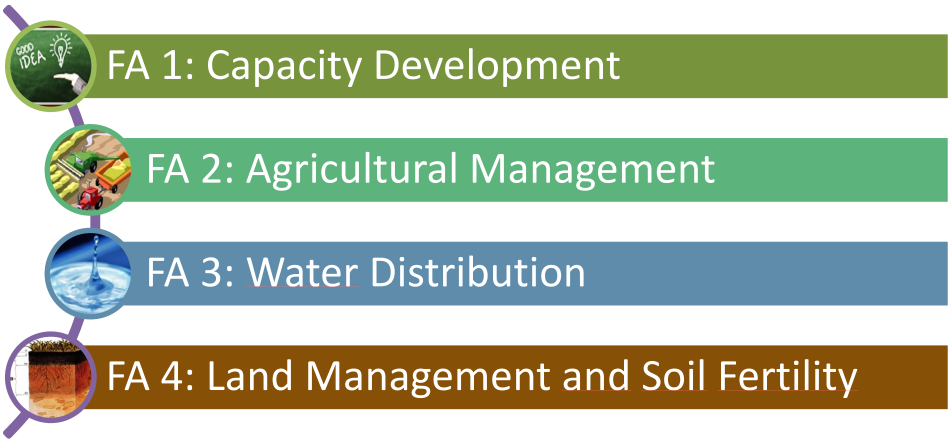


Figure 1.2: Focus areas of the agricultural transformation strategies for the Zayandeh Rud Basin

The information gained in through the participatory process was synthesized into the ten transformation strategies in this report. These are listed in **Table 1.1** below, grouped according to their respective focus area. This structure is used in the later chapters of the report, where the targeted impacts of each strategy is described, along with the measures needed to achieve the desired outcomes and their associated activities. An initial evaluation of the strategies and activities for the agricultural transformation was carried out by various actors through a questionnaire. The focus was on identifying critical points especially on why this strategy is not currently being implemented. This is discussed in the final chapter.

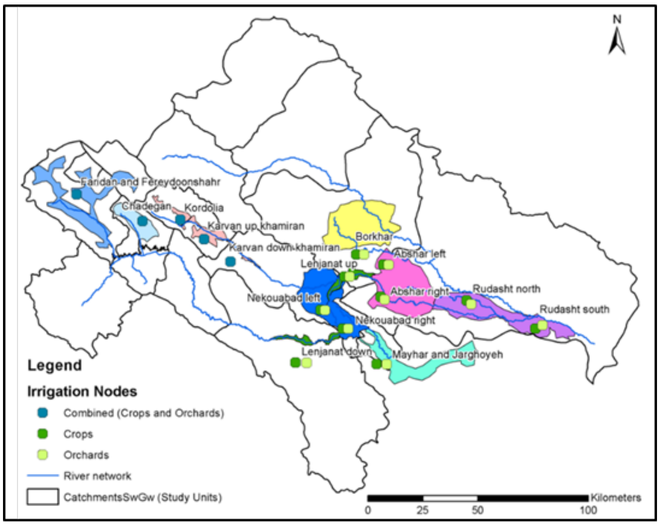
Table 1.1: List of the focus areas (FA) and strategies (S) on agricultural transformation

Focus areas	Transformation strategies
FA1 Capacity development	S1 Improve Agricultural Extension, Education and Consulting
	S2 Improve performance of agricultural production cooperatives
FA2 Agricultural Management	S1 Improve irrigation management according to crop water requirement
	S2 Establish new crop varieties and value chains
	S3 Install water-efficient, medium scale greenhouses
	S4 Foster development of aquaculture ponds
FA3 Water Distribution	S1 Improve water distribution for agriculture in ZR Basin
	S2 Increase proper use of urban wastewater for crops
FA4 Land Management and Soil Fertility	S1 Improve soil fertility and water holding capacity
	S2 Adapt land use to water supply

2 Water and land management in Zayandeh Rud Basin

The closed semi-arid Zayandeh Rud River Basin is one of the most important river basins in Iran. It supplies some 4.5 million people with water in the region of Isfahan, which is among the most important industrial and agricultural production centers in the country (MOHAJERI et al., 2016, FELMEDEN et al., 2014). The basin with 225,000 ha of irrigated agricultural land lies in the central plateau in two provinces, stretching from the northwest mountainous semi-arid region to the arid Gav Khuni salt lake region in the southeast (**Figure 2.1**). The annual snowfall in the Zagros Mountains is the source of the Zayandeh Rud River. The river is regulated by an upstream dam, which creates the Chadegan reservoir, and ends in the ecologically important Gav Khuni wetland. Interbasin water transfer from the Kuhrang River to the west supplements the water supply, while transfer to cities outside the basin depletes it. In face of an unreliable and possibly diminishing water supply, the region is in the process of implementing an integrated water resource management system, supported through a BMBF research project in its second phase.

(Source: https://water.fanack.com/specials/zayandehroud-river-iran/characteristics-zayandehroud-basin/#_ftn2)



(Source: Raber et al., 2015)

Figure 2.1 a): Location of the Zayandeh Rud Basin in Central Iran, b) Location of the irrigation districts in the Zayandeh Rud Basin

2.1 Water supply

Around 90 percent of the water resources withdrawn in the basin are required for agricultural irrigation and agriculture is almost wholly dependent on access to irrigation water (TORFE et al., 2017). The annual irrigation consumption in the basin estimated at 3,300 MCM (SAFAVI et al., 2013), with the water supply mainly dependent on groundwater resources (approximately two thirds) and surface water releases (one third). However, the relative amounts from each source used in individual farming systems vary largely depending on region and infrastructure. The natural average flow of the Zayandeh Rud River is about 650 MCM/year (ESLAMIAN et al., 2017). Three tunnels for inter-basin transfers from the Kuhrang River have an annual capacity of 820 MCM/year (SAMADI BOROUJENI and SAEEDINIA, 2013). The agriculture water supply experiences a gradient in quantity as well as quality along the 405 km river course, from the wetter northwest regions, with an annual rainfall of 1,500 mm, to the now almost completely dry Gav Khuni marsh at the end with 50 mm/year (MOHAJERI et al., 2016, ESLAMIAN et al., 2017).

Releases from the Chadegan reservoir, which has an efficient storage capacity of 1,470 MCM/year, are timed to provide water for domestic and industrial use, and as last priority for irrigation, if water is available. Due to changes in rainfall over the last decades, the amount of water released from the dam has varied over a broad range, as low as 560 MCM in the drought year 2000 - 2001 (**Figure 2.2**). Recent droughts have led to severe restrictions in the irrigation surface water supplies (**Figure 2.3**).

The frequency and amount diverted to the irrigation districts have been very variable in the last decade (**Figure 2.4**). The environmental water flow to the Gav Khuni wetlands needed to maintain a "functionally healthy wetland ecosystem" has not been met. Estimates for this flow range from 70-243.5 MCM (TORFE et al., 2017). Projections for the next 30 years are that streamflow could decrease between 8 – 43 % due to climate change (GOHARI et al., 2014). Furthermore, overuse of the groundwater resources has led to decreasing groundwater levels by 20 - 50 m over the last 15 years (MOHAJERI et al., 2016).

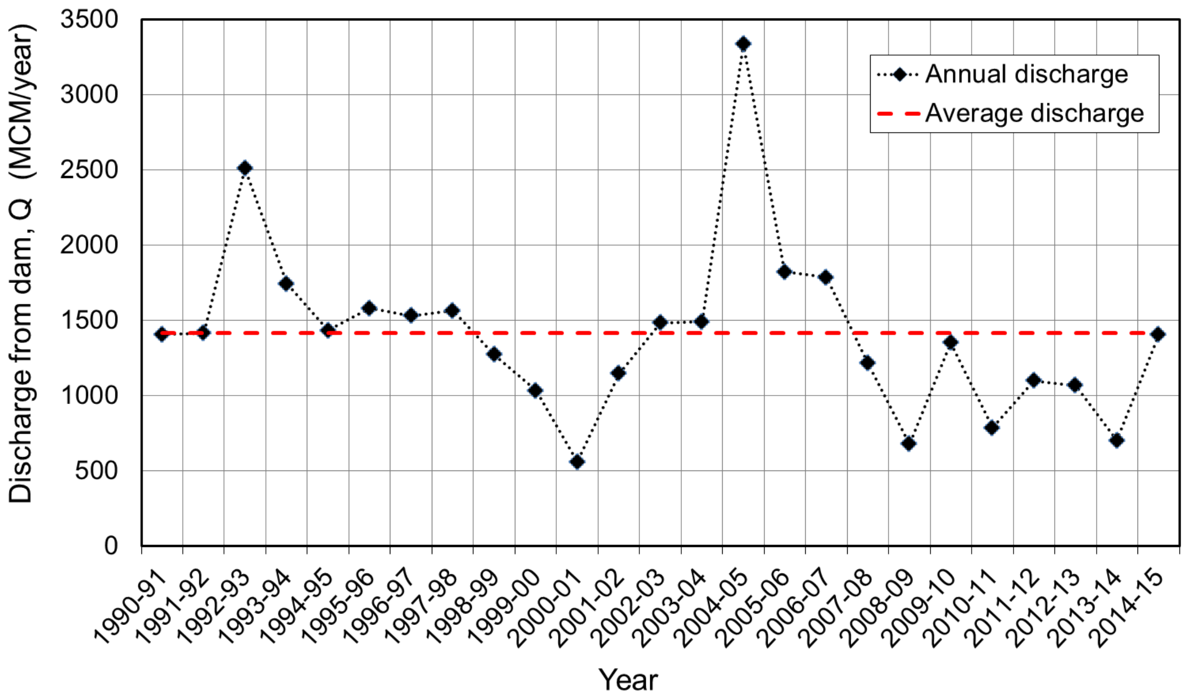


Figure 2.2: Historical changes in water supply from 1990 to 2015 (Data source: MINISTRY OF POWER, 2018)

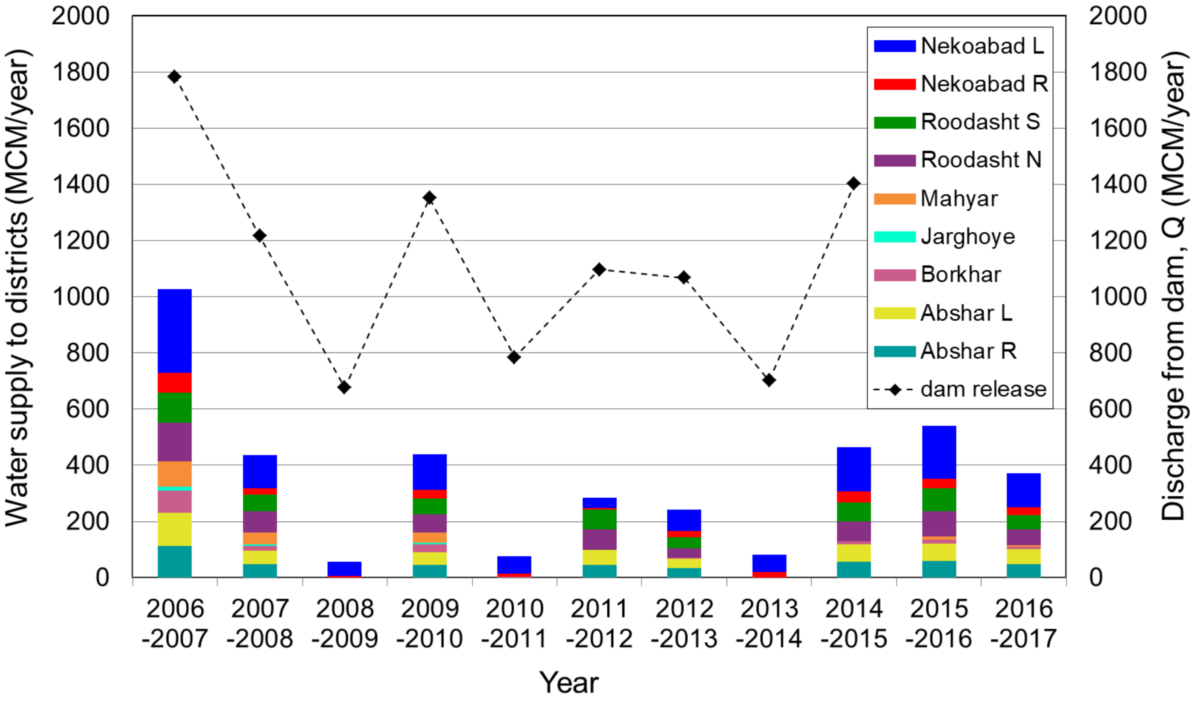


Figure 2.3: Water supply to 9 (out of 15) irrigation districts from 2006 - 2016 (Data source: MINISTRY OF POWER, 2018)

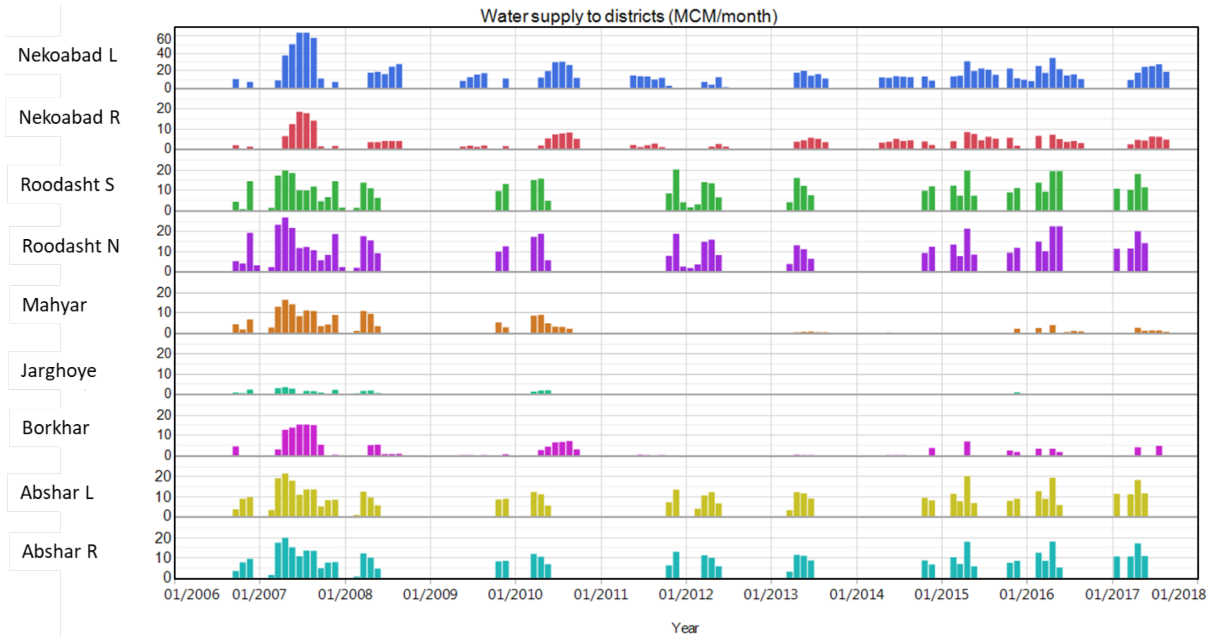


Figure 2.4: Frequency and monthly amount of water supply to 9 (out of 15) districts from 2006 - 2016 (Data source: MINISTRY OF POWER, 2018)

2.2 Land use

The total area of arable land in the basin is about 450,000 ha while only 225,000 ha is regularly irrigated (SAFAVI et al., 2013, MOHAJERI et al., 2016). The water source for approximately 137,000 ha comes from surface water, while approximately 86,000 ha rely on ground water and other resources (MOHAJERI et al., 2016). The 15 irrigation networks considered in the IWRM project are located along the length of the river (**Figure 2.1 a**), and receive an annual precipitation ranging from 400 in the upstream districts to 100 mm downstream. The distribution of cultivated area between crops and orchards in the entire basin shows that 90 % of the cultivated area is covered by crops and only 10 % by orchards. Looking at the distribution of the area between crop and orchard for each district, it can be seen that crops dominate in most districts (**Figure 2.5 a**). The distribution of the cultivated crop area by district is shown in **Figure 2.5 b**.

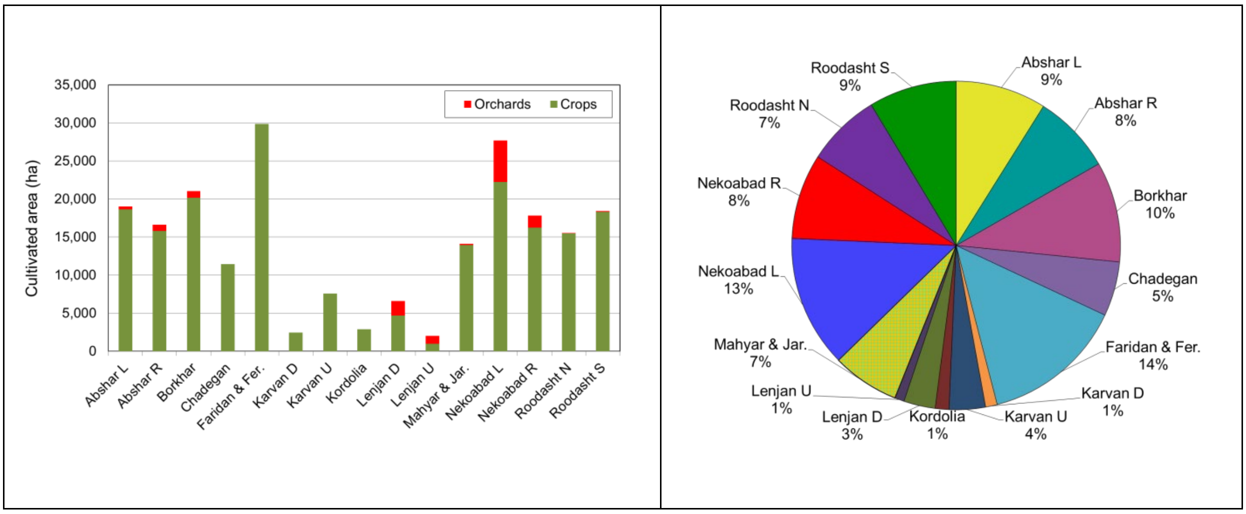


Figure 2.5: a) Cultivated area in each district for crops and orchards, b) Distribution of the cultivated area for crops by district (Baseline from 2005 - 2006)

The values for agricultural land area, types of crops and orchards were developed in Phase 1 for 2005 - 2006 (1384 - 1385), a year with a normal to high water supply and used as a baseline year in the project (RABER et al., 2015). However, the cultivated area for crops fluctuated largely from 2002 to 2013 within the province Isfahan (**Figure 2.6**). The main share of the cultivated area relies on irrigation and, depending on the availability of the irrigation water, the size of the cultivated varies strongly. The uncertainty of water availability is a critical factor for the farming systems within the Zayandeh Rud Basin. Not knowing the water supply situation, the farmers prepare every year for the cultivation of the available land, but if no or not enough water is allocated to the fields, all the efforts and expenses (e.g. seed, fertilizer) are for nothing.

The cropping pattern shifts across the basin: the upstream part has more orchards and a distribution of crops between summer and winter crops such as potatoes, rice and wheat, while downstream in the Roodasht irrigation district the winter crops wheat and barley dominate (**Table 2.1**).

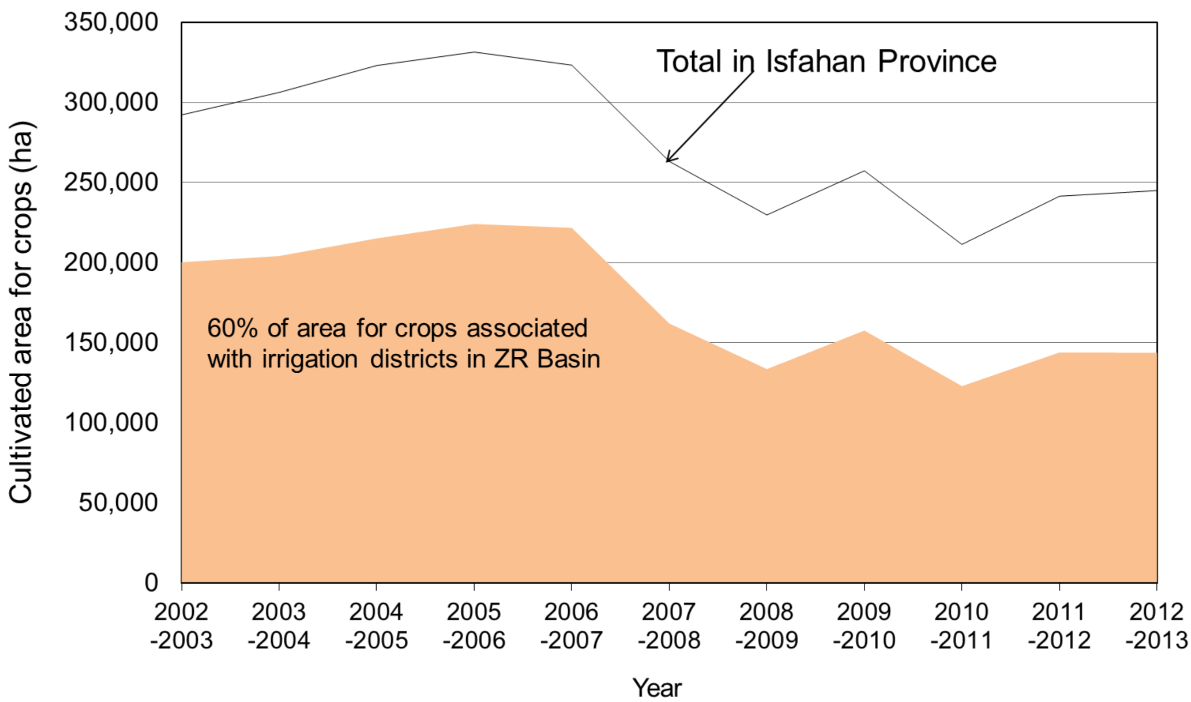


Figure 2.6: Historical changes in cultivated land area in Isfahan Province, one of two provinces with land area in the basin from 2002 to 2013. (Data source: MINISTRY OF AGRICULTURE JIHAD, 2017 Values for cultivated area from 2013 - 2015 not available)

Table 2.1: Four irrigation districts with their total cultivated area and their three most planted crops (values from RABER et al., 2015)

Irrigation district	**Total cultivated area [ha]**	**Three most cultivated crops and their cultivated area [ha]**		
Faridan & Fereydoonshahr	29950	Potato (9100)	Wheat (7400)	Alfalfa & Sainfoin (6072)
Nekoabad Left	27834	Rice (6654)	Wheat (3330)	Alfalfa & Sainfoin (2094)
Abshar Left	19035	Wheat (6600)	Maize (3300)	Alfalfa & Sainfoin (1970)
Roodasht South	18400	Wheat (10500)	Barley (2240)	Cotton (2100)

The most cultivated crop in the basin, though, is winter wheat, with 33 % of the total area. Alfalfa, barley, rice and forage maize each account for about 10 %, so that almost 70 % of the cultivated area in the basin is allocated to these 5 crops (**Figure 2.7**). The crops are irrigated with two methods. Gravity methods (flood and furrow) are traditionally used in the region, while some farmers use pressure methods (drip, sprinkler). Especially in the upper parts of the river, sprinkler irrigation is popular to irrigate potato and wheat. See RABER et al. (2015) for a detailed overview of further agricultural values.

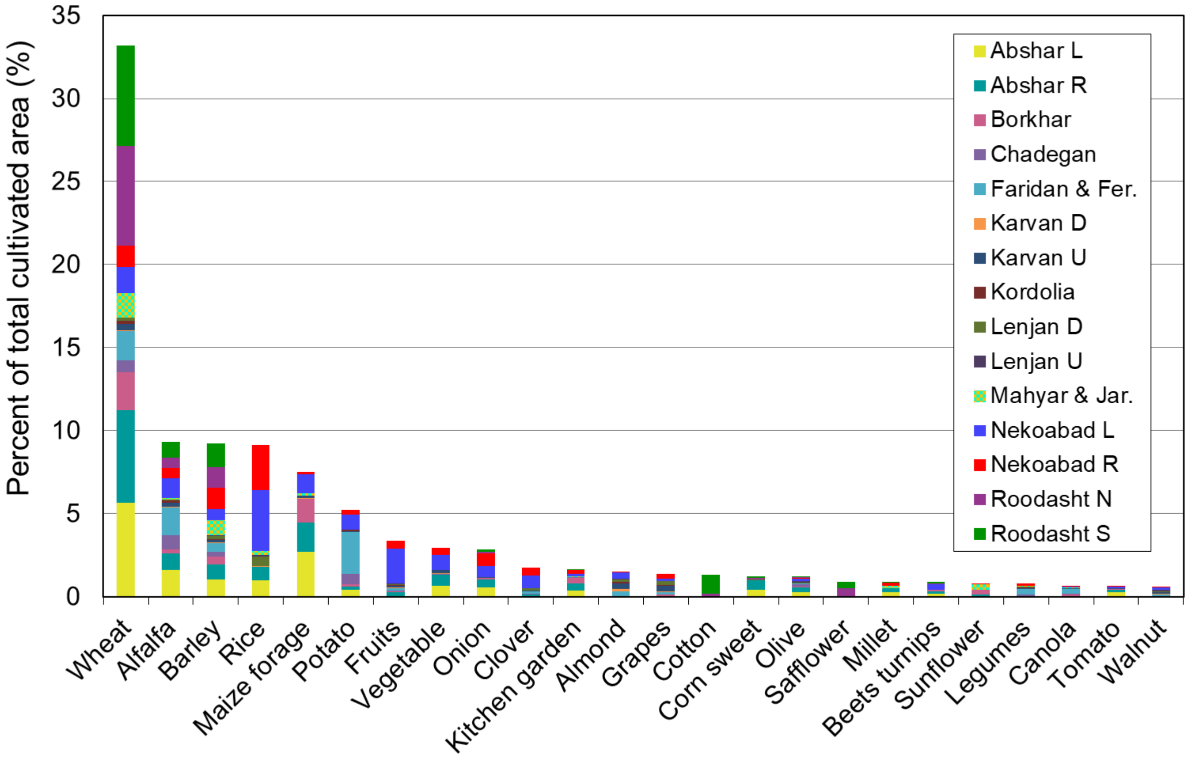


Figure 2.7: Percentage of allocated area to each crop in the Zayandeh Rud Basin for the baseline year 2005 - 2006 (Data source: RABER et al., 2015)

2.3 Water and land management

Reservoir releases are timed to provide water for domestic, environmental, industrial use and, with last priority, for irrigation. Recent droughts have led to sharp reductions in the annual volume of water discharged from the Chadegan Reservoir of up to 60 % compared to the baseline year 2005 - 2006, resulting in an often unpredictable irrigation water supply (**Figure 2.8**). In recent years, the river has repeatedly dried up before reaching the city of Isfahan due to climatic changes and the increased demand for water in the upper river reaches. Groundwater levels have sunk in areas by 20 to 50 m, disrupting traditional water supply systems such as qanats and shallow wells (MOHAJERI et al., 2016). **Figures 2.2** and **2.6** show the large fluctuations in the annual surface water supply and cultivated land area over the last 10 to 20 years compared to the baseline year. The cultivated area was reduced by almost 40 % in the drought year 2010. Changes in the regional agricultural practices and land use are necessary to cope with the limited water availability in the basin.

The agricultural water consumption needs to be adjusted to levels that are in balance with the regional water budget and expected fluctuations. This may require a reduction in agricultural production and cultivated land in the basin, as well as changes in agricultural land use. The time series data in **Figure 2.8**, comparing reductions in surface water supply and cultivated land to the baseline year 2005 - 2006, shows that the cultivated area fluctuated year by year as a response to the drastic changes in surface water supply. Farmers decreased the total cultivation area in the Zayandeh Rud Basin 40 % below the baseline cultivated area in the years with relatively scarce water supply. The surface water supply decreased up to 60 %.

The integrated management of land and water resources in the basin is facing many challenges. At the regional level, water consumption by agricultural and industrial activities, as well as the growing urban population, needs to be aligned with the water resources carrying capacity in the basin. Additional factors causing water availability and access problems for farmers are the current intransparency of water allocation within the Zayandeh Rud Basin, as well as water transfers to neighboring basins. These need to be reconsidered. Effective plans to prepare appropriately for water scarcity conditions are needed, such as to reduce agricultural water demand seasonally dependent on the current water availability, or long term by reducing the over-all cultivated area in the Zayandeh Rud Basin.

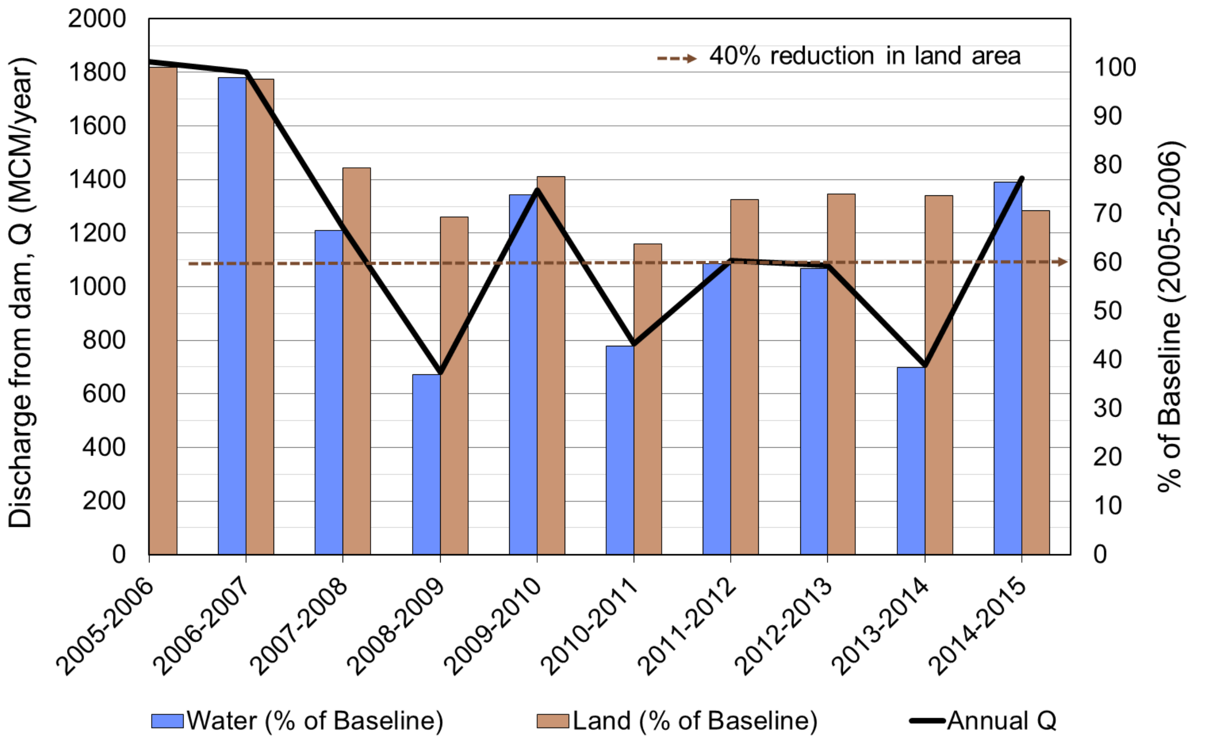


Figure 2.8: Historical changes in water supply and cultivated land area compared to the baseline year 2005 - 2006 (Data source: MINISTRY OF AGRICULTURE JIHAD, 2017, MINISTRY OF POWER, 2018)

3 Methods

A variety of methods and tools were used in the project to develop strategies for the agricultural transformation in the Zayandeh Rud Basin in a technically feasible, economically viable, ecologically sound and socially acceptable way (**Figure 3.1**). Using participatory activities, such as workshops, interviews, questionnaires, diverse stakeholders in the basin were involved to develop agricultural and water management plans. A backcasting method was used for the development of storylines for scenarios in the first phase (SCHRAMM and SATTARY, 2014, HORLEMANN, JAFARI BERENJI, 2017). In order to collect and integrate the knowledge of local farmers and expert, several workshops were used based on the Citizens´ Jury approach and Strategic Pathway Analysis in this phase. In addition, case studies based on farmer interviews, scenario analysis using water modeling tools, historical analysis of land use using satellite observation as well as climate and agricultural data, and literature analysis were also carried out.

This report synthesizes the results from the various methods, which are described in more detail later in this chapter. In general, the Transaction Interdependence Cycle was used as a guiding framework for the participatory activities (HAGEDORN, 2008). Using the approach insures the inclusion of both the physical and the social perspective within the agricultural processes in the development of the transformation strategies for the Zayandeh Rud Basin. The investigation followed this overall framework, adapting the questions explored with the participants and their depth appropriately to the activity (**Table 3.1**).

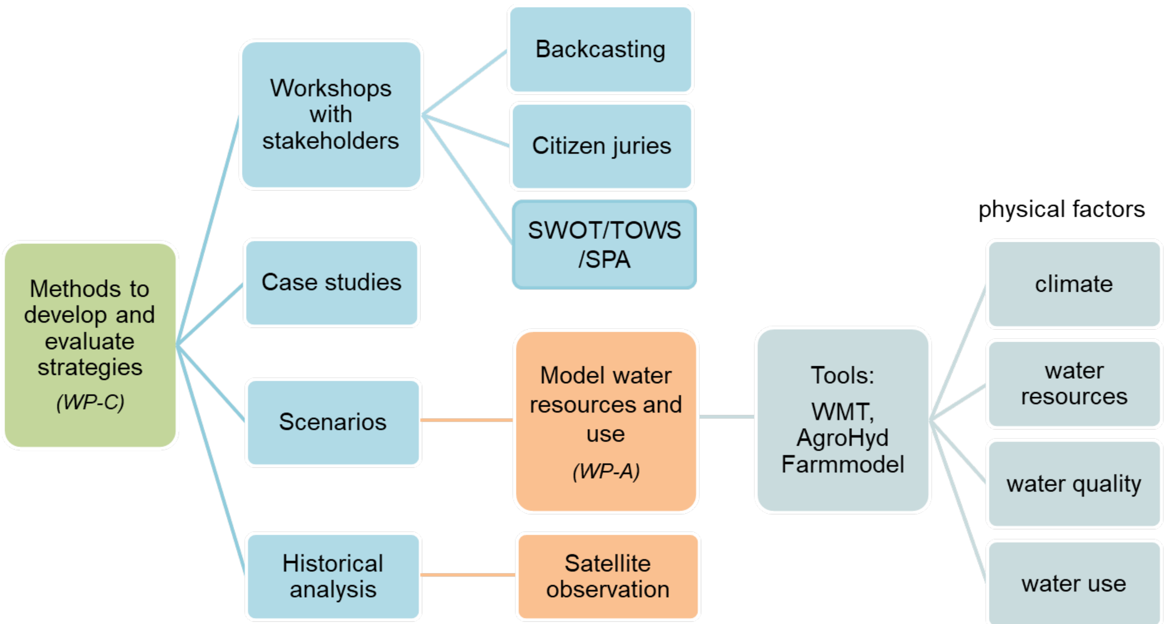


Figure 3.1: Methods used in IWRM project to develop and evaluate strategies for agricultural transformation

Table 3.1: Framework for the participatory activities: General areas and questions explored in the workshops and questionnaires

	Areas and questions
1	Actions identified as part of the transformation strategies: • What concrete actions can be taken by the farming community? • What preconditions need to be fulfilled at the farm level?
2	Expected impact on (agricultural) system components (resources) at the production site and farm: • How will the actions affect the local water, soil, air and other physical resources at the farm level?
3	Changes in the wider physical system resulting from the actions taken (or proposed): • How will the actions affect the village, catchment area, settlements and neighboring catchments, industrial areas? • Can the biophysical system adapt to these changes?
4	Interdependences of actors: • Who will be affected positively or negatively by these changes resulting from the actions?
5	Interactions (Conflicts/Synergies): • Which interactions (negotiations, etc.) need to take place between which actors on what issues?
6	Adaptations: • How can the costs and benefits resulting from the actions be shared? • What technical solutions can contribute to overcoming the existing discrepancies? • What social, organizational and economic solutions (institutions) can contribute to overcoming the dissonances between the actors and implement the actions in a sustainable way? • How can the problems that arise be solved? What rules and regulations need to be made to regulate the impacts of the actions/measures/changes?
7	Pathways towards adaptation: • Which barriers must be overcome to introduce the technical, social and economic solutions? • What is needed to facilitate the rulemaking and adoption of the rules? Who has to participate in the development of the rules and regulations? • Who has to take the initiative and who needs to get involved? • What changes in the legislative or administrative framework are necessary? • How would you assess the strategies and actions in terms of the criteria used?. • How can the actors' choices be directed?

3.1 Goal system and strategy development

Planning transformation in a river basin requires agreement between diverse stakeholders on what goals should be targeted and which actions will be taken to fulfill them. Often, misunderstandings can arise due to unclear terminology about goal systems leading to unnecessary conflicts. Clear communication must be developed so that real disagreements can be identified and moderated. Within the project, we developed the structure for terms shown in **Figure 3.2**. In general, we use the term "strategy" to mean - a description of how to achieve a goal. Goals are formulated as "focus areas" for overall goals and "targeted impacts" for more specific ones. Three levels are used in the goal system hierarchy: at the top, the term "transformation strategies" is used for actions that cover the broader overall goals and that are applicable basin-wide. On the second level, for each transformation strategy, the overall goals are broken down into specific "targeted impacts" and plans of action ("measures") are formulated to meet these targeted impacts. Further detailed steps for implementation on the third level are called "activities". In order to make the discussion and tables in the report easier to follow, we introduced a numbering for the focus areas, strategies, targeted impacts, measures and activities that can be seen in

Figure 3.2. A variety of individual strategies to support sustainable agricultural development were collected from regional experts and from the literature for diverse regions. An overview of these strategies is given in **Chapter 4**. In the project, we clustered them into four focus areas relevant to the Zayandeh Rud Basin, and chose ten strategies to discuss with diverse stakeholders in the basin. The participatory methods used to prioritize the strategies and develop pathways for their implementation are described in the following section.

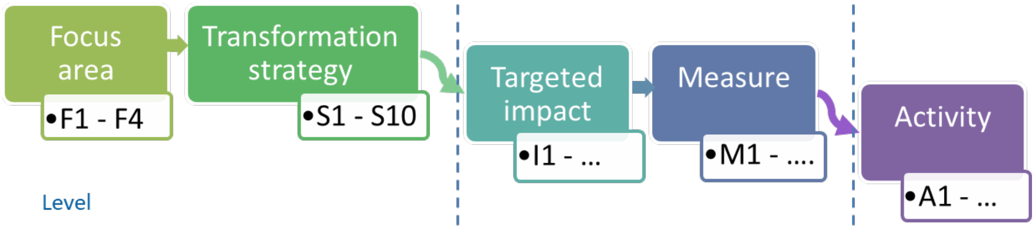


Figure 3.2: Hierarchy of the goal system and numbering used in this report

3.2 Stakeholder workshops

In order to create a common understanding of agricultural transformation in the Zayandeh Rud Basin and the strategies needed, various stakeholders from different sectors in the Zayandeh Rud Basin participated in developing the transformation strategies through a series of workshops and activities (**Table 3.2**). The basic goals of the workshops were to identify and prioritize strategies for agricultural transformation, develop measures to implement the strategies, estimate impact and determine preconditions of the measures and formulate pathways for their implementation. Participants were chosen according to the workshop design, often a mixture of farm advisers, experts from scientific institutions/offices, NGOs, local administrators, farmers.

Table 3.2: Overview of participatory activities

No	Activity	Participants/Location	Date
1	Expert Workshop on Agricultural measures	Isfahan	April 2015
2	Citizens' Jury	farmers and agricultural functionaries from up and downstream in the basin & agricultural and water experts/Isfahan	December 2016
3	Strategic Pathway Analysis (SPA)	farmers' representatives, agricultural and water experts/Isfahan	14 and 16 of August 2017
4	Scenario Workshop	agricultural and water experts/Isfahan	December 10-13, 2017
5	Questionnaires Scenario Strategy validation	agricultural and water experts/Isfahan	2018
6	Interviews	local farmers in Roodasht irrigation district/Isfahan	2015

A Citizens' Jury Approach was used in one workshop to identify priority areas of action (HORLEMANN et al., 2017a). A further workshop was conducted using the Strategic Pathway Analysis (SPA) to substantiate the activities of agricultural transformation projects in the previously defined priority areas (HORLEMANN et al., 2017b). In the Strategic Pathway Analysis workshop, a combination of three methods was used: 1) the SWOT Analysis – in order to characterize the setting for agricultural transformation, the strengths, weaknesses, opportunities and threats (SWOT) for the various strategies were identified and discussed, 2) the TOWS Analysis – based on the previously identified strengths, weaknesses, opportunities and threats short-term, medium-term and long-term measures to implement the strategies were developed, 3) the SPA was then used to identify a pathway and preconditions for the implementation of each strategy in the region based on results from the TOWS Analysis.

Table 3.3: Methods in the Strategic Pathway Approach

Goal	Method	For each strategy:
Characterize the setting for measures for agricultural transformation	SWOT	identify the Strengths, Weaknesses, Opportunities and Threats involved in each strategy
Identify and prioritize measures for implementing the strategy	TOWS	develop short-term, medium-term and long-term measures based on the SWOT analysis
Explore impact of measures and pathways for their implementation	SPA	describe Strategic Pathways to implement the measures developed in the TOWS analysis

Further validation of the strategies and actions for the agricultural transformation determined in the Citizens´ Jury-Workshop and the SPA-Workshop was carried out by various actors through interviews and a questionnaire. One goal was to estimate the impact of strategies and actions and explore requirements for their implementation. In the questionnaire, eight topics taken from the results of the stakeholder workshops with additions from the Roodasht Action Plan, other literature and experience were used. Each topic was broken down into a number of strategy elements with a description of the expected impacts, outcomes and associated activities. The criteria used to evaluate the activities are listed in **Table 3.4** along with suggestions given for categories to be considered when evaluating the activities in the questionnaire. Experts that had taken part in the previous workshops, as well as a few additional experts familiar with project, evaluated the activities to determine whether they are valid for the region or not using the scoring method (1 - not relevant, 5 - very relevant).

Table 3.4: Criteria for validating the strategies

Relevance:	Is the strategy/action pursuing the right thing?
Feasibility:	Is the set objective attainable?
Effectiveness:	Will the strategy/action contribute to achieving the set objective(s)?
Impact:	Is the strategy/action contributing to the achievement of overarching development results?
Efficiency/Feasibility:	Are the objectives being achieved cost-effectively?
Sustainability:	Are the positive results long-lasting?

3.3 Case studies

A simulation model-based farming systems impact analysis (FSA) was used to assess alternative scenarios of timing and reduced water supply in terms of their impacts on agricultural land use and food crop production in one of the most hard hit irrigation districts in the Basin, Roodasht, and evaluates its implications for the development of different farming systems in the Roodasht irrigation. A monthly disaggregated Positive Mathematical Programming (PMP) model was used to assess the scenarios. The technical coefficients and economic parameters used in the model (crop prices, crop water requirement, crop yields, input requirements, input prices and the current land use as the baseline) were derived from interviews of 30 local farmers within the basin selected based on simple random sampling. The coefficients and parameters gathered include monthly water requirement per hectare, machinery use (cost per hour), labor use, fertilizer (nitrate, phosphate and potash) requirement per hectare and chemical use per hectare for all crops. Details can be found in ZAMANI et al. (2019).

3.4 Scenario analysis using water modeling tools

A scenario analysis using water modeling tools is being carried out within the IWRM project to ask questions about the effect of water management decisions on the water supply and water consumption in the Zayandeh Rud Basin. Simulations considering changes in water supply (water resource management) and/or water demand (industrial, domestic, environmental and agricultural sectors) are planned by the partner DHI-WASY. Four scenarios will be simulated over 20 years of climate data with the Water Management Tool (MIKE Basin) by DHI-WASY. The four scenarios can be used to estimate changes in water resources and water use due to (physical) measures in the basin. In two of the scenarios, agricultural measures will be simulated. The goal of the agricultural scenarios is to estimate the effect of reducing agricultural water use on the water resources in the whole basin. The drivers of change for the agricultural scenarios being considered fall into the environmental and political/economic categories. Two scenarios have been suggested by ATB based on an analysis of historical changes in climate and land use, and estimates from agricultural and water experts in Isfahan at the Scenario Workshop in December 10 to 13, 2017. A mix of criteria (economic, social, environmental, food security) was used to develop them. Preliminary analyses of changes in the irrigation water demand (IWD) due to the measures in the scenarios have been made using the AgroHyd Farmmodel and are described in **Chapter 5** and in the Scenario Report (ZARE, LIBRA 2018).

The estimates for agricultural water use for crops and fields in the Zayandeh Rud Basin were calculated with the AgroHyd Farmmodel which is based on the FAO 56 dual coefficient method using the Penman-Monteith equation for potential evapotranspiration (ALLEN et al., 1998, DRASTIG et al., 2013, KRAATZ et al., 2019). It must be noted that the IWD values reported should be considered as a minimum irrigation water demand (IWD_{min}), since they do not reflect any losses in the irrigation system nor in the field distribution system or most importantly, any excess water for leaching. The goal was not to simulate the current water use, but rather determine the potential water savings due to implementing technical measures to improve irrigation and changes in land use.

The IWD_{min} values were estimated using the crop sequence from 2001 to 2010 with cultivated land area, irrigation type, and crop distribution between the irrigation districts as detailed for the baseline year 2005 - 2006 in RABER et al. (2015). Both crops and orchards were modeled. The values reported are either for the baseline year 2005 - 2006 or the 5-year average from 2004 - 2009, which includes both wet, dry and normal years. The calculation for the IWD_{min} is based on the assumption that the irrigation water supply could be added according to the crop water requirements (CWR) and controlled to hold the soil water moisture content (SWC) in the field appropriate for each crop, i.e. irrigation was started when the fraction of soil saturation (S_{sa} = SWC/TAW) dropped below (1-p_{adj}). A detailed description of the model and data used in it can be found in GEBEL et al. (2017a and b).

4 Strategies for agricultural transformation and expected impact on agricultural water

Not only in Iran, but in many regions of the world, changing rainfall patterns and water levels in local water bodies are jeopardizing traditional agricultural production methods. Concerted efforts involving all stakeholders in the food value chain are required to adapt the numerous systems involved (farming, processing, distributing, marketing, consumers, etc) to these challenges. Most strategies for adapting to climate change that have been proposed for water-constrained regions are aimed at improving agricultural water productivity, an indicator usually defined as the ratio of output to water input, with a focus on farming systems.

Developing practical strategies to adapt farming systems to water-scarcity conditions and assessing their potential impacts is not an easy task, considering their complexity. Farming systems have been described as an inter-related matrix of soil, water, plants, animals, implements, energy, labor, capital and other inputs controlled in parts by farming families and influenced to varying degrees by political, economic, institutional and social forces that operate at many levels (DOPPLER, 2000). Strategies for changes must take the bio-physical aspects (e.g. soil, water, plants, animals, energy) and the economic aspects (e.g. labor, capital, policies), as well as social and political aspects into consideration at both the level of a farming system and at the basin level. Interactions in a river basin between the economic and physical systems are complex, therefore, the evaluation of potential strategies must include this complexity.

Many suggestions for strategies for adapting agriculture to changes in water availability have been made by a large number of authors and organizations dealing with widely diverse farming systems in the world (ASIAN DEVELOPMENT BANK, 2009, MAINUDDIN et al., 2010, TURRAL et al., 2011, MIJATOVIĆ et al., 2012, ALTIERI et al., 2015, IWRM WORKSHOP, 2015). However, the potential strategies are surprisingly consistent across climates and continents (MIJATOVIĆ et al., 2013, ALTIERI et al., 2015). They focus on four areas: 1) development of human and social capital (i.e. **capacity building**) such as improving organization across systems (water user associations, cooperatives) and policy encouraging farmers to diversify farming activities or move into non-farm activities (education and consulting, market and financing opportunities). 2) adjustments in **agricultural management**, which includes changing plant and animal production methods (crop calendar, greenhouses, animal integration), diversification (crop and animal diversification, maintaining local genetic diversity), use of resistant species and varieties and stress-tolerance improvement (conservation of resistant species, selection, breeding and distribution), 3) adjustments in **water management and distribution** (water conservation and harvesting, irrigation, water storage, supply and distribution), and 4) adjustments in **land management and soil fertility** (soil organic management, soil conservation, conversion of farmland to non-agricultural purposes), as well as protection and restoration of ecosystems (watershed restoration, reforestation, habitat protection). The strategies from these diverse sources have been collected and organized here in **Table 4.1**.

A major task in the project was organizing these strategies in a way that they could be analyzed, discussed and further developed for the Zayandeh Rud region with the diverse stakeholders in the basin. The first step was to look at which system they would affect: land, plant and animal, water, ecosystem, and human and social capital, and then further divide them according to the system focus, the specific aspect at which the strategy was aimed. Seventeen categories were used to describe the system focus and grouped according to the five systems. The next step was to classify the strategies into four types, depending on what must be changed in order to implement them: agronomic production, technology, organization, socio-economic policy. This method of grouping the system focus and strategy type is visualized in **Figure 4.1**. In a final step, the strategies were clustered according to the four focus areas described above (FA1: capacity building, FA2: agricultural management, FA3: water distribution, FA4: land and soil fertility). All these elements were used to order the 71 strategies in **Table 4.1**.

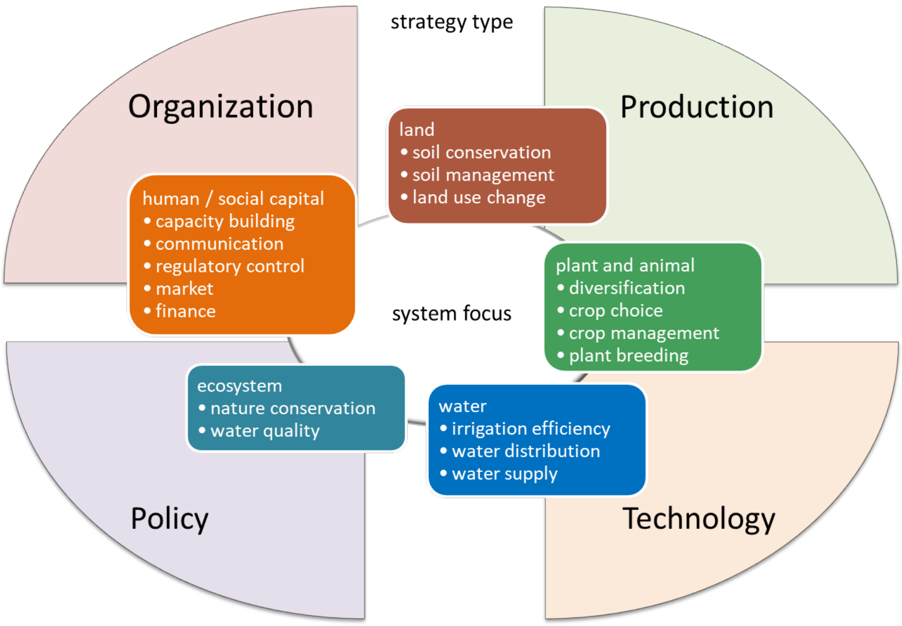


Figure 4.1: Categories used to organize the strategies: system focus and strategy types.

Note: the colors for the strategy types in this figure are used to color-code the strategies in Table 4.1.

The main sources for the strategies were the numerous workshops and expert interviews in the IWRM project, and the literature, where there was much overlap in the strategies named between the sources. Some were modified to clarify and/or improve the distinctions between them. Only a few key sources for the strategies are listed, since most strategies have been suggested by multiple sources and not all can be listed. Looking at **Table 4.1**, it can be seen that the majority of the strategies collected in this project focus on changing agronomic production methods on the farm scale. Another large group of strategies focuses on improving organization between the stakeholders and changing socio-economic policy to support change in farming systems. Strategies that rely on improving technology are fewer. They encompass both on-farm water management and larger scale management of the water supply.

In order to choose promising strategies for further discussion with stakeholders in the Zayandeh Rud Basin from this long list, an initial attempt was made to evaluate which impacts can be expected from the strategies for the region. First, seventeen impact categories were defined, based on indicators developed in the literature for assessing resilience and productivity (e.g. MIJATOVIĆ et al., 2012, ALTIERI et al., 2015, GIORDANO et al., 2017). They were used to evaluate the strategies to answer the following questions: will regional food or feed security be affected? can real water savings in the basin be expected? will water productivity (either physical PWP or economic EWP) be increased? will it increase farm net income? will soil functions and properties be improved (soil organic build up, nutrient cycling, soil cover, evapotranspiration (ET) reduction, runoff reduction, waterholding capacity, infiltration, microclimatic amelioration, reduction of soil compaction, reduction of soil erosion, hydrological regulation, mycorrhizal network)?

The initial evaluation of which impacts can be expected from the strategy was made in the project group. The categories where impacts can be expected from the strategy are marked in **Table 4.1** using the abbreviation for the impact. Parallel to this, a short list of promising strategies was developed with stakeholders through the participatory activities described in **Chapter 3** (e.g. Expert workshop, interviews). We chose ten strategies (highlighted in **Table 4.1** by bold italics) to build on in the subsequent participatory activities. These are also summarized in **Table 1.1**. Through participation in the Citizens´ Jury, Strategic Pathway Analysis, and other activities, the stakeholders were able to prioritize the strategies and develop pathways for their implementation.

For most of the strategies, only qualitative estimates of impacts could be made in the project. However, for some of the strategies, quantitative estimates were made of expected changes in crop water requirements and irrigation water demand using the Agro-Hyd Farmmodel and discussed with stakeholders (Scenario workshop). The results of the simulation of these strategies for the 15 irrigation districts in the Zayandeh Rud Basin are presented in **Chapter 5**. Expert opinions were gathered through questionnaires for strategy validation and these are reported in **Chapter 7**.

In order to continue the IWRM process in the basin, a River Basin Organization (RBO) is being developed to coordinate the management process. Important next steps to evaluate the strategies for their impact on the basin are: 1) develop more detailed quantitative estimates for local conditions with relevant stakeholders. Based on these expected changes, 2) set priorities for further refining and implementing strategies in the integrated water resource management system for the basin. These steps are summarized in **Figure 4.2**.

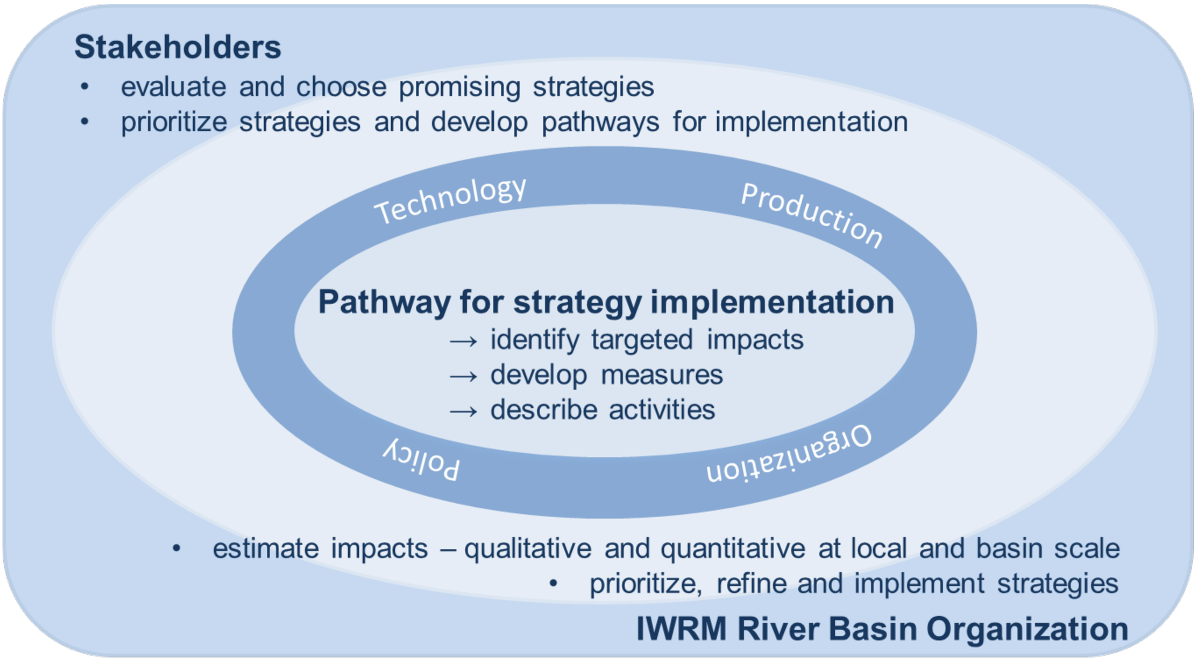


Figure 4.2: Steps for developing transformation strategies

Table 4.1: Overview of strategies gathered from stakeholders and literature, grouped according to the four focus areas and 17 system focuses, with estimates on their main impacts. *The strategies are color-coded according to strategy type: organization, production, policy, technology. The ten strategies chosen for the participatory activites are highlighted by bold italics.*

	System focus	Strategies	Food and feed security	Real water savings	Physical water productivity	Economic water productivity	Farm net income	Soil organic build up	Nutrient cycling	Soil cover	ET reduction	Runoff reduction	Waterholding capacity	Infiltration	Microclimatic amelioration	Reduction soil compaction	Reduction of soil erosion	Hydrological regulation	Mycorrhizal network	Source
	FA1	*Capacity development*																		
1	***Capacity building***	***Train and promote activities for optimizing water productivity***		***ws***	***pwp***	***ewp***														***[9, 10]***
2	Communication	Establish a system for distributing information to farmers	fs	ws		ewp	fni													[9, 10]
3	Communication	Digitalize communication with farmers (water distribu-tion, land management, subsidies etc.)		ws	pwp															[13]
4	Finance	Make crop insurance mandatory					fni													[9, 10]
5	Finance	Governmental investment instead of compensation in drought years			pwp															[9, 10]
6	Finance	Terminate energy subsidies for farmers		ws																[9, 10]
	FA2	*Agricultural Management*																		
7	Crop choice	Change crop to one with greater resilience, e.g. re-sistant to water stress and salinity	fs							sc							rse			[4, 9, 10, 11, 14]
8	Crop choice	Develop medicinal plantations or crops of greater value				ewp														[9, 10]
9	Crop choice	Change to new or different crops with higher yield (mass, nutrition, and/or value) per unit of water con-sumed.	fs		pwp	ewp	fni													[8, 12]
10	Crop choice	Decrease crop area of expensive cultivars				ewp														[9, 10]
11	Crop choice	Plant early cultivars	fs		pwp	ewp														[9, 10]
12	Crop management	Develop cultivation seedlings			pwp	ewp														[9, 10]
13	Crop management	Increase mechanization efficiency				ewp	fni													[9, 10]
14	Crop management	Optimize use of non-water inputs: fertilizers, plant protection (for higher yield and quality)				ewp	fni													[8, 9, 10]
15	Crop management	Introduce high intensity cropping system	fs				fni			sc										[4, 11, 14]
16	Crop management	Optimize use of seeds	fs		pwp															[9, 10]
17	Crop management	Change planting dates to better match water availa-bility and rainfall.		ws	pwp	ewp														[4, 8, 11, 14]
18	***Diversification***	***Promote aquaculture***	***fs***		***pwp***	***ewp***	***fni***		***nc***						***mca***					***[7, 9, 10]***
19	Diversification	Implement agroforestry			pwp			soc	nc	sc	et	rr	whc	inf	mca	rsc	rse			[3]
20	Diversification	Intensive silvopastoral system			pwp			soc	nc	sc	et	rr	whc	inf	mca	rsc	rse			[3]
21	Diversification	Mixed and intercropping			pwp					sc	et	rr			mca	rsc	rse			[2, 4, 11, 14]
22	Diversification	Crop rotation			pwp			soc	nc	sc		rr		inf		rsc	rse			[2, 4, 11, 14]

	System focus	Strategies	Food and feed security	Real water savings	Physical water productivity	Economic water productivity	Farm net income	Soil organic build up	Nutrient cycling	Soil cover	ET reduction	Runoff reduction	Waterholding capacity	Infiltration	Microclimatic amelioration	Reduction soil compaction	Reduction of soil erosion	Hydrological regulation	Mycorrhizal network	Source
23	Diversification	Local variety mixtures	fs						nc	sc										[3]
24	Finance	Adjust pricing for agricultural goods (market mechanism to influence crop production)			pwp	ewp	fni					rr								[9, 10]
25	Irrigation efficiency	Land leveling for better irrigation distribution			pwp															[8, 9, 10]
26	Irrigation efficiency	Improve construction, management of irrigation networks (conveyance/monitoring)	fs			ewp	fni													[8, 9, 10]
27	Irrigation efficiency	Change to precision irrigation methods (equipment and control)			pwp		fni													[8, 9, 10]
28	***Market***	***Create regional value chain with cooperative companies to improve agricultural productivity***				***ewp***	***fni***													***[9, 10, 13]***
29	***Market***	***Establish new crop varieties and value chains based on regional production***				***ewp***	***fni***													***[9, 10, 13]***
30	Market	Expand livestock farming systems	fs			ewp	fni													[2, 6]
31	Market	Expand and develop organic farming (crop/animal production). Certify organic products for higher prices				ewp	fni	soc												[9, 10, 13]
32	Market	Use entire processing chain (using every part) of a product to gain higher income				ewp		soc												[9, 10]
33	***Market***	***Increase number of greenhouses in agriculture***	***fs***		***pwp***	***ewp***	***fni***					***rr***								***[9, 10]***
34	Plant breeding	Expand or develop the varieties resistant to drought (though low yielding)	fs	ws	pwp	ewp				sc										[9, 10]
35	Plant breeding	Breed cultivars to better fit local planting dates		ws		ewp												hr		[9, 10]
36	Soil conservation	Bunds - low embankments with compacted earth or stones (crops/forest/rangeland)															rse			[1]
37	Soil conservation	Terracing										rr		inf			rse	hr		[3]
38	Soil conservation	Contour farming										rr	whc	inf		rsc	rse	hr		[3]
39	Soil conservation	Grass strips/living barriers								sc		rr		inf			rse	hr		[1, 3]
40	Soil management	Cover cropping						soc	nc	sc	et	rr	whc	inf		rsc	rse	hr		[3]
41	Soil management	Green manures			pwp			soc	nc	sc	et	rr	whc	inf		rsc	rse		mr	[3]
42	Soil management	Use organic matter: manure and compost						soc	nc				whc		mca				mr	[1, 3]
43	Soil management	Mulching			pwp			soc		sc	et							hr		[2, 4, 11, 14]
44	Soil management	Conservation agriculture (organic, no-till)						soc				rr	whc			rsc	rse			[2, 4, 8, 9, 10, 11, 14]
45	***Water distribution***	***Provide better timing of water supplies to reduce stress at critical crop growth stages***	***fs***		***pwp***	***ewp***	***fni***													***[8, 15]***
	FA3	*Water Distribution*																		
46	Control	Eradicate illegal wells within the catchment		ws																[9, 10]
47	Finance	Institute water pricing		ws																[9, 10]
48	Nature conservation	De-construct artificial route of the river (buildings, dams)												inf						[9, 10]
49	Soil conservation	Install check dams along gullies		ws								rr		inf			rse	hr		[9, 10]

	System focus	Strategies	Food and feed security	Real water savings	Physical water productivity	Economic water productivity	Farm net income	Soil organic build up	Nutrient cycling	Soil cover	ET reduction	Runoff reduction	Waterholding capacity	Infiltration	Microclimatic amelioration	Reduction soil compaction	Reduction of soil erosion	Hydrological regulation	Mycorrhizal network	Source
50	***Water distribution***	***Decide on water distribution / withdrawal according to water availability (each year)***		***ws***																***[9, 10]***
51	Water distribution	Create regional water user associations (ground- and surface water) responsible for water distribution		ws	pwp															[9, 10]
52	Water distribution	Involve all water users in water management		ws	pwp															[9, 10]
53	Water distribution	Water rights (self-determination, trade) / water sharing		ws																[9, 10]
54	Water distribution	Reallocate water among uses from lower- to higher value				ewp														[8]
55	Water distribution	Increase water supply reliability to enable farmers to invest more in other inputs	fs		pwp	ewp	fni													[8]
56	Water distribution	Adjust timing of irrigation for leaching to reduce salinity (e.g. winter leaching with winter rains)			pwp	ewp	fni													[5]
57	***Water supply***	***Reuse urban waste water for agricultural purposes***			***pwp***	***ewp***		***soc***												***[9, 10]***
58	Water supply	Store water in subsurface at head of irrigation networks or transfer pipeline			pwp						et									[13]
	FA4	*Land Management and Soil Fertility*																		
59	***Land use change***	***Decrease cultivated area in the basin to allow crops to receive optimum amounts of water***		***ws***	***pwp***	***ewp***					***et***									***[12]***
60	Land use change	Transfer some farmlands to orchards				ewp							whc	inf	mca		rse			[9, 10]
61	Land use change	Develop garden lands in areas with high slope										rr		inf			rse			[9, 10]
62	Land use change	Diversify into non-farm activities		ws			fni													[4,11,14]
63	Land use change	Develop greenhouse settlements	fs		pwp	ewp	fni													[9, 10]
64	Nature conservation	Increase role of agriculture for nature conservation								sc										[9, 10]
65	Nature conservation	Implement assisted natural regeneration						soc		sc							rse	hr		[1]
66	Nature conservation	Develop meadow plants to prevent desertification								sc		rr		inf			rse	hr		[9, 10]
67	***Soil management***	***Propagate soil conservation and conservation techniques***	***fs***		***pwp***			***soc***	***nc***	***sc***	***et***	***rr***	***whc***	***inf***		***rsc***	***rse***		***mr***	***[1, 2, 8, 9, 10, 11, 14]***
68	Soil management	Manage regional biomass for compost production for increasing soil organic carbon						soc	nc					inf						[13]
69	Water quality	Adapt agricultural practices to water quality	fs			ewp														[9, 10]
70	Water quality	Shunt polluted water to sinks to avoid the need for dilution with high quality water		ws																[8]
71	Water quality	Minimize salinization (or pollution) of recoverable return flows		ws																[8]

Key references for **Table 4.1.** (see Reference list for full citations)

1	ABDO, 2014
2	ALEXANDRA, 2018
3	ALTIERI et al., 2015
4	ASIAN DEVELOPMENT BANK, 2009
5	AYERS, WESCOTT, FAO, 1985
6	BLACHE et al., 2016
7	CORNER et al., 2020
8	GIORDANO et al., 2017
9	IWRM WORKSHOP, 2015 Expert workshop with agricultural and water experts
10	IWRM, 2016 Discussions with agricultural and water experts
11	MAINUDDIN et al., 2010
12	MORID, BAVANI, 2010
13	RABER et al., 2018a
14	TURRAL et al., 2011
15	ZAMANI et al., 2019

5 Modeling water saving options in the agricultural sector in the Zayandeh Rud Basin

Technical improvements in the agricultural sector have been modeled in the AgroHyd Farmmodel to estimate the potential water savings from the measures. An overview of the measures is given in **Table 5.1**. These are the technical measures that can be modeled in agricultural scenarios in the WMT. Combinations of these measures are expected to reduce agricultural water use in comparison to the methods chosen for the baseline scenario. Ideally, these measures are to be evaluated with the basin-wide water supply in the WMT; many aspects of water supply and timing can then be considered. However, for this study, the water supply-side could not be simulated and major simplifications were made in order to estimate the magnitude of reduction that can be expected due to these technical measures.

Table 5.1: Technical measures in that can be changed in the agricultural scenarios

Technical measure	Description
Change irrigation management	Irrigation type (IT): furrow, sprinkler, drip Irrigation control (IC): Deficit irrigation + with water stress
Reduce loss due to evaporation	Mulching (M): organic or plastic
Change cultivation pattern	Cultivate alternative crops

For the baseline calculations, the supply of irrigation water was not limited during the growing season and was added according to the crop water requirements (CWR) (no water stress). As pointed out in the methods section, the values for the theoretical irrigation water demand (IWD_{min}) were calculated as minimum water requirements and do not reflect any losses, neither in the irrigation system nor in the field distribution system, nor water requirements for salt leaching. Consideration of salt leaching and increased water use due to soil salinity is possible in the AgroHyd Farmmodel, however, the current version of the WMT does not provide water quality information to the fields, so this option was not considered here. The basic functions of the AgroHyd Farmmodel have been described in two reports for the project “IWRM Zayandeh Rud” (GEBEL et al., 2017a, KRAATZ et al., 2019).

An overview of the cultivated area for the baseline year (2005 - 2006) for each irrigation district in the Zayandeh Rud Basin is seen in **Figure 5.1**. Estimates of the theoretical IWD_{min} for furrow irrigation with irrigation control for just meeting the crop water requirement with no water stress is also shown. The water requirements are relatively proportional to the cultivated areas in each district, although the cropping patterns differ between the districts. This can also be seen by the similar distribution in cultivated area-and IWD_{min} between the districts even though different crops are grown in the different districts (**Figure 5.2**).

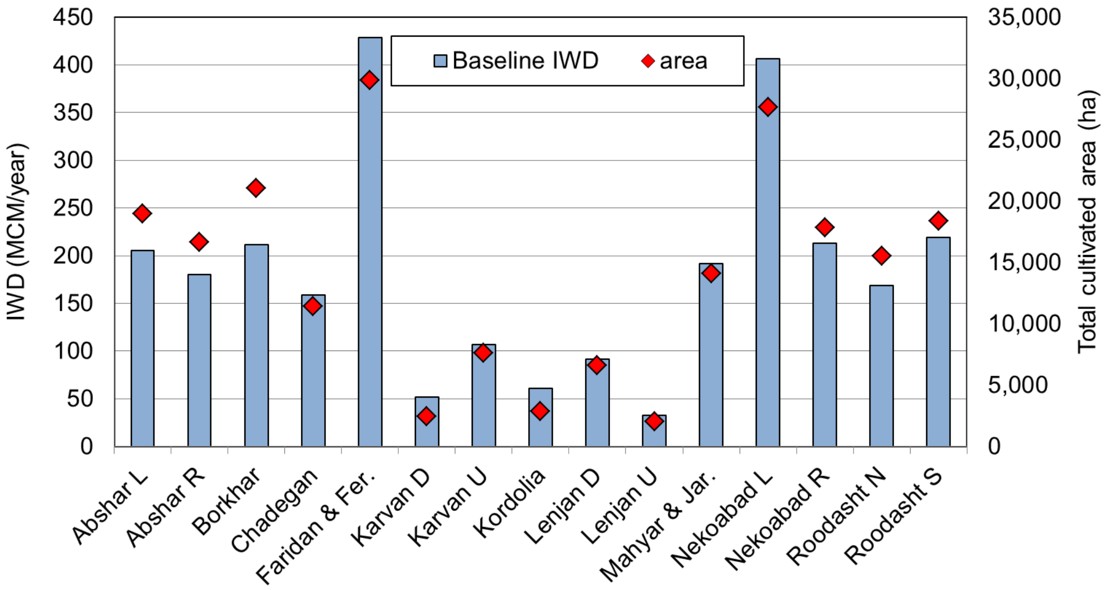


Figure 5.1: Overview of cultivated area (crops and orchards) and the theoretical IWDmin for the baseline year (2005 - 2006) for each irrigation district. (Baseline scenario, irrigation control with no water stress)

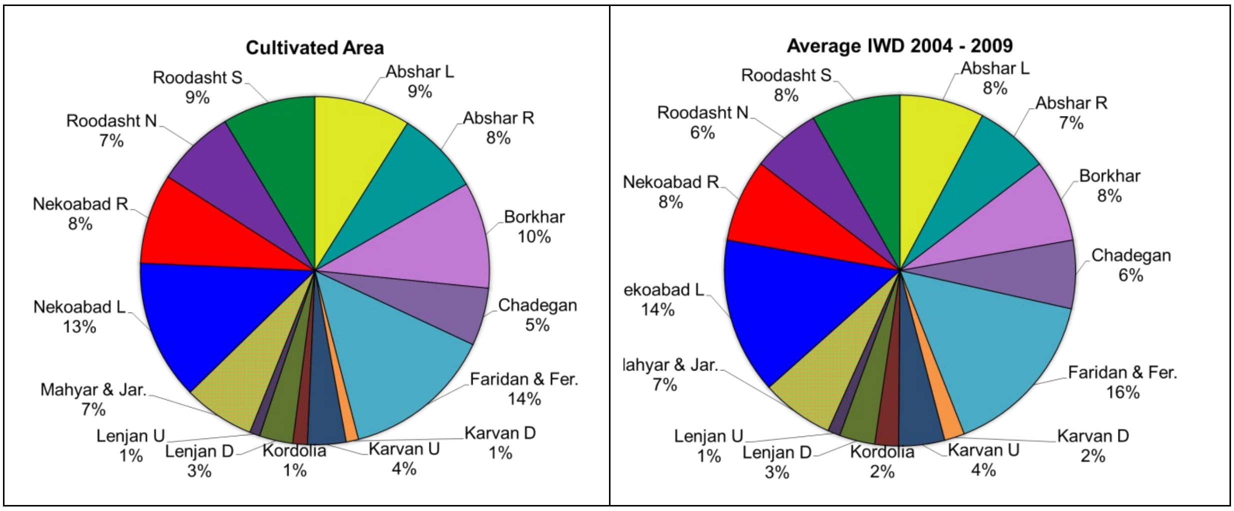


Figure 5.2: Distribution of the a) cultivated area and b) 5 year average IWDmin for all crops and orchards between the 15 irrigation districts. (Baseline scenario, irrigation control with no water stress)

5.1 Change irrigation management

This measure has two parts: the irrigation type (e.g. furrow, sprinkler and drip) and/or the control (e.g. deficit irrigation). By changing the **irrigation type** from furrow to either sprinkler or drip method, calculations show the IWD_{min} can be changed by a large margin, depending on the crop and type, e.g. +19 % and -10 %, respectively (see **Figure 5.3**). Losses in the furrow-irrigated field due to pooling and infiltration are not considered here. Sprinkler irrigation actually has a higher theoretical IWD_{min} than furrow irrigation mainly due to the effects of evaporation from a larger wetted area and interception in the model.

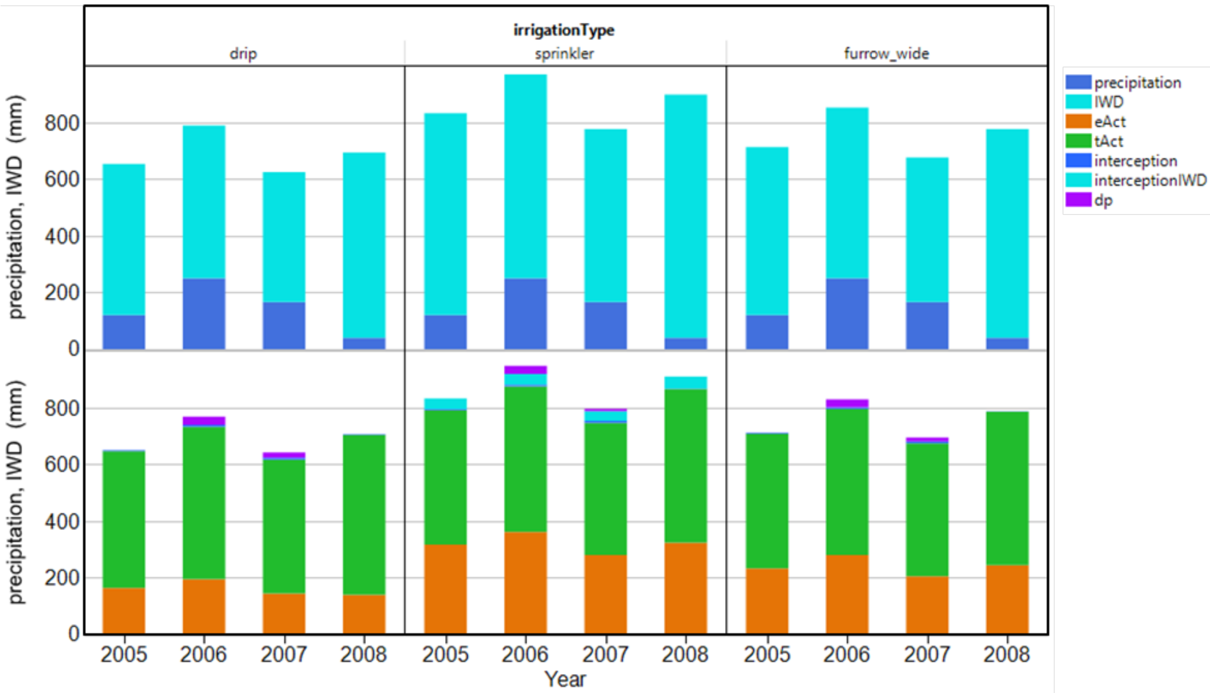


Figure 5.3: Annual sums of water flows for potato in Abshar Left for the 3 irrigation types. Example for the effect on IWDmin for changing from furrow-wide (baseline) to drip or sprinkler

Estimates of the effect of changing the technical measure **irrigation control** were made to determine whether changing from just meeting the crop-specific CWR with no water stress to deficit irrigation with water stress can significantly increase water savings. **Figure 5.4** shows that changing the trigger value for the start of irrigation to allow water stress, e.g. (1-p_{adj}-0.2) produces water savings. The decrease in yield due to water stress, however, could not be estimated. The comparison between the districts shows that the magnitude of change in IWD_{min} depends on the crops and district (**Figure 5.4**). The range of reduction in IWD_{min} in each district is between 21 to 30 %. The change in the CWR for individual crops and orchards due to different control is between 11 to 40 % (**Figure 5.5**). Summing this reduction up over the basin results in an estimated decrease in IWD_{min} of 24 %. Although the yield reduction could only be estimated for a few crops, this level of water stress would be expected to cause reductions in yield and or quality for most crops.

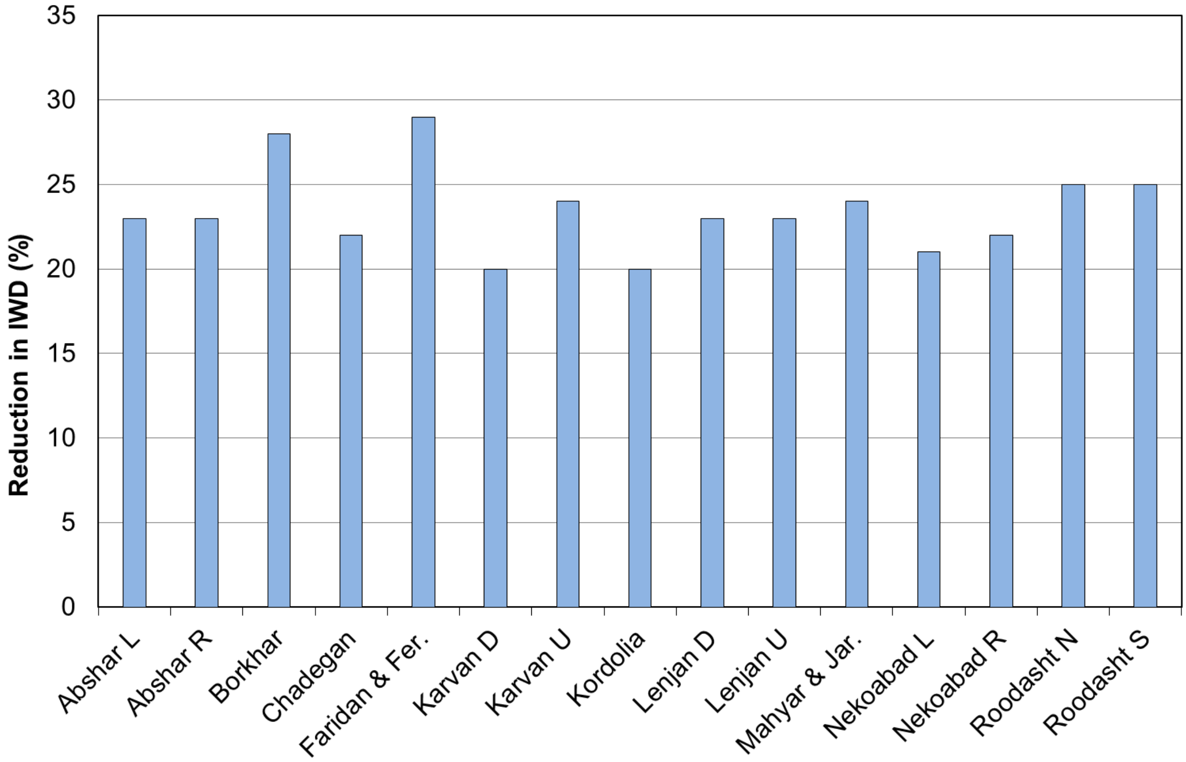


Figure 5.4: Potential IWD_{min} reduction for each district using deficit irrigation with water stress for all crops and orchards in each district

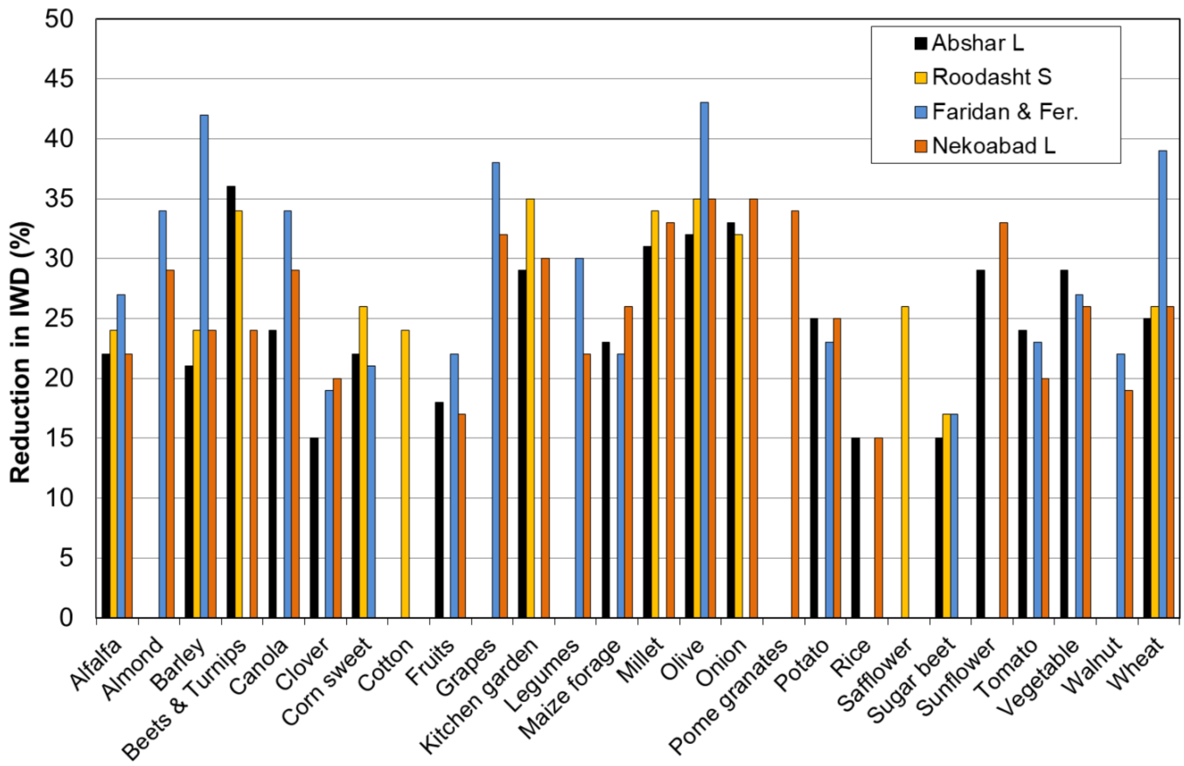


Figure 5.5: Reduction in IWD_{min} through changing irrigation control by crop and orchard: reduction using deficit irrigation with water stress for four districts

5.2 Reduce loss due to evaporation (mulching)

Mulches are used primarily to increase water infiltration, reduce evaporation, modify soil temperatures, control weeds, prevent evaporation, and increase crop yields. The average reduction in evaporation is in the range of 50 - 80 %, whereas the plastic mulch increases the transpiration by factor of 10 – 30 %. In the case of using organic mulches, the reduction in evaporation is dependent on the depth of mulch and the fraction of covered soil surface. Mulching using crop residues will enhance the organic matter content also besides reducing the evaporation. The use of inorganic materials as mulch on the soil surface, e.g. gravel, stones, pebbles, and sand, has also been shown effective as a conservation practice, reducing evaporation by up to 76 % (JIMENEZ et al., 2005).

By assuming 50 % reduction in evaporation with irrigation control set to meet CWR without water stress, the reduction in IWD_{min} for all crops and orchards is between 7 to 10 %. The results for each district are shown in **Figure 5.6**. The reduction basin-wide may reach 10 %.

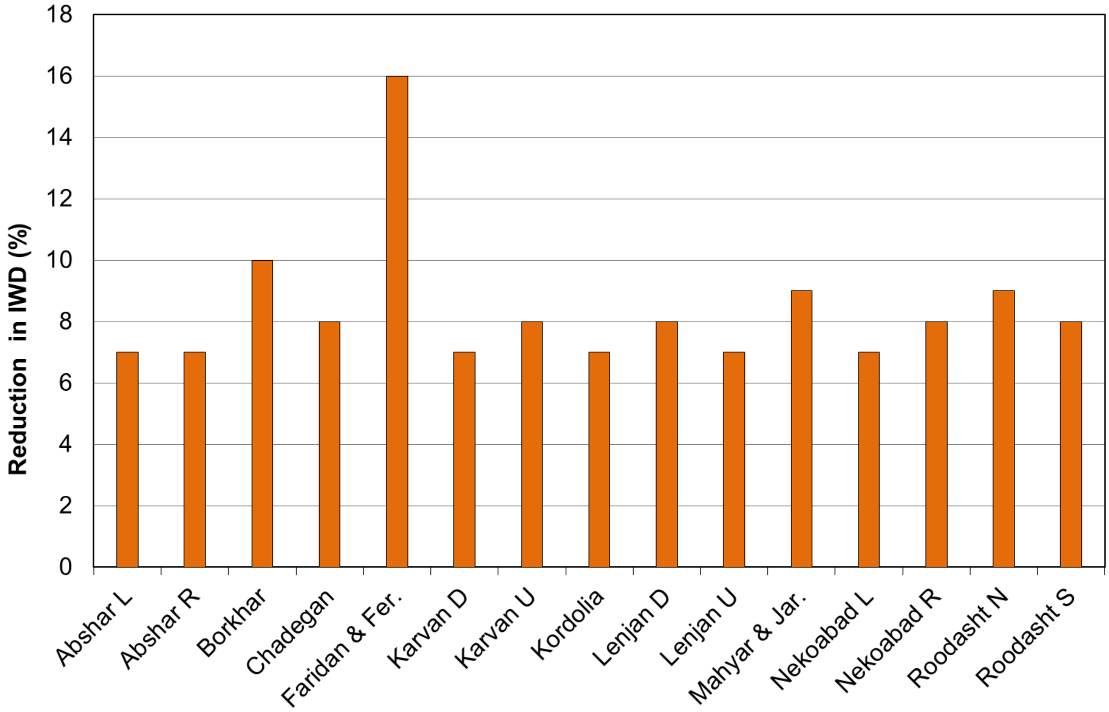


Figure 5.6: Reduction in IWD_{min} when evaporation is halved; average for the crops and orchards in each district

5.3 Change cultivation pattern (alternative crops)

Agricultural planning in arid and semi-arid areas like the Zayandeh Rud Basin is usually faced with the problem of how to find a suitable cultivation pattern under various constraints, such as the limited availability of water and land area, as well as strategic crop considerations. In these areas usually the available irrigation water is significantly less than crop water demand, especially in drought conditions which are taking place more frequently. Therefore, shifting the cultivated plants to crops that mature more quickly, such as small grains, cool season oil seeds, or various pulse crops such as peas and lentils could be a suitable policy for saving water. Shifts to deep rooted, drought-tolerant crops such as safflower may also maximize the use of precipitation stored in the soil. Depending on climatic conditions during the season, longer-season crops such as wheat, barley and maize (corn) can experience higher reductions in yields and quality (EVANS and SADLER, 2008). The main objective of using alternative crops is not only a reduction in IWD_{min} but also shifting the high water demand period to better match water availability (**Figure 5.7**).

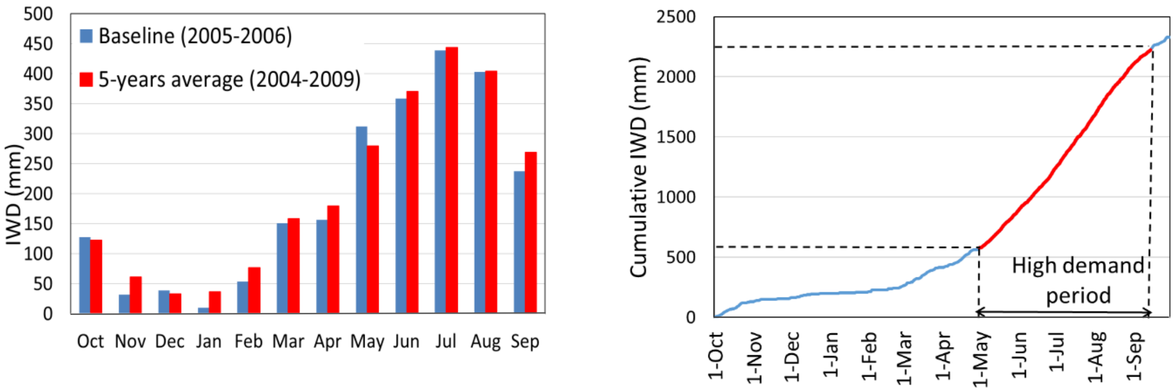


Figure 5.7: a) Average monthly IWD_{min} (mm) in Zayandeh Rud Basin for the baseline year 2005 - 2006 and the 5-year average; b) Cumulative IWD_{min} (mm) to highlight the high water demand period (1. May - 15. Sept)

Therefore, some crops were recommended by experts during the Isfahan Workshop in Dec 2017 that they expect to reduce the IWD_{min} and/or shift the high water demand period. We made estimates by comparing crop coefficients to determine whether reductions in IWD_{min} can be expected for various configurations of crop substitutions (**Tables 5.2, 5.3**). Some substitutions such as changing the cultivated area from rice to wheat are expected to save water. To visualize the impact of this substitution, the estimation of change in IWD_{min} for the crops rice and winter wheat is shown in **Table 5.3** and **Figure 5.8**. The substitution reduces the annual IWD_{min} by 36 %, but perhaps more importantly, in the high water demand period, a reduction of approximately 53 % can be achieved.

Table 5.2: Estimated reductions in IWD_{min} for alternative crops recommended by experts in the IWRM Scenario workshop, December 2017, Isfahan

	Current crops				
Alternative crops	Rice	Wheat	Barley	Corn	Vegetable
Wheat	+	---	x	x	x
Barley	0	x	---	x	x
Sorghum	x	x	x	+	x
Saffron	x	x	x	x	0
Safflower	x	0	+	+	0
Canola	0	0	0	0	0
Oat	0	0	0	0	0
Millet	+	+	+	+	0
others (medicinal, sesame, cactus, herbs, etc)	n.a.	n.a.	n.a.	n.a.	n.a.

+ reduction expected; 0 no reduction expected; x not mentioned by experts; n.a. crop parameters not available

Table 5.3: Reduction in annual and high IWD_{min} period for the crops rice and winter wheat for unit area (1 ha) in 2005 - 2006

IWD_{min} (mm)	**Rice**	**Wheat**	**Reduction (%)**
Annual	1489	944	36
High demand period (1.05.-15.09.)	1489	697	53

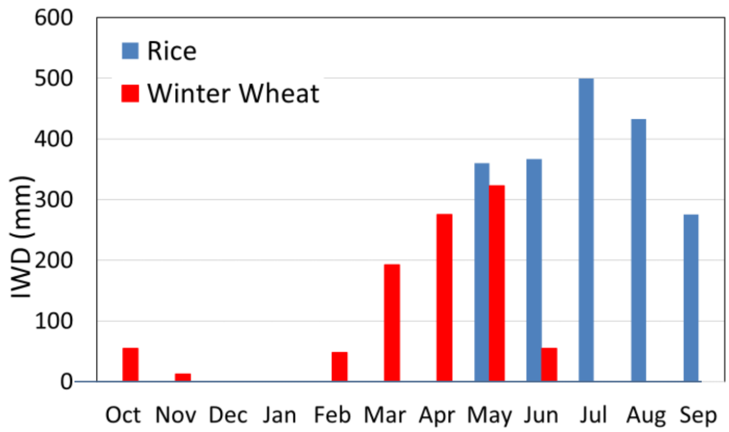


Figure 5.8: Estimated shift in high IWD_{min} period for the crops rice and winter wheat. Comparison of monthly IWD_{min} for 1 unit area (1 ha) in 2005 - 2006

5.4 Spatial distribution of the crop water requirement

As indicated in **Chapter 2**, the most cultivated crop in the basin is winter wheat, with 33 % of the total area. Significant changes in IWD_{min} for wheat due to technical measures would be expected to have an impact on the water demand in the basin. Initial results are shown for deficit irrigation and mulching in each district (**Figure 5.9**). These were visualized in Google Earth. The building of a database with such information is called for in the chapter on management strategies (**Chapter 6.2**) as an important measure for improving water productivity according to the crop-specific water requirements. A finer spatial distribution of the IWD_{min} and expected changes due to technical measures is theoretically possible in the AgroHyd Farmmodel with a more extensive GIS-based field description in the crop sequence. However, the current number of weather stations and available soil data is limited. Data from eight synoptic weather stations were used for the 15 districts. Therefore, it is not feasible to model smaller independent fields.

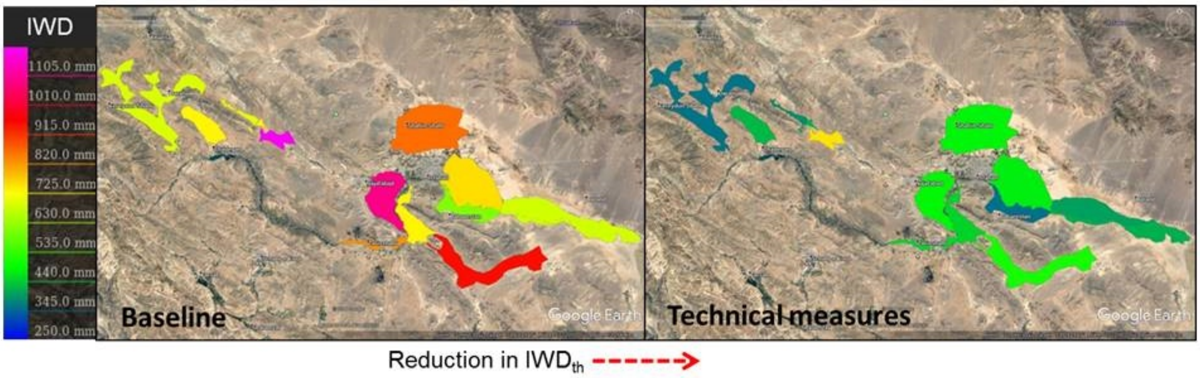


Figure 5.9: Visualization of the changes in IWD_{min} (mm) for winter wheat in 2008 due to technical measures: deficit irrigation with water stress and mulching (Source: AgroHyd Farmmodel, Scenarios- Baseline, Technical measures)

Many data inputs for the farming systems and region have already been collected in the IWRM Iran project. These should be expanded using remote-sensing for estimating current crop water requirements as well as developing sensor networks sensor network for soil-plant-atmosphere measurements (**Chapter 6.2.1**). In addition, further soil, agricultural and economic data need to be collected and stored.

A web service such as Sponge-JS, an open source data library developed in the AgroHyd project, can be used to couple the required biophysical and socio-economic models and databases (http://rl3.github.io/Sponge-JS/).

5.5 Conclusions

Simulation of improved irrigation technology for two extreme cases (better control of irrigation events allowing water stress; and mulching for all fields) showed that some water savings through lower IWD_{min} can be expected. However, the decrease for irrigation control with water stress overall in the basin is only 24 % and 10 % for mulching (**Figure 5.10**). The decrease in crop yield and/or quality could not be predicted. While modern control methods such as just meeting the CWR or deficit irrigation are theoretically possible, this requires that the periods of water demand can be matched by periods of water supply. With the current variability in surface water supply, this is difficult to impossible to implement. The simulations with the WMT are necessary to show how water demand can be matched with water supply in the basin.

The third measure, changing cultivation pattern, e.g. changing to crops more resilience to water stress or that allow shifting the water demand to better match water supply, may not results in real basin-wide water savings, but it has the potential to raise increase physical and economic water productivity. Again, these options need to be estimated in conjunction with the water supply in the WMT in order to evaluate what benefits can be expected by shifting water demand. The potential economic impacts of the farm strategies for the regional stakeholders also need to be evaluated before action can be taken.

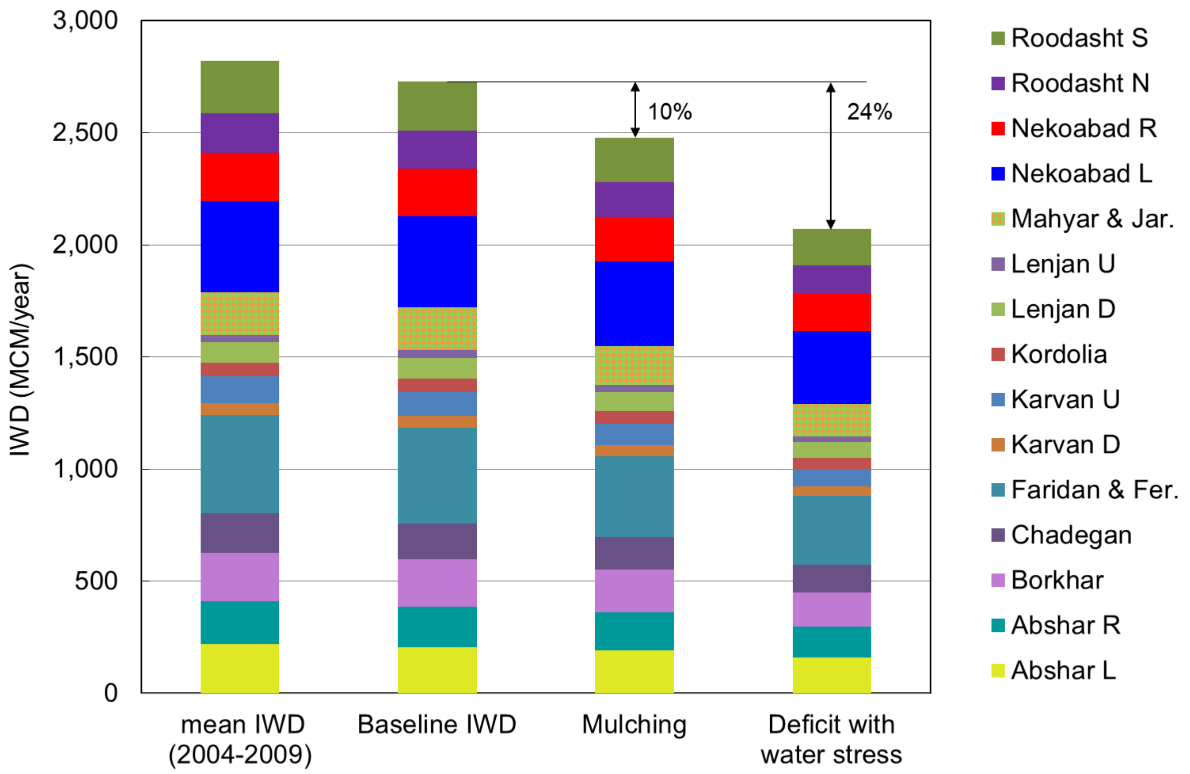


Figure 5.10: Comparison of the five year average (2004 - 09) and baseline (2005 - 06) IWD_{min} for all crops and orchards in all irrigation districts, considering a) meeting the crop-specific CWR, b) deficit irrigation with water stress (irrigation triggered at 1-padj-0.2) and c) with mulching (E_{factor} = 0.5)

6 Focus areas

Preliminary expert group discussions resulted in four focus areas for the transformation of agriculture in the Zayandeh Rud Basin These focus areas are considered of high relevance by the experts for the future development of agricultural production within the basin. In this chapter transformation strategies are described which are seen as supportive for a successful agricultural transformation in the Zayandeh Rud Basin (**Figure 6.1**). The following collection of strategies is the outcome from the participatory actions carried out in the project, and the analysis and modeling results in **Chapters 4** and **5**.

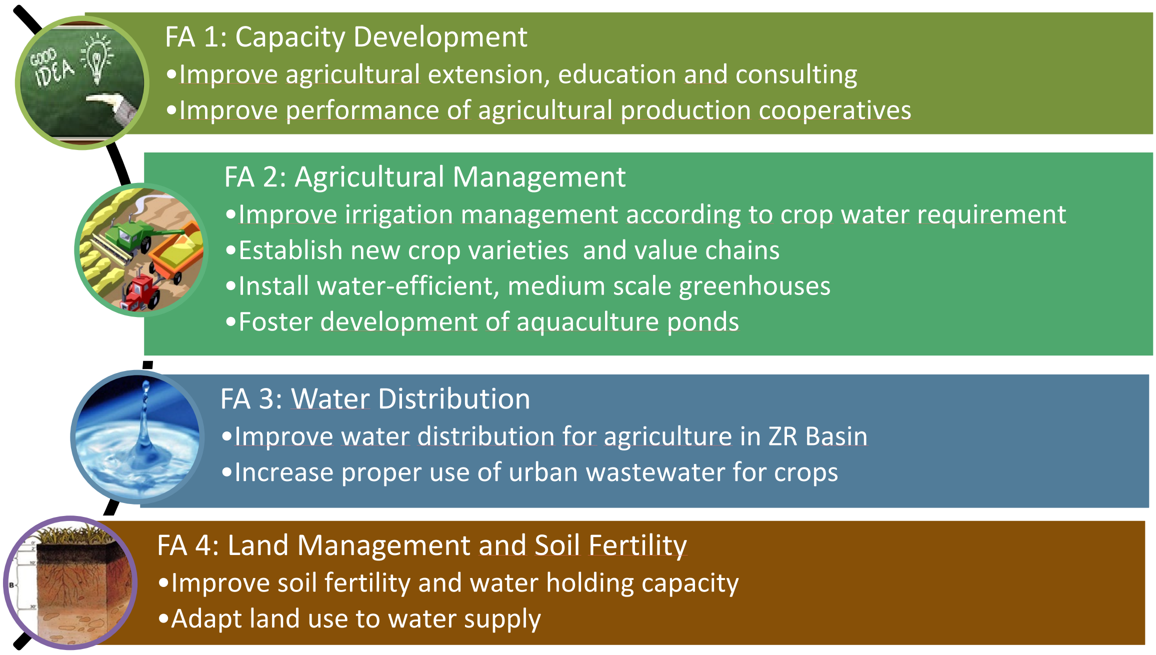


Figure 6.1: The four focus areas and strategies for agricultural transformation

6.1 Focus Area 1: Capacity development

Changes in climate and site conditions are affecting agriculture in the Zayandeh Rud Basin. A key element for meeting the agricultural challenges in the basin is information exchange, increasing the knowledge base as required, organizing and disseminating it to the stakeholders. An important role for IWRM in the basin is coordinating and enabling this learning and communication. This focus area includes two strategies in which agricultural extension, education and consulting can help to improve the agricultural understanding and support a more efficient use of water and other resources in the Zayandeh Rud Basin:

- Improve agricultural extension, education and consulting
- Improve performance of agricultural production cooperatives

The first strategy expands the understanding of extension from technology transfer to facilitation, active learning and support in implementation, while the second strategy illustrates what capacity development measures can support a concrete goal. The implementation of these strategies requires the support of numerous organizations that can form a bridge between research and education on the one side, and farmers, business and enterprises on the other side. The IWRM River Basin Organization needs to be one of these bridging institutions (**Figure 6.2**). In addition, the current participatory process in this BMBF project of getting to know the stakeholders, working together and learning from each other through joint activities should also be continued through formalizing a stakeholder platform as part of the IWRM organization. The stakeholder platform needs to continue the current process aimed at building trust and mutual understanding of the individual requirements and at creating the right conditions for collective decision-making.

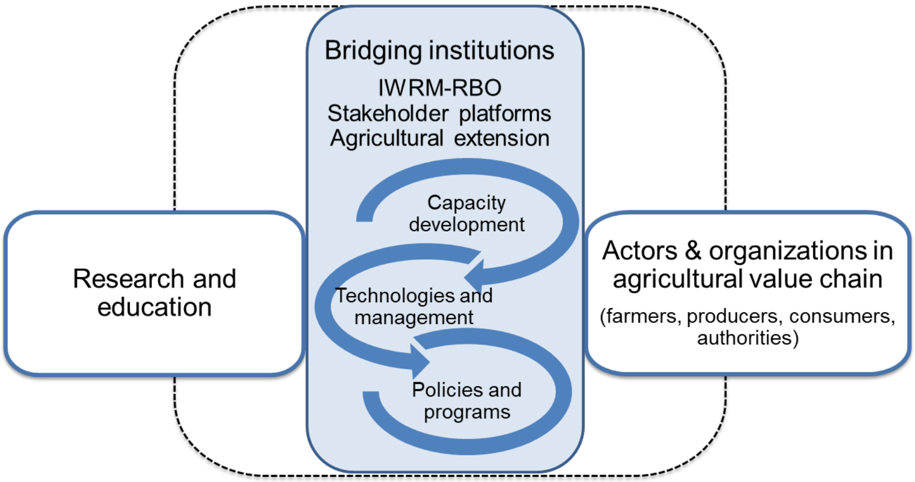


Figure 6.2: Framework for integrating agricultural extension, education and consulting in IWRM. (Source: adapted from AERNI et al., 2015.)

6.1.1 FA1 Strategy 1: Improve agricultural extension, education and consulting

Agricultural Extension was conceived as a service to “extend” research-based knowledge to the rural sector in order to improve the life of farmers. The traditional view of extension in developing countries was very much focused on improving yields, enhancing production, training farmers, and technology transfer. Nowadays the understanding of extension goes beyond technology transfer to facilitation, beyond training to learning, and includes helping farmers form groups and deal with marketing issues. Therefore, agricultural extension can be defined as the entire set of organizations that support people engaged in agricultural production and facilitate their efforts to solve problems, link to markets and other players in the agricultural value chain; and obtain information, skills, and technologies to improve their livelihoods (DAVIS, 2009). The targeted impacts for this strategy, I1) Capacity development in agricultural value chain, I2) Technologies and management information, I3) Facilitating, brokering and implementing policies and programs, need to include all these aspects and be highly interlinked (**Figure 6.3**).

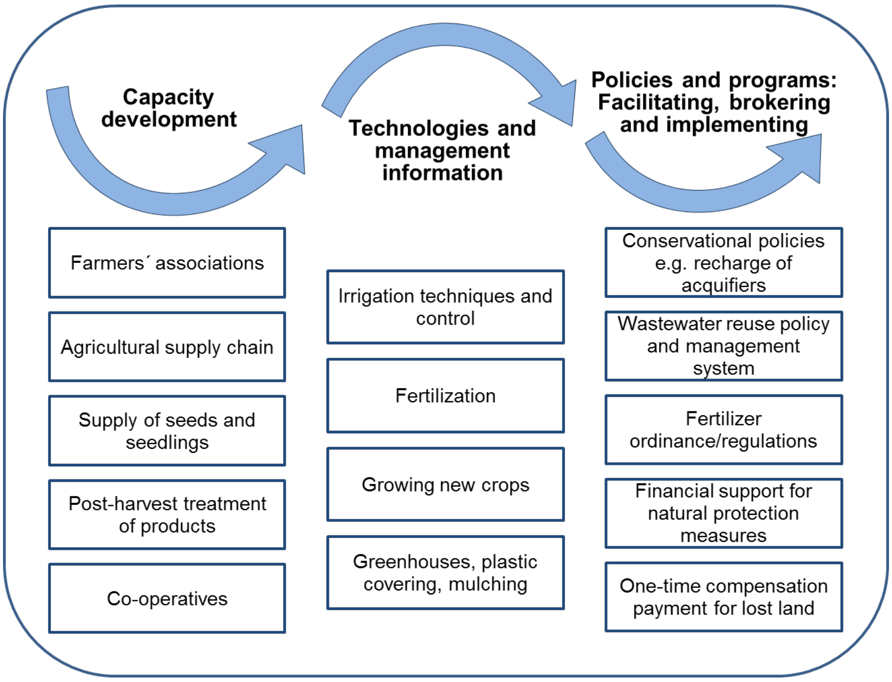


Figure 6.3: Three targeted impacts and their measures to improve agricultural extension, education and consulting

Table 6.1: Targeted impacts and measures for the strategy FA1 S1: Improve agricultural extension, education and consulting.

No.	Impact	No.	Measure
I1	Capacity development in agricultural value chain	M1	Farmers' associations
		M2	Agricultural supply chain
		M3	Supply of seeds and seedlings
		M4	Post-harvest treatment of products
		M5	Co-operatives
I1	Technologies and management information	M1	Irrigation techniques and control
		M2	Fertilization
		M3	Growing new crops
		M4	Greenhouses, plastic covering, mulching
I3	Facilitating, brokering and implementing policies and programs	M1	Conservational policies e.g. recharge of acquifiers
		M2	Wastewater reuse policy and management system
		M3	Fertilizer ordinance/regulations
		M4	Financial support for natural protection measures
		M5	One-time compensation payment for lost land

Targeted Impact 1 (FA1 S1 I1): Capacity development in agricultural value chain

Capacity development throughout the whole agricultural value chain is necessary to enhance interaction, build trust and create synergy between research institutions and public and private sector actors, farmers and co-operatives to enable them to address a whole range of activities, investment and policies to make agricultural transformation happen. Capacity development is not politically neutral. It involves questioning and sometimes even upsetting the status quo. It might lead to conflicts and therefore it needs a strong, facilitative leadership and commitment of the stakeholders. The interactions in **Figure 6.2** demonstrate the need of a comprehensive structure to enhance the agricultural system in an innovative way. Capacity building will be needed in several parts of the system. Giving it a central position allows us to generalize the recommendation of specific ideas how to implement capacity building targeted and successful.

The establishment of **farmer´s associations** (e.g. DBV, 2018, LANDVOLK, 2018 and LBV, 2018 in Germany) and the further support of existing farmer associations is one tool to help farmers and processors to organize themselves to meet their mutual agricultural interests respective to the site-specific goals. The farmers in the Zayandeh Rud Basin have different needs according to their different site conditions and water availability and it is recommended to engage the farmer in a united association to tackle the challenges which belong to the upper part of the basin and the lower part of the basin together. It will be essential to support the economic self-reliance and the participation of the members in their organization´s activities financially to promote farmer´s associations successfully (RIVERA, 2001 (FAO)). The Agricultural Trade Union (Nezam Senfi Keshavarzi) is a recently strengthened association which has already taken great efforts to get farmers to follow up on common concerns and demands in Isfahan and in the basin. Despite of the challenges that the Agricultural Trade Union has faced to become accepted by all famers and effectively get involved in the process of decision making, it has a high potential to be able to build a bridge between farmers and policy makers, bring all affected and affecting stakeholders together, and finally resolve the conflicts between farmers and other water users or providers. Furthermore, it is important to establish structures and organizations to implement regional agricultural measures related to diverse topics e.g. financing for buying machinery that could be shared or seeds and seedlings.

Agricultural Research (e.g. LWK, 2018 and LANDWIRTSCHAFTSKAMMER NRW, 2018) and **Extension Centers** (e.g. from local universities or agricultural organizations and FAO initiatives) are a useful solution by doing applied research to meet future challenges and to help to establish the application of new discoveries. To target the challenges within the Zayandeh Rud Basin, it is recommended to establish those centers with individual focus on the water use issue in agricultural production for the upper part, the middle part and the lowest part of the basin. New knowledge concerning water management and business training has to be accessed by the target groups fast. Besides gaining knowledge by experts from research, policy and industry, it is recommended to introduce lessons from “farmer to farmer”. The exchange of own experiences will enforce a stronger commitment as community. From our point of view it will be fertile to organize the communication of the farmers within the separate parts of the basin, but also through the whole basin. Gaining knowledge on the different challenges of the farmers will lead to a better understanding of stated scope of action by policy makers.

The agricultural supply chain is seen as an important support for a successful agricultural transformation within the basin (**Chapter 6.4**). It will be important to establish the infrastructure that is needed for the agricultural production of probably changing products. The access to e.g. fertilizer, seeds and seedlings as well as necessary machinery has to be ensured. The benefits of a regulated cultivation structure appropriate for each part of the basin should be highlighted with the provision of specific seeds and seedlings. Therefore, characteristics have to be set up in each part of the basin (see **Chapter 5.3**-new crops).

The capacity building needs to be done facing the reality on the ground. The agricultural production has to be connected with the successful post-harvest treatment of the products. Related to the agricultural products it will be necessary to identify gaps in infrastructure especially for post-harvest handling, but also for e.g. road networks and supply cooling systems and electricity.

Targeted Impact 2 (FA1 S1 I2): Technologies and management information

Modern technologies have a fundamental role to play in making agriculture successful and sustainable. The farmers in the Zayandeh Rud Basin have been forced to respond flexibly to water availability in the past. Their ability to manage the challenges of water scarcity and changing climate conditions will be needed even more in the future. It will be challenging for extension agents, farmers and researcher to react in terms of knowledge and information systems on the changing conditions. The farmers within the Zayandeh Rud Basin will need to be able to quickly respond to water scarcity or water availability to adeptly manage the risk.

It is important to accompany all measures changing production techniques and products with adequate training offers. The use of irrigation techniques (site- and plant oriented) as well as using appropriate irrigation management (**Chapter 5.1**) has to be learned. The implementation of water saving agricultural measures e.g. organic and plastic mulching/covering (**Chapter 5.2**), alternative crops (**Chapter 5.3**) and greenhouses (**Chapter 6.2.3**) must go hand-in-hand with building capacity to handle the new measures sustainably. For example, farmers applying new fertilization strategies must be given methods that avoid nutrient contamination of water resources. On the other hand, the fertilizer and the machinery to spread the fertilizer have to be available. The introduction of new crops and value chains (**Chapter 6.2.2**) has to be accompanied by optimizing results not only in term of yields, but also water productivity and nature protection as well.

The farmers need modern information and communication technologies (ICT) to reach information easily - be it irrigation water information, forecasts, adaptive technology innovations, or markets. This is especially important for young farmers and agripreneurs. Networking can be carried out by using the modern technologies. The farmers can use online platforms such as social media groups (Facebook, mobile apps) or mailing lists to facilitate sharing information and knowledge on good agricultural practices and their own experiences with each other. Furthermore e-advisory services (text message-based alert systems, etc) offer access to important information such as markets, weather, irrigation tools (e.g. ATB-Cropi, a web-based applications to calculate IWD), e-extension services, financial services and information on outbreaks of pests and diseases, etc. Also new business opportunities can be opened up through the modern ICTs. The farmer can reach distant markets/clients for their products and services.

Targeted Impact 3 (FA1 S1 I3): Facilitating, brokering and implementing policies and programs

Agricultural and rural policies should aim at improving infrastructure, credit and markets for the farmers. Furthermore, the extension services will be in the role of an honest broker between different actors within the rural sector. With the increasing water scarcity in the region, it will be more important in the future to strongly improve the farmers´ access to input suppliers, transport agents and the markets for selling their products. Increased access to meteorological information will be imperative as well as the information from the water agency related to the availability of irrigation water. Extension services will also be needed to deal with the challenge in bringing together farmers concerns and those of other actors as they address both the water related and market uncertainties together. Support for the farmers will be needed in implementing policies and programs that deal with the water scarcity in the Zayandeh Rud Basin. For instance, involving them in the implementation of environmental protection measures (such as wetland or rangeland restoration) or conservational policies like the recommended recharge of aquifers. The implementation of sustainable gray water policies and management systems will be supportive to enhance a reuse of water (**Chapter 6.3.2**) and it reaches not only the farmers but a bigger part of the population in the rural areas. The establishment of an adaptive fertilization ordinance and its regulations will need assistance in the basin. Besides disseminating information on adaptive fertilization strategies, it will be necessary to explain how the site-specific handling with fertilizer will be supportive for the improvement of water and soil salinization (**Chapter 6.4.1**). The change in agricultural land use will be an enormous challenge especially in the lower part of the Zayandeh Rud Basin. Reduction in land in reaction to changing water availability for the agricultural production will be inevitable. Extension should use this chance to make a significant contribution to support this challenging process by playing a bridging role together with the stakeholder platform as part of the IWRM organization to enable active involvement of farmers in the decision-making process.

6.1.2 FA1 Strategy 2: Improve performance of cooperatives in agricultural production

Farmers within the Zayandeh Rud Basin haves to deal with several challenges related to the impacts of the water scarcity and climate change in the region. The need of new management strategies in connection with using new plant varieties and land use change requires a high adaptability of the farmers. It is seen as a successful solution to take these challenges within a strong group of stakeholder in the agricultural sector. Establishing new cooperative companies in the rural areas will be adding value in a successful transformation of the agriculture in the basin. Two targeted impacts were defined to accomplish this goal: 1) Empowerment of cooperatives (members, brokers, structure), 2) Governmental support for cooperative companies. The two targeted impact and measures are listed in **Table 6.2**. In the following section, impacts, measures and activities for the strategy are presented.

Table 6.2: Targeted impacts and measures for the strategy FA1 S2: Improve performance of cooperatives in agricultural production

No.	Impact	No.	Measure
I1	Empowerment of cooperatives (members, brokers, structure)	M1	Promote cooperative companies as the right place for producing healthy, organic and exportable products
		M2	Enhance the level of knowledge and expertise of members and staff of agricultural cooperative companies.
		M3	Provide the necessary basis for the sale of products
I2	Support cooperative companies through governmental policy	M1	Provide necessary subsidies to the agricultural sector for supporting agricultural cooperative companies and grant low interest rate from financial facilities
		M2	Modify rules to fix the position of the utilization system and then determine the scope of the relevant associations
		M3	Apply related laws to the field of corporate governance.
		M4	Assign governmental funding to provide agricultural infrastructure (such as land equipment and modernization, water conveyance, etc).

Targeted Impact I1: Empowerment of cooperatives (members, brokers, structure)

The targeted impact might be reached by tackling the measures (outcomes) listed in **Table 6.3**. Fundamental for a successful empowerment of agricultural cooperatives is the establishment of adjusted marketing opportunities. Target markets have to be identified to sell the products. Having a network structure between the cooperatives and the retailer will be needed. Desirable are fixed contracts to sell for the agricultural products adapted to e.g. new implemented products. A successful work in an agricultural cooperative will also need a high expertise of its leading members at least. The cooperatives will become lighthouses in the different sized villages, cities and regions so that they can influence the surrounding significantly. The work of the cooperatives should therefore be sustainable from the environmental, economic and social point of view. The development of a regular exchange of knowledge between multi-stakeholder (education and research centers with the farmers and at least the regional politicians) will be essential.

Table 6.3: Measures and activities for the impact FA1 S2 I1: Empowerment of cooperatives (members, brokers, structure)

No.	Measure	No.	Activity
M**1**	Promote cooperative companies as the right place for producing healthy, organic and exportable products	A1	Create the basis for the establishment of agricultural cooperative companies in areas without production facilities
		A2	Identify the needs of cooperative members and specialized and launch revenue generating units.
		A3	Strengthen the financial and logistical power of agricultural cooperative companies by members.
M**2**	Enhance the level of knowledge and expertise of members and staff of agricultural cooperative companies	A1	Develop short, medium and long term training courses for cooperatives
		A2	Hold training courses for members and operators of cooperative companies and farmers in various fields.
		A3	Organize scientific visits from domestic and foreign successful co-operatives
		A4	Strengthen the relationship between educational and research centres with farmers in the agricultural sector
M**3**	Provide the necessary basis for the sale of products	A1	Identify target markets for the sale of products and support market entry
		A2	Guarantee the purchase of the products of agricultural cooperative companies
		A3	Establish a network structure to connect the cooperative companies and distributors/exporters of products

Targeted Impact I2: Support cooperative companies through governmental policy

The adaptation on the climate change in the Zayandeh Rud Basin is a far-reaching challenge. The farmers and the agricultural cooperatives will need financial support to tackle this important regional task (**Table 6.4**).

The payment of land use based subsidies will help to support the inevitable and controlled land use change. Governmental grants will be needed to build the required infrastructure to enhance the agriculture production process (e.g. availability of seeds, fertilizer, machinery, qualified worker and the retail of the products.

Table 6.4: Measures and activities for the impact FA1 S2 I2: Support cooperative companies through governmental policy

No.	Measure	No.	Activity
M1	Provide governmental subsidies, grants and low interest loans to help and support agricultural sector for establishing agricultural cooperative companies	A1	Facilitate administrative bureaucracy of grants and financial assistance for production cooperatives, preferably through the agricultural development support fund
		A2	Pay subsidies to export agricultural products
		A3	Pay subsidies to successful and superior production cooperatives to create a competitive environment
		A4	Pay subsidies to organic and healthy producers
		A5	Pay subsidies for the modernization of agricultural machinery of agricultural cooperatives
M2	Modify the rules to consolidate an operational framework and then determine the scope of associations between relevant bodies	A1	Re-promote the position of the utilization system as the trustee of the agricultural cooperative at the level of the deputy minister.
		A2	Support job security for brokers in agricultural cooperative companies
M3	Apply related laws to the field of corporate governance.	A1	Assign the training of farmers to agricultural cooperatives
		A2	Assign the audit of Cooperative Companies to the Union of Agricultural Cooperatives
		A3	Assign land licensing procedures (maintenance of use and prevention of land use change in agriculture and natural resources)
		A4	Establish agencies for the purchase and sale of agricultural products by cooperative companies
		A5	Issue licenses for agricultural sector (livestock, greenhouse, fisheries, mechanization, water and soil, etc)
M4	Assign government funding to provide agricultural infrastructure (such as land equipment and modernization, water conveyance, etc.)	A1	Provide governmental grants to build the required infrastructure of cooperative companies
		A2	Allocate government credits and grants for infrastructure projects, such as land equipment and modernization, implementing and improving modern irrigation systems, laser leveling of land (based on landscape designing plan)

6.2 Focus Area 2: Agricultural Management

Strategies for changing agricultural management in the basin need to take into account the expected variability in water supply and the competition from other water users (domestic, environmental, and industrial). Development of basin-wide plans to prepare appropriately for water scarcity conditions are seen as a priority by the stakeholders. Furthermore, there is consensus that the strategies must consider not only the physical water productivity of farming systems (i.e. "more crop per drop"), but also the economic productivity of the water (i.e. profit or value derived per drop), as well as other resources such as land, energy, labor and the environment. Water allotment plans must include the environmental water requirements in the basin and consequences for regional food security must also be taken into account.

To develop appropriate strategies for agricultural management, the focus of numerous participatory activities and analyses within the framework of the project was on how to meet the challenge of the expected variability in water supply. Four strategies with targeted impacts, and required measures and activities were determined:

- Improve irrigation management activities according to crop water requirement
- Create value chains e.g. by introducing and developing new crop varieties
- Increase number of water-efficient medium scale greenhouses in temperate regions
- Construct aquaculture ponds

The first three have been further refined in this section through a discussion of impacts, measures and activities. The tables for the strategy aquaculture ponds can be found in the appendix.

Most of the impacts expected from the four strategies center around better planning and coordination of agricultural activities throughout the basin, and expanding capacity building activities (**Table 6.5**). This will be achieved mainly by measures for aggregating and disseminating current knowledge, creating new structures and networks to coordinate the stakeholders, with the goal to improve the economic productivity of the water and land. The measures and associated activities for each strategy are found in the following sections. While some measures do call for further research to build the foundation for new or improved technologies (e.g. crop variety, crop monitoring, greenhouses, ponds), adaptation of on-going work in many regions of the world to local conditions can lead to regionally appropriate solutions.

The strategies need to be embedded in an over-all integrated basin management plan to reduce agricultural water use and respond flexibly to changes in water resources and distribute them equitably between the water users. As discussed in **Chapter 5**, none of the strategies can be expected to reduce basin-wide agricultural water use by themselves if the overall area of irrigated cultivated land area is not reduced. Indeed, local water savings through reduced farm or district irrigation system losses (conveyance losses, return flow, etc) often motivate farmers to expand their irrigated area or shift to crops with higher value but with higher water consumption, so that basin-wide water consumption is not reduced (WARD and PULIDO-VELAZQUEZ, 2008, JÄGERMAYR et al., 2015). A transparent water accounting system needs to be developed based on the water consumed, not on the water applied or diverted. Innovative schemes need to be applied, mixing technical improvements with policy to create real water savings and increase the amount of water available for the environment. For example, a series of water reforms is being tried by the Australian government that include subsidies to farmers to reduce irrigation losses at the field and district level in the Murray-Darling Basin, and buying back the saved surface water entitlements to increase environmental flows (QURESHIA et al., 2010). Although major progress had been made in coordinating stakeholders and redistributing water rights to increase environmental flow, a recent scandal with thefts of water, highlights that no matter how good or bad the plan was in its conception, it is vulnerable to fraud without strong enforcement measures and oversight (ALEXANDRA, 2018).

Table 6.5: The four strategies in FA2: agricultural management and targeted impacts

No.	Strategy	No.	Impact
S1	Improve irrigation management according to crop water requirement	I1	Improve water productivity
		I2	Provide access to knowledge on water requirements of plants and irrigation management
		I3	Prepare appropriately for water scarcity conditions
S2	Establish new crop varieties and value chains	I1	Train farmers and upgrade their knowledge and awareness
		I2	Develop new plants cultivation and strengthen product value chains
		I3	Establish value chains for new agro- products (from farm to table)
S3	Install water-efficient medium scale greenhouses	I1	Build capacity and knowledge transfer for greenhouse production
		I2	Manage and provide financial resources for greenhouse production
		I3	Create economic value chain and marketing for products
S4	Foster development of aquaculture ponds	I1	Promoting of education and science of using modern methods and processes in production
		I2	Enhance governmental and institutional support
		I3	Improve efficiency of resources use, produce eco-friendly products

Many strategies (e.g. greenhouses, ponds, new value chains) can only be successful if the water supply is secure. These strategies must be combined with changes in supply side factors such as governance and institutional issues, as well as with strategies to manage risk and uncertainty. For example, the potential of greenhouses to reduce overall cultivation area while producing similar amounts of food at higher quality with less water, must be evaluated in conjunction with the increased requirements for a secure water supply of high quality and risks to the local water resources of overexploitation, nitrate contamination and salinization of aquifers. Although there is potential for real water use reduction basin-wide, especially through water reuse technologies in greenhouses and aquaculture ponds (e.g. water condensation, purification), these additional technologies increase the already high capital costs, energy consumption, labor-intensity and skill requirements (managers and workers) of such installations.

Increasing the economic water productivity may theoretically allow similar levels of income to be attained by a larger number of farmers with the same amount of water; however, this requires an equitable distribution of resources. The results of the various participatory activities in the project show that there is discontent with the current state of water distribution and water rights. A water allocation rights reform is needed, including re-evaluation of water transfers within the basin and to other basins (Raber et al., 2018a and b). In their reports, they outline actions for reform. In the face of reoccurring restrictions on water use due to water scarcity, they point out that more transparency in water allocation rights is a prerequisite for implementing transformation strategies.

In the following sections, impacts, measures and activities for each of the four strategies are presented. A few are highlighted in more detail. The important prerequisite for all strategies, the establishment of an equitable supply and distribution of water resources, will be dealt with in the chapter on water distribution. Common to most strategies are activities to continue development of a common knowledge base and set of tools, so that resource management plans can be put forward and evaluated. The knowledge base and tools need to be developed with participation of all stakeholders to improve the current situation, where fear of bias has prevented widespread use of many important tools and much detailed knowledge that has been developed in the basin (MOHAJERI et al., 2016). The further development of a neutral database and the jointly developed water management tool is essential to build the basis for generally accepted decisions. The documentation of the current spatial distribution in the basin of agricultural production (yields, harvest, soil), water availability (quality and quantity), and water use (by crop and location), and making it accessible to stakeholders is an important step. Technological advancements in satellite analysis, data processing, modeling, and end-user devices (PCs, cell phones, apps) can be used to reach this goal. Stakeholder acceptance and knowledge of this information will support the development of implementation plans. Tools such as the WMT must be used to evaluate whether or not the strategies will translate into real water savings at a basin scale, or just in the local farming systems.

Indeed, not only is further analysis of the hydrological interactions between the field, the farm and the entire river basin required, but also the trade-offs between water and energy consumption, product quality, food security and flexibility to react to market demand need further investigation. Changing water productivity can also change the economic productivity of other resources such as land, energy and labor, as well as the regional food supply. Improvements in the efficient use of one resource often entail increased use of other resources, e.g. fertilizer, energy, construction materials; infrastructure so that changes must be evaluated holistically. The process of integrated analysis of the various regions of the basin was started in the IWRM project and the accompanying vulnerability analysis of the Roodasht region (RABER et al., 2018a). This type of analysis needs to be continued and expanded to the other regions in the basin as part of the IWRM process.

6.2.1 FA2 Strategy 1: Improve irrigation management according to crop water requirement

Irrigation management in arid and semi-arid areas like the Zayandeh Rud Basin is faced with the problem of matching the limited and variable available water resources with an appropriate and flexible cultivation area and pattern. As was seen in the historical analysis of the surface water supply from the Zayandeh Rud River (**Chapter 2**), in many years the available irrigation water is significantly less than the available cultivable land area and associated crop water requirements. Under the reoccurring drought conditions, many fields could not be planted and/or harvested in the lowest irrigation district of Roodasht (RABER et al., 2018a).

Strategies for irrigation management that focus on technologies and control options for fields, farm or district level often have little impact on water availability at the basin level. Local reduction in irrigation system losses can lead to reallocation of water, not to a real water reduction in basin-wide water consumption (GIORDANO et al., 2017, PERRY, HELLEGERS 2012). A basin-wide water accounting and regulation framework must be built that can track, assess and regulate these changes. The reduced irrigation system losses potentially allow the water to be distributed more evenly to the intended fields, resulting in improved crop yield and/or quality, however, the water previously "lost" to the groundwater (or surface water) may no longer be available for the environment or other users downstream. The local savings by more efficient conveyance or micro-irrigation systems, such as sprinklers or drip, may tempt farmers to plant larger areas without considering the threat of possible shortages in water supply during the growing season which will cut their ability to irrigate the larger area and/or apply enough water to avoid soil salinization.

Furthermore, while the current trends towards precision control of irrigation equipment with sensor-based monitoring can reduce field water losses by responding to changing plant water needs over the growing season, in areas without a secure source of water over the season, implementing irrigation management according to the plant's water need is next to impossible. Due to the fixed water supply and distribution system of surface water (time and irrigation intervals), farmers without groundwater resources have little leeway to respond flexibly to plant water needs. Without a more reliable supply, technical measures to reduce water use such as sprinkler and drip irrigation or irrigation control with soil sensors are not feasible. Thus, the suggested strategies by the stakeholders are focused on improving crop and irrigation planning according to the crop water requirement, rather than on implementing technologies. The targeted impacts are 1) Improve water productivity, 2) Provide access to knowledge on water requirements of plants and irrigation management, 3) Prepare appropriately for water scarcity conditions. The need to determine the water requirements of different products in the basin, assess the productivity of current and alternative water use and provide access to this information plays a large role in the impacts and measures suggested to attain this strategic goal (**Table 6.6**). Based on this information, planners and farmers can adapt the crops and cultivation pattern.

Targeted Impact 1 (FA2 S1 I1): Improve water productivity

Since the mid-1990s, understanding and improving agricultural water productivity have been important goals in the area of agricultural management (GIORDANO et al., 2017). Agricultural water productivity is usually defined as the ratio of farm output to water input. However, a variety of definitions have been advanced for water productivity: The output can be the product mass or nutritional value, i.e. the physical water productivity PWP or the value derived from the product, the economic water productivity, while the water input can be the total water supplied (rainfall and/or irrigation water), plant evapotranspiration, transpiration, etc. Therefore, it is essential to agree upon what exactly is meant by improving water productivity between the stakeholders. In the case of the measures and activities suggested for this impact (**Tables 6.7**), both the physical and economic water productivity is in focus.

Table 6.6: Targeted impacts and measures for the strategy FA2 S1: Improve irrigation management according to crop water requirement

No.	Impact	No.	Measure
I1	Improve water productivity	M1	Determine water requirement of plants in different areas of the basin with the aim of increasing water productivity and providing for the environmental water need.
		M2	Improve cropping patterns to provide water for all sectors
		M3	Improve irrigation practices to increase water use efficiency (i.e. increase % of water used productively by crop, transpiration/water input)
I2	Provide access to knowledge on water requirements of plants and irrigation management	M1	Create integrated service for farmers including software/ database/ web accessibility with participation of all relevant institutions
		M2	Develop tools and guidelines for crop planning and irrigation management for farmers with all relevant institutions
		M3	Develop educational programs for changing crop pattern and irrigation management for relevant stakeholders
I3	Prepare appropriately for water scarcity conditions	M1	Propose land use change plans
		M2	Stop or reduce extraction from the Zayandeh Rud River
		M3	Develop allocation plans for water distribution for drought conditions with all stakeholders

The key steps to improve water productivity are to assess the status-quo and then act upon it. At the core of the measures in **Table 6.6**, is the plan to use the analysis of the historical crop water requirements to better distribute crops between districts, fitting the cropping pattern to the available water supply and to the requirements of the local population for food and feed. In the first measure a basin-wide spatially differentiated information system on crop water requirement (CWR), crop yields and profits, irrigation water demand and supply should be set-up for data over the last decades. An important objective is to determine the past and current water productivity (physical and economic) and compare the values between farms and districts and with other regions. This analysis of the differences in values of the water productivity indicators between farms and/or regions is the basis to determine potential measures with local experts.

Discussion with local farmers and experts is necessary because the differences are not necessarily due to water-related issues, but may be the result of many other factors, e.g. different agronomic inputs and/or outputs and their related prices (GIORDANO et al., 2017). For low yields, e.g. less than 40 – 50 % of the potential yield, non-water factors such as land degradation and nutrient depletion may limit yield and crop water productivity (MOLDEN et al., 2010). Agronomic measures such as improving soil fertility, controlling weeds and disease, adjusting fertilizer application and/or the timing of planting may be needed to increase yield. However, when yields are above 40 – 50 % of their potential, increases in yield are almost proportional to increases in the plant transpiration. Thus, in order to increase yields even more, reliable and higher amounts of water are required. Evaluation of whether such potential realistically exists by local stakeholders is necessary. Target ranges for water productivity for the different crops should be set and guidelines for farmers developed.

Table 6.7: Measures and activities for the impact FA2 S1 I1: Improve water productivity

No.	Measure	No.	Activity
M1	Determine basin-wide spatially differentiated crop water requirement (CWR) to increase water productivity and provide for environmental water need.	A1	Collect, evaluate and disseminate information on crop water requirements in different areas of the basin from all relevant institutions
		A2	Create a shared database on CRW and irrigation water demand (IWD) with access by all stakeholders
		A3	Improve forecasting ability of IWD models for farmers
M2	Improve cropping patterns to provide water for all sectors	A1	Determine appropriate cropping patterns for the different regions and propagate their implementation
		A2	Determine the net economic profit of each crop (gross income -costs) to choose more economic crops for irrigated farming
		A3	Determine required (minimal) land area for feed crops for livestock in the region
M3	Improve irrigation practices to increase water use efficiency (i.e. increase % of water used productively by crop, transpiration/water input)	A1	Restore and renovate water infrastructure throughout basin, e.g. structures and water transfer canals, to reduce water losses
		A2	Equip extraction and delivery points (Levels II) with control and measuring equipment
		A3	Plan water supply timing based on basin-wide economic analysis
		A4	Implement irrigation scheduling and control to match crop water requirements and reduce evaporation losses (e.g. deficit irrigation and mulching)
		A5	Determine appropriate irrigation practices for each field (soil/crop/weather) with expert surveys to produce guidelines for optimal irrigation efficiency and uniformity

Determination of the spatially differentiated crop water requirement (CWR) can be done using an appropriate model based on the Food and Agriculture Organization (FAO) Paper 56 (ALLEN et al., 1998), e.g. the AgroHyd Farmmodel or another GIS-based model, local values for the crop parameters, field data on seeding/harvest/land area, weather and soil data for each region. Another approach is to use satellite images and crop models to estimate CWR and yields. Remote sensing can be a powerful tool for estimating vegetation indices (VI), like the normalized vegetation index (NDVI) and the soil-adjusted vegetation index (SAVI). Moreover, CWR (based on soil and aerial environment) and water stress (based on crop water content) can be estimated by remote sensing satellite images and thermal infrared methods (CASA et al., 2009, YI et al., 2013, ZARE, 2017). It is recommended that the Landsat satellite images will be used for Zayandeh Rud Basin due to the relatively high resolutions (30 m for 9 operational land imager bands and 100m for 2 thermal infrared sensors) and the free availability of all data from USGS website (http://earthexplorer.usgs.gov). The most recent one, which was launched on February 11, 2013, is Landsat 8. The Landsat 8 data is suitable for methods which calculate either CWR (e.g. SEBAL method, BASTIAANSSEN ET AL., 2005) or crop water stress indices (e.g. VEYSI et al., 2017). Using two TIRS bands from the Landsat 8 is suitable for methods which calculate the LST using either two thermal bands e.g. split window algorithm or one band such as single channel algorithm (JIMENEZ-MUNOZ et al., 2014).

Another approach which can be applied in Zayandeh Rud Basin is to develop a low cost sensor network for soil-plant-atmosphere measurements and an information communication technology (ICT) frame with automated decision support capabilities using smart algorithms for irrigation management and Geographical Information System (GIS) based spatial data aggregation together with tools for end user farmers for remote monitoring and control of their farms. This is the focus of current research. The overall structure is shown in **Figure 6.4**.

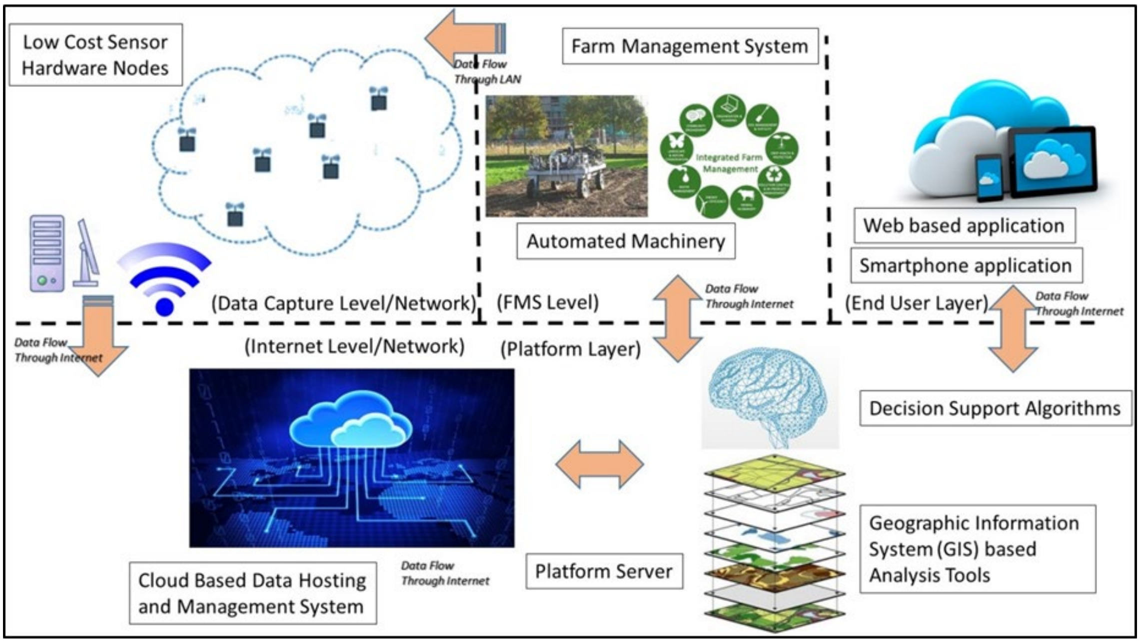


Figure 6.4: Overall structure of a potential ICT system for determining spatially differentiated crop water requirements (Source: adapted from YONG et al., 2018)

A crucial next step is that the regional experts should agree on which methods and models should be used in the region. It is possible to combine all these methods, locating pilot projects in specific parts of the basin as a basis to determine appropriate methods for the different regions. Plans should be made to determine the degree of precision desired for the various data and models. For example, it needs to be decided whether the current weather and hydrological data collection stations are adequate and how they should be expanded to increase coverage to provide the required degree of spatial differentiation. An expandable system for data storage and models at the field scale, such as the data library Sponge-JS, needs to be developed for the basin (GEBEL et al., 2017a). The next steps are to calibrate and validate the model results with experimental water use data, e.g. from lysimeters, and upgrade the model.

Another objective for developing the database is to provide a basis for improving the forecasting ability of IWD models. The improved models can be integrated into the information system that is easily accessible for all stakeholders to provide farmers with a tool to estimate their daily or seasonal irrigation water demand of their crops. This will allow them to make informed decisions on their farming options. The third measure complements the other two by gathering information on irrigation water supply and use. Local knowledge on appropriate irrigation practices will be used to produce guidelines to improve irrigation.

Targeted Impact 2 (FA2 S1 I2): Provide access to knowledge on water requirements of plants and irrigation management

All of the above activities will produce knowledge that needs to be transferred to the relevant stakeholders, in most cases, the farmers. A key step will be to create an integrated service for farmers that includes developing the software and database as well as assuring the web accessibility to this knowledge (**Table 6.8**). Training materials for using the knowledge on water requirements to change crop patterns and irrigation management need to be developed. However, in addition to the capacity development activities, hardware and software tools need to be developed that will enable the farmers to implement the expanded knowledge. Low cost sensors to measure field conditions that are appropriate for the region are required. Irrigation scheduling based on decision support algorithms and GIS analysis synthesizing the knowledge gathered in the above measures will support water savings and yield increases.

Table 6.8: Measures and activities for the impact FA2 S1 I2: Provide access to knowledge on water requirements of plants and irrigation management

No.	Measure	No.	Activity
M1	Create integrated service for farmers	A1	Make the data on CWR, IWD, PWP, EWP developed in the previous measures accessible to all stakeholders via the appropriate software/databases/web accessibility
M2	Develop tools and guidelines for crop planning and irrigation management for farmers with participation of all relevant institutions	A1	Develop tools for farmers to use in irrigation scheduling based on decision support algorithms and GIS analysis
		A2	Develop low cost sensors to measure field conditions related to soil, plants, atmosphere (e.g. soil moisture, humidity, temperature, pressure, carbon dioxide)
		A3	Develop recommendations for irrigation frequency based on past water productivity
M3	Develop educational programs for changing crop pattern and irrigation management for relevant stakeholders	A1	Identify relevant training priorities
		A2	Develop educational materials and conduct training workshops
		A3	Provide educational programs through various media

Targeted Impact 3 (FA2 S1 I3): Prepare appropriately for water scarcity conditions

Climate changing phenomena are affecting rainfall temporally and spatially all over the world (IPCC, 2007). Changing hydrological conditions, as well as the increasing exploitation of surface and groundwater resources are causing water scarcity conditions, especially in arid and semi-arid areas. The cultivated area in the Zayandeh Rud Basin has fluctuated year by year as a response to the drastic changes in water supply (**Chapter 2**). In the years with relatively scarce water supply, farmers have been forced to decrease the total cultivation area by 40 % below the baseline cultivated area (2005 - 2006), causing loss of farm income and social unrest. Therefore, a coordinated plan to prepare appropriately for the variable water supply in the Zayandeh Rud Basin is needed. Three measures with several related activities are suggested (**Table 6.9**). The measures and activities center on developing land use change plans based on an improved knowledge base about the potential effects. An important tool for estimating the impact of various measures is the Water Management Tool. It can be used to investigate whether reductions in water consumption in one part of the basin can make water available for other parts of the basin (e.g. transfer water use through purchase from relevant water users).

Table 6.9: Measures and activities for the impact FA2 S1 I3: Prepare appropriately for water scarcity conditions

No.	Measure	No.	Activity
M1	Propose land use change plans	A1	Evaluate reductions in the area of irrigated farming
M2	Stop or reduce extraction from the Zayandeh Rud River	A1	Determine the seasonal environmental water requirements at the basin level
		A2	Estimate minimum discharge for ecological demands for the different regions of the basin
M3	Develop allocation plans for water distribution for drought conditions with all stakeholders	A1	Document historical data on the distribution of water supply to help farmers to make better crop choices based on the approximate time of water delivery
		A2	Investigate whether reductions in water consumption in one part of the basin can make water available for other parts of the basin (e.g. transfer water use through purchase from relevant water users) with the Water Management Tool
		A3	Coordinate research on forecasting drought conditions

6.2.2 FA2 Strategy 2: Establish new crop varieties and value chains

Changing the crop pattern by introducing and developing new crop varieties is one of the challenges for agricultural activities in the Zayandeh Rud Basin. It takes time and needs financial resources to support the establishment of new crop varieties from selection, production in the field to consumption. Creating new value chains is often combined with diverse uncertainties. Especially the financing of new value chains has to be discussed and organized appropriately. The new crop varieties have to be considered holistically regarding their function in the Zayandeh Rud Basin. Three targeted impacts were developed in the workshops to help enhance the development of new value chains through new crop varieties in the basin (**Table 6.10**).

Table 6.10: Targeted impacts and measures for the strategy FA2 S2: Establish new crop varieties and value chains

No.	Impact	No.	Measure
I1	Training farmers and upgrading their knowledge and awareness	M1	Carry out training and knowledge transfer to farmers out by presenting the results of practical applied researches.
		M2	Build farmer´s trust in accuracy and applicability of research results
		M3	Accomplish building culture and justifying farmers for long-term acceptance of crop pattern change
I2	Developing cultivation of new plants and strengthening the economic chain of products	M1	Provide financial resources to explore the potential for the development of new plantings.
		M2	Provide financial incentives, grants and loans, to develop cultivation of high value-added plants.
		M3	Develop the cultivation of new high value added crops based on the government landscape design plan.
I3	Support the establishment of value chains for new agricultural products (from farm to table)	M1	Support access to inputs, technologies and services, and production facilities required in the value chain.
		M2	Develop and organize the market for products in accordance with the new cropping pattern.

Capacity building will be one important factor to support implementation of new plant varieties. This strategy must be coordinated with the overall agricultural management strategy in the basin. As described in **Chapter 2** and Focus Area 4, the basin will have to deal with substantial changes in agricultural use of land and also in the amount of arable land for the agricultural production. The stakeholders in the basin have to be aware that the new crop varieties fulfill diverse tasks within the basin which causes different ways to implement them appropriately into the rural areas. The farmers have to be taken along early in the development process. They have to be involved in the future visions for farming in their regions. More specifically, their knowledge should be promoted about the economic, environmental, or community values of new implemented crops (**Table 6.11**).

The goal of creating value chains will be to improve the welfare of the stakeholders for present and future conditions. Focusing on new crop varieties to reach a better income from the land includes risks for the farmer of market failure and production problems to grow the crops (FAO Report 145). In this regard the establishment of a profitable market should be supported by the government (**Table 6.12**). It is seen as useful to develop a specific funding for the implementation of new crops. Targeted funding can be provided to promote the entrepreneurial interests of the farmer in the new crops and products. The funding might be in form of specific loans or direct financing for e.g. machinery, technical equipment and seeds.

Providing a start-up support for the agricultural part of the process is the first step. But the implementation of a new value chain needs a holistic point of view which additionally includes the support within the whole value chain beyond the farm scale (e.g. transport, cooling, processing, retail) (**Table 6.13**).

As mentioned earlier the new crop varieties can be used to reach different goals. One elementary goal of new crop varieties will be for environmental restoration (e.g. agroforestry plants, haloculture). The environmental protection and restoration of the land by using new crop varieties serves long-term effects for the Zayandeh Rud Basin. Rural areas which might become hosts of larger or smaller environmental protection programs on their land have to be compensated with expense allowance or even better paid for landscape maintenance measures and ecosystem services. Another thinkable solution is the payment of financial compensation to the owner of the land. The discussion on this kind of new value chain in the Zayandeh Rud Basin has to be built on the recent ongoing difficulties of water and land salinization, desertification and water scarcity (**Chapter 2**). Here it will be important to set a powerful signal from the governmental institutions to work against the further destruction of these valuable resources. To gain a higher understanding of those measures it is recommended to increase the communication between the numerous stakeholders in the whole basin.

Table 6.11: Measures and activities for the impact FA2 S2 I1: Training farmers and upgrading their knowledge and awareness

No.	Measure	No.	Activity
M**1**	Carry out training and knowledge transfer to farmers out by presenting the results of practical applied researches	A1	Provide and allocate financial resources (both public and private) and human resources needed to transfer knowledge and present research results
		A2	Create a researcher-promoter network by identifying and employing field researchers with qualified research backgrounds.
		A3	Utilize the media by creating radio and television networks related to agriculture (at national and regional levels)
		A4	Establish an inter-agency committee to allocate budget and human resources for the purpose of extension synergies
		A5	Operate the findings of research on the farm level
		A6	Needs assessment and prioritization of research topics and announcement to the Agricultural Research Center
M**2**	Build trust in the accuracy and applicability of research results to farmers	A1	hold workshops
		A2	Conduct field visits to leading farmers
		A3	use local potentials such as farmers' representatives
M**3**	Accomplish building culture and justifying farmers for long-term acceptance of crop pattern change	A1	Define agricultural courses for rural schools
		A2	Promote advertising in order to introduce new food products and familiarize people with these products.

Table 6.12: Measures and activities for the impact FA2 S2 I2: Developing cultivation of new plants and strengthening the economic chain of products

No.	Measure	No.	Activity
M1	Provide financial resources to explore the potential for the development of new plantings.	A1	Finance a feasibility study on the development of new plant cultivation
		A2	Determine the basis for exporting the new agricultural products
M2	Provide financial incentives, grants and loans, to develop cultivation of high value-added plants.	A1	Guarantee the purchase of product to encourage farmers for developing cultivation of new plants.
		A2	Provide income protect insurance (IPI) plans for farmers to cultivate high value added plants
M3	Develop the cultivation of new high value added crops based on the government landscape design plan.	A1	Compile and implement a government landscape design plan to locate areas prone to developing new plant cultivation
		A2	Change the planting season from warm seasons to cool and cold seasons (winter beet, silage forage, etc)
		A3	Develop cultivation of plants with high value added and low water consumer and resistant to environmental stress
		A4	Cultivate medicinal plants and developing processing products
		A5	Perform necessary studies and compile the crop pattern plan
		A6	Implement the determined crop pattern plan

Table 6.13: Measures and activities for the impact FA2 S2 I3: Support the establishment of value chains for new agricultural products (from farm to table)

No.	Measure	No.	Activity
M**1**	Support access to inputs, technologies and services, and production facilities required in the value chain.	A1	Analyze the value chain to identify weak points in the chain and support actions to add more value.
		A2	Identify the quality and safety standards for new products in target markets and revise guidelines accordingly
M**2**	Develop and organize the market for products in accordance with the new cropping pattern.	A1	Determine marketing and sales strategies

6.2.3 FA2 Strategy 3: Install water-efficient medium scale greenhouses

In water scarce regions such as the Zayandeh Rud River basin, greenhouses can be built to increase water use efficiency in plant production, to achieve better control of product quality and quantity, and finally to better respond to market demand (BAUDOIN et al., 2013). Increasing the number of greenhouses in temperate regions of Zayandeh Rud River Basin was selected as an important strategy throughout the workshops. The construction of water-efficient medium scale (5,000 - 10,000 m²) greenhouses in temperate regions from Najafabad to Baraan (the central part of the basin) was recommended. The challenges of developing greenhouses production systems are multifaceted ranging from the high capital costs, to the high level of technology and management skills required for production, to developing the value chain and marketing system, the logistics delivering products to customers.

Furthermore, although greenhouses have the potential to reduce overall cultivation area while producing similar amounts of food at higher quality with less water, energy requirements increase dramatically as well as the demand for other resources (construction material, equipment, labor, etc). The benefits of reducing land and water use must be evaluated in conjunction with the increased requirements for a secure water supply of high quality and risks to the local water resources of overexploitation, nitrate contamination and salinization of aquifers (GALLARDO et al., 2013).

Through water reuse technologies in greenhouses and aquaculture ponds (e.g. water condensation, purification), even more water can be saved (ZARAGOZA et al., 2007, BUCHHOLZ et al., 2008). It is also possible to integrate saline water in the greenhouse water cycle (BUCHHOLZ et al., 2008). However, the already high capital costs, energy consumption, labor-intensity and skill requirements (managers and workers) of such installations will be increased even further. The high physical water productivity is achieved at the expense of higher production costs. For example, lettuce in a soil-free (hydroponic) greenhouse achieved an eleven times higher PWP, but required 82 times more energy compared to conventionally produced lettuce (BARBOSA et al., 2015).

Therefore, the emphasis of the three targeted impacts of this strategy is on 1) capacity building and knowledge transfer about appropriate technologies for the regional conditions, 2) management and provision of financial resources and 3) creating a local value chain for processing and marketing of the greenhouse products (**Table 6.14 - 6.17**).

Table 6.14: Targeted impacts and measures for the strategy FA2 S3: Install water-efficient, medium scale greenhouses

No.	Impact	No.	Measure
I1	Capacity building and knowledge transfer to support greenhouse products	M1	Support domestic greenhouse manufacturers to have more engagement with farmers.
		M2	Enhance knowledge of farmers for the construction and operation of the greenhouse.
		M3	Reduce barriers to adapt new technology
I2	Management and Provision of financial resources for greenhouse production	M1	Award loans with special conditions to agricultural graduates and other applicants for greenhouse construction.
		M2	Entrepreneurship for agricultural graduates
		M3	Build new greenhouses in areas where required infrastructure is available.
		M4	Facilitate and amend rules and process relating to the product insurance and loans for greenhouse construction.
I3	Create economic value chain and marketing of the greenhouse products	M1	Develop and organize the market for greenhouse products.
		M2	Support access to inputs, technologies and services, and production facilities required in the value chain.
		M3	Identify the target markets for the export of greenhouse products and support market entry.
		M4	Prepare appropriate guidelines for high quality and safe products and Good Agricultural Practices.

In general there is high demand from consumers for a year-round supply of quality products (edible or ornamentals) from greenhouses. So that the strategy of installing greenhouses in the basin has potential to save water and provide income to farming communities. However, extensive planning for developing a large number of greenhouses in the region is required, starting from deciding on how to match regional water supply with demand, to choosing sites (ground conditions, infrastructure access), ensuring financial resources, selecting markets, planning product chains (production stages, post-harvest processing, market logistics) as well as developing a marketing strategy to sell products **(Figure 6.5)** (BAUDOIN et al., 2013).

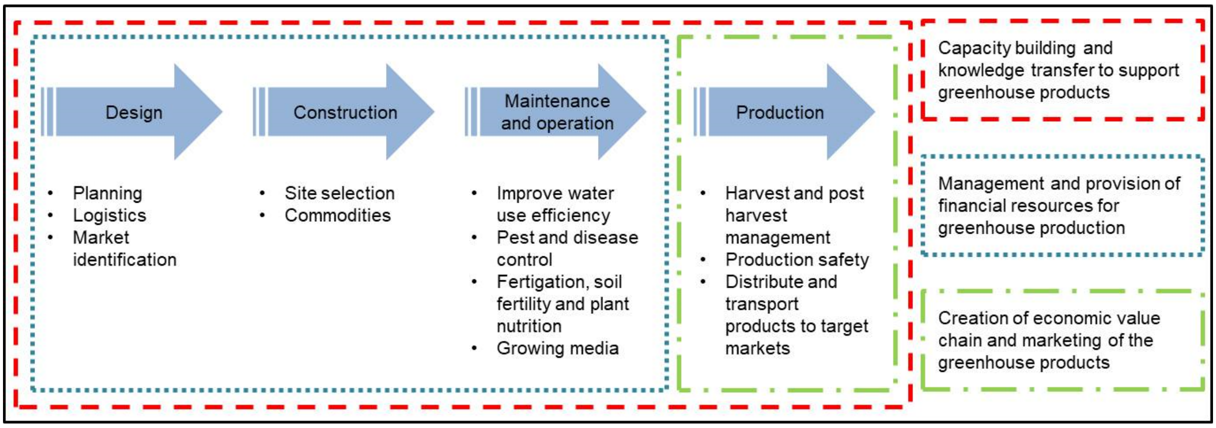


Figure 6.5: Phases of development process for greenhouses

New technologies can improve the water and energy efficiency of the greenhouses. Especially the use of the latest information and communications technology (ICT) and machine - learning methods (as a predictor model) can help to reduce water consumption and increase energy efficiency In **Figure 6.6,** a cloud based system for smart greenhouse is depicted which can provide real-time monitoring of water parameters data so that irrigation control can react appropriately to water stress conditions.

The cloud based system tightly monitors the water condition by manipulating a wide range of data aggregators (sensors). The collected data is sent to the cloud platform instantaneously. In the backend, the real-time water data stream and previous action experiences from enterprise resources planning (ERP) system are sent to the designed predictor model. Then the predictor model ranks data and overall water condition. In case of an abnormal condition, the cloud back end immediately generates an event which will be triggered by human and internet of things (IoT) hub. Based on the water demands, irrigation valve, water pumps, vent and cooling system start/stop to work by a) manually by explicit user order; b) automatically by IoT function app. Such real-time data analysis and action model provides the possibility to increase water productivity.

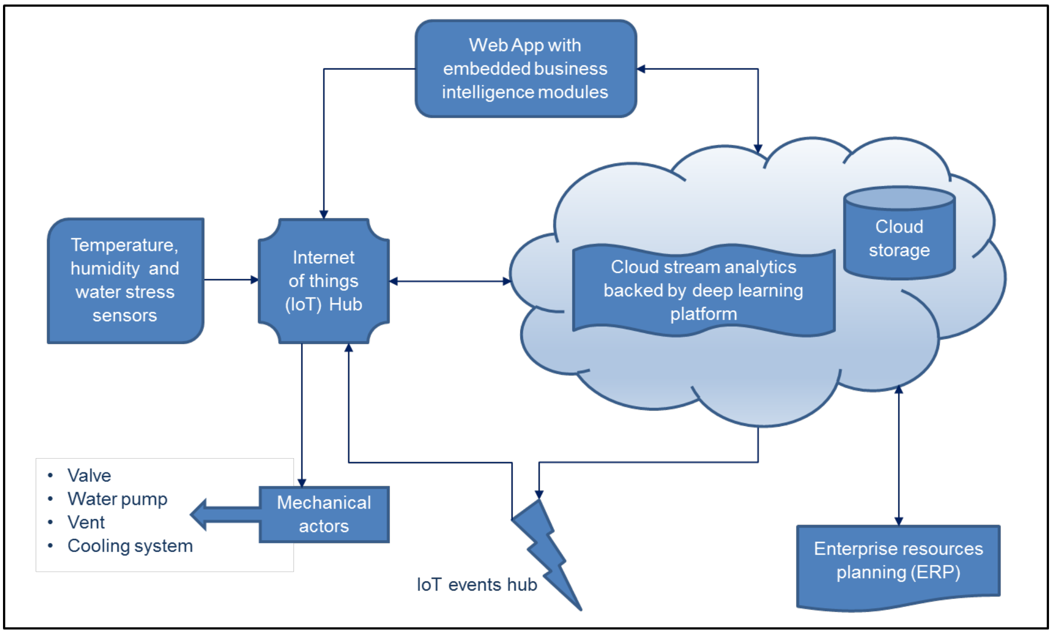


Figure 6.6: Schematic of modern intelligent greenhouse

Table 6.15: Measures and activities for the impact: Capacity building and knowledge transfer to support greenhouse products – FA2 S3 I1

No.	Measure	No.	Activity
M1	Support domestic greenhouse manufacturers to have more engagement with farmers.	A1	Fund demonstration projects in which domestic greenhouse manufacturers and famers cooperate to develop and operate innovative pilot greenhouse facilities.
M2	Enhance knowledge of farmers for the construction and operation of the greenhouse.	A1	Deploy elite graduates to leading countries in greenhouse industry
		A2	Invite greenhouse experts from leading countries in the greenhouse industry for education purposes
		A3	Empower agricultural graduates by holding practical training courses in the country's leading greenhouses.
		A4	Create educational websites for various levels of expertise from experts to operators and respond to farmers' questions about pesticide and disease control, fertigation, plant nutrition and growing media
		A5	Qualify and issue certificates for experts and specialists in construction and operation of greenhouse
M3	Reduce barriers to adapt new technology	A1	Develop a knowledge base on appropriate greenhouse technologies for the ZR Basin by funding demonstration projects and expert surveys, e.g. greenhouse design, equipment types and control, fertigation, cultivars, mulch, plant training and pruning techniques, integrated pest management, the use of pollinator insects, climate control, soil solarization etc
		A2	Provide short time training programs on the advantages of using new technologies (targeted programs) by either research institutes or agricultural technology companies for stakeholders
		A3	Support the development of advice and consulting services on efficient greenhouses production technologies and management policies
		A4	Provide financial supportive schemes for renovating greenhouses irrigation and cooling systems to improve water use efficiency, e.g. using Information and Communication Technologies (ICT).

Table 6.16: Measures and activities for the impact: Management and Provision of financial resources for greenhouse production – FA2 S3 I

No.	Measure	No.	Activity
M	Award loans with special conditions to agricultural graduates and other applicants for greenhouse construction.	A1	Support the greenhouse production by National Development Fund
		A2	Reduce the interest rate lower than 7%
		A3	Remove the condition of paying off existing debts to the National Development Fund for receiving new loans
		A4	Share profit and loss of given financial loans with banks
		A5	Solve the problem of providing bank collateral by changing bank collateral from estate property collaterals in the city to rural estate and other property such as cars, tractors, and livestock.
		A6	Insure crops and greenhouse with reasonable cost
		A7	Provide current greenhouse costs by paying low interest rate financial facilities
M**2**	Entrepreneurship for agricultural graduates	A1	Employ agriculture graduates for construction and supervision of greenhouses.
M**3**	Build new greenhouses in areas where required infrastructure is available.	A1	Facilitate the administrative bureaucracy in the issuance of a license for greenhouse construction
		A2	Establish greenhouse Joint stock companies to coordinate greenhouse construction and production
		A3	Carry out studies on the landscape designing and location of greenhouses
		A4	Obtain information on water resources availability from regional water companies
M**4**	Facilitate, amend rules, process relating to product insurance and loans for greenhouse construction.	A1	Offer income/yield protection insurance plans for damaged products due to pests and diseases

Table 6.17: Measures and activities for the impact: Creation of economic value chain and marketing of the greenhouse products – FA2 S3 I3

No.	Measure	No.	Activity
M1	Develop and organize the market for greenhouse products.	A1	Provide information on short-term and long-terms fluctuation of target market demand by developing models to predict the changes in prices and demand using data driven models
M2	Support access to inputs, technologies and services, and production facilities required in the value chain.	A1	Introduce companies active in the field of greenhouse inputs and supervising the sale of standard greenhouse inputs (i.e. machinery and equipment seed, fertilizer and pesticides)
		A2	Launch the transportation and transit companies for greenhouse products
M3	Identify the target markets for the export of greenhouse products and support market entry.	A1	Improve performance of the Chamber of Commerce in order to identify target markets
		A2	Conduct a conference and establishing an information site for connecting the producers and exporters of greenhouse products
		A3	Establish commercial offices at Iranian embassies in target countries for marketing of greenhouse products
		A4	Capacity building for establishment of export companies
		A5	Provide financial incentives to exporters of greenhouse products
		A6	Make brands for greenhouse products
M4	Prepare appropriate guidelines for high quality and safe products and Good Agricultural Practices.	A1	Identify the quality and safety standards for greenhouse products in target countries and revising the production guidelines for greenhouse products so that they meet market demand, standards and regulations
		A2	Develop labelling and packaging standards that meet the requirements of the global food market
		A3	Prepare and revise the standard guidelines for the transportation of greenhouse products
		A4	Qualify and grade the companies that export greenhouse products

6.2.4 FA2 Strategy 4: Foster development of aquaculture pond

Fostering the growth of aquaculture in the Zayandeh Rud Basin is a strategy with the potential to expand the local production of animal protein and farmer incomes sustainably. By integrating livestock-fish, birds-fish or rice-fish production systems, food production can be increased while making efficient use of water resources, even in semi-arid regions (CORNER et al. 2020). Many studies over the last decade emphasize looking beyond crops to consider more efficient uses of water to boost food production (CGIAR 2011; CRESPI and LOVATELLI, 2011; GODDEK et al. 2015; JOYCE et al. 2019). In their major study on 10 river basins, the CGIAR Challenge Program on Water and Food found that water policies often ignore the role livestock and fish play (or could play) in local diets and livelihoods (CGIAR, 2011). Fish and crustaceans are rich sources of protein, micronutrients and essential fatty acids and often the cheapest and most accessible animal-source food (FAO 2020).

A variety of technologies especially those that combine agriculture and aquaculture production (Integrated Agri-Aquaculture or IAA) exist that can be adapted to semi-arid regions (CORNER et al. 2020). Water consumption in aquaculture systems can be due to evaporation, infiltration, and water discharge and replacement to control harmful substances or for temperature control (VERDEGEM and BOSMA, 2009). Environmental impacts from these water uses depend on the production intensity and system chosen (DIANA et al. 2013). Aquaculture systems can range from energy-intensive recirculating aquaponic systems (RAS) where fish and vegetable production are directly linked often in greenhouses to extensive flow-through systems where the wastewater from fish production in ponds or tanks, or even in some cases irrigation channels, is used for irrigation of cropland. There are trade-offs between the use of resources for the systems – recirculating aquaponic systems rely on a high degree of technology, infrastructure and energy use to achieve a low water input, while flow-through systems, although much more water intensive, can be added to an existing agriculture farm to produce aquatic organisms as a secondary crop. Water consumption as low as 100 L/kg fish has been reported for RAS which combine vegetable production with treatment systems to remove or convert harmful nutrients (e.g. conversion of ammonia produced by fish into nitrate) (BAGANZ et al. 2020), while semi-intensive pond or tank systems require water inputs between 2 000 and 5 000 L/kg fish (CORNER et al. 2020). The discharged water can be used for irrigation purposes to fertilize the land and improve soil fertility. Current IAA production systems operating in some Middle Eastern and North African countries are predominantly small extensive to semi-intensive tanks or ponds with the wastewater used for cropland irrigation, where the fish is grown for home use and/or sale at local markets and the agricultural crops are sold in the usual markets (CORNER et al. 2020). Through the dual use of the water, there is potential to reduce overall land use and achieve basin-wide water savings while supporting the current level of income for the farmers.

The introduction of aquaculture to the Zayandeh Rud region faces many challenges similar to those discussed in the previous section on greenhouses. Depending on the technology chosen, the challenges for farmers and local economies range from learning new skills in technology and management, over high capital costs, to developing the value chain with its crucial logistics and marketing systems. The development of a local market is often necessary, especially since freshwater fish may not fit local eating habits in semi-arid regions. Furthermore, eco- or bio-branding of the products may be necessary to build customer trust in the IAA systems and to achieve higher prices in order to sustain the business. Therefore, the three targeted impacts of this strategy focus mainly on capacity building: 1) promoting education and science of using modern methods and processes in production, 2) Enhancement of governmental and institutional support, 3) Improving the efficiency of resource use and producing eco-friendly products (**Table 6.18 - 6.21**).

Table 6.18: Targeted impacts and measures for the strategy FA2 S4: Foster development of aquaculture ponds

No.	Impact	No.	Measure
I1	Promoting education and science of using modern methods and processes in production	M1	Introduce required technical and scientific training and guidance to licensed ponds.
I2	Enhancement of govern-mental and institutional support	M1	Grant required permits for the development and establishment of aquaculture ponds.
		M2	Provide the formation for establishment of aquaculture associa-tions.
		M3	Provide the necessary facilities to maintain production and improv-ing the performance of aquaculture ponds.
I3	Improve the efficiency of resources use and produce eco-friendly products	M1	Take environmental considerations into account for establishment and development of sustainable aquaculture ponds and healthy production.

Table 6.19: Measures and activities for the impact FA2 S4 I1: Promoting education and science of using modern methods and processes in production

No.	Measure	No.	Activity
M1	Introduce required tech-nical and scientific training and guidance to licensed ponds.	A1	Require the operators to take training courses related to the type of aquaculture activity in order to obtain the necessary permits (ac-cording to production capacity and type of activity, headings and training hours)
		A2	Visit aquaculture activists from modern plants in the country and abroad to get familiar with the new technologies
		A3	Promote the scientific level of governmental experts involved in aq-uaculture production by sending experts to leading countries.
		A4	Improve the quality of advisory services provided by relevant com-panies related to aquaculture activities

Table 6.20: Measures and activities for the impact FA2 S4 I2: Enhancement of governmental and institutional support

No.	Measure	No.	Activity
M**1**	Grant required permits for the development and establishment of aquaculture ponds.	A1	Develop appropriate aquaculture permits with various institutions and organizations based on the comprehensive Animal Husbandry Act of the country and the Law on Aquaculture Conservation
		A2	Carry out comprehensive studies for establishment of the infrastructure of aquaculture complexes with emphasis on available water resources
		A3	Legal custody and prevention of unauthorized aquaculture ponds in accordance with the Guidelines for Aquaculture Violations
M**2**	Provide the foundation for establishment of aquaculture associations.	A1	Encourage operators to establish aquaculture associations at provincial and county levels
		A2	Support by governmental sector through providing affordable facilities to aquaculture associations
		A3	Distribute aquaculture inputs (baby fish, fish food, etc) by aquaculture associations
M**3**	Provide the necessary facilities to maintain production and improve the performance of aquaculture ponds.	A1	Provide grants and loans with a minimum interest rate to purchase machinery and equipment related to mechanization in aquaculture schemes.
		A2	Support the private sector related to the manufacture of mechanization equipment for aquaculture schemes
		A3	Facilitate the process of improving the quality of processing industries and export of aquaculture products in order to develop and suitable supply of processed products.
		A4	Reject financial loans applications from unauthorized aquaculture ponds

Table 6.21: Measures and activities for the impact FA2 S4 I3: Improving the efficiency of resource use and producing eco-friendly products

No.	Measure	No.	Activity
M1	Take environmental considerations into account for establishment and development of sustainable aquaculture ponds and healthy production.	A1	Withhold new water resources for the establishment and development of aquaculture ponds
		A2	Avoid breeding unauthorized aquatic species
		A3	Cost-benefit analysis of aquaculture with an emphasis on the real value of water and energy
		A4	Do not issue license to units that negatively affect the quantity and quality of surface water and underground water resources
		A5	Restrict use of unauthorized drugs in aquaculture ponds and observe all instructions for authorized drugs, such as the time avoidance of drug use
		A6	Establish required standards for healthy aquaculture production
		A7	Supervise and check the performance of aquaculture ponds and relevant processing industries for the production and supply of healthy products.

6.3 Focus Area 3: Water distribution

The changing hydrological conditions in the Zayandeh Rud Basin due to variability in precipitation, the increasing exploitation of surface and groundwater resources to fulfill increasing water demand has caused fundamental variations in the surface water flow regimes and severe drops of groundwater levels in this area. The trend of basin wide water scarcity is reflected by a drop of over 40 % of annual release from Zayandeh Rud dam between the years 2007 and 2015. Therefore, two major challenges have come to the forefront for IWRM in the Zayandeh Rud Basin: a) equitable water distribution between stakeholders in all sectors; b) planning reliability. Appropriate measures are needed to overcome current problems and plan for the future. As a result of a recent in-depth vulnerability analysis of the Roodasht region, the irrigation district furthest downstream, strategies to overcome these problems have been put forward in two reports: Vulnerability Analysis of Farmers in Roodasht and Roodasht Action Plan (RABER et al., 2018a and b). The analysis showed that major obstacles for agriculture in the region were the uncertainty of the allocation and the enforcement of the water rights. The key problems were identified as: decrease in water availability year to year, lack of transparent and agreed quantity documentation of water rights and water shares, political decisions sometimes do not follow the legal water distribution rules, consequently there is only weak enforcement of existing laws and regulations and, finally, lack of farmers awareness about spatial and temporal water distribution patterns. These difficulties are also present in other agricultural regions of the basin and must be addressed in the context of the whole basin and through the integrated management of land and water. As described in **Chapter 2**, the water supply has already changed greatly within the last decades and it is predicted that the water availability will decrease in the future even more. Furthermore, the water quality is also expected to decrease. The share of water with high salinity has already increased. The higher salt load to the fields, compounded by reduced water for leaching can be expected to cause further damage to the fields.

Therefore, an important prerequisite for developing implementation plans for agricultural transformation in the basin is the development of a long-term plan for water allocation and distribution throughout the whole Zayandeh Rud Basin. This is discussed in the following section. The second strategy discussed in the following section is improving the use of urban wastewater resources for agriculture. The use of reclaimed wastewater cannot be expected to produce real water savings for closed basins such as the Zayandeh Rud, since this water is already used for irrigation or is considered part of the environmental flows. Instituting regulations for the degree of treatment required and defining wastewater quality standards for reuse would, however, improve the quality of the surface and affected groundwater, and the water quantity can be included in water distribution plans.

6.3.1 FA3 Strategy 1: Improve water distribution for agriculture in Zayandeh Rud Basin

Improving the timing of water supply and the farmer's awareness about spatial and temporal water distribution patterns can lead to higher water productivity, agricultural output and gross margins from agricultural activities. Especially the uncertainty of water distribution within the Zayandeh Rud Basin is a major concern regarding a successful transformation strategy in agriculture. Therefore three main targeted impacts are defined (**Table 6.22**):

The prerequisite to improve the water distribution is a clear overview of water availability and water user in the basin (**Table 6.23**). Therefore, the first steps will be to install an accounting framework and monitoring system. The establishment of a transparent monitoring program will gather trustworthy knowledge in this sector. This implementation of a control system related to water use and water allocation to enforce compliance should be built hand in hand with water and agricultural experts/authorities to reach most sustainable solution to enhance the water productivity in the basin.

Table 6.22: Targeted impacts and measures for the strategy FA3 S1: Improving water distri-bution for agriculture in Zayandeh Rud Basin

No.	Impact	No.	Measure
I1	Transparent water rights	M1	Determining actual water rights in the basin acceptable by affecting stakeholders
		M2	Participatory development of a water distribution formula taking the current and changing situations into account for all irrigation networks in the basin
		M3	Repurchase of agricultural areas and water rights designated by land use zoning with farmers
		M4	Launch a water scarcity compensation mechanism or program
I2	Enforce water laws and regulations	M1	Establishment of a common data bank in the basin
		M2	Upgrade monitoring system on surface and ground water extractions
		M3	Establish "water courts", and prevent illegal surface and ground water extractions
I3	Coordinate and implement	M1	Empowerment of River Basin Organization
		M2	Facilitate, coordinate, operationalize and continuously improve the execution of transformational strategies

An important method to determine those goals is the simulation of the optimal use of the available and dwindling water resources (ZARE, 2017). It is recommended that the WMT be further developed to allow questions to be explored on the conjunctive management of surface and groundwater to meet the water demand of the users in the Zayandeh Rud Basin. The steps would include implementing the module for agricultural water demand that was developed by ATB within this project – the Irrigation water Demand Module (IDM). And then developing further scenarios for different allocation methods for water supply to fields, as well as changes in the cultivated land area and crop types. The water use in the basin for all sectors can then be simulated in the WMT in conjunction with database developed in the IWRM project. In the IDM, the water rights can be assigned to each field within the basin. The huge benefit of the IDM is its ability to calculate on field scale. The current number of fields considered can be expanded and spatially located. Using the IDM gives the opportunity to calculate the effect of changes in water allocation rights on crop specific water amounts used in the different fields in the basin.

Table 6.23: Measures and activities for the impact FA3 S1 I1: Transparent water rights

No.	Measure	No.	Activity
M**1**	Determine actual water rights in the basin	A1	Design a participatory process for discussing the water rights
		A2	Determine the water rights via a negotiation process acceptable by all water users
		A3	Implement public awareness rising campaign
M**2**	Develop a water distribution formula taking the current and changing situations into account for all irrigation net-works in the basin	A1	Determine minimum water for environmental protection (e.g. river, Gav Khuni wetland, and desertification) with stakeholders
		A2	Negotiate for normal and minimum water requirements in the scale of districts and basin
		A3	Develop a mathematical formula for water distribution agreed by all water users
M**3**	Repurchase of agricultural areas and water rights des-ignated by land use zoning with farmers	A1	Participatory land use zoning with involvement of farmers and relevant institutions
		A2	Repurchase agricultural areas and water rights (in particular Haghe Eshteraki)
		A3	Build capacity of farmers and relevant institutions on land use change
M**4**	Launch a water scarcity compensation mechanism or program	A1	Negotiate and agree on a compensation mechanism
		A2	Assign a supervisor and launch the compensation program

The development of an adaptable allocation for water distribution in the Zayandeh Rud Basin is a highly sensitive challenge. The multi-stakeholders in the basin are aware of the different interests in the water availability in the basin and have to be willing to be prepared to commit to compromises. It must be kept in mind that the adaptation of strategies will be an ongoing process. Since the climate, site and economic conditions are changing continuously, it is emphasized that a flexible solution based on an interdisciplinary developed management plan must be the goal. The prioritization of irrigated land has to be done according to the fertility of the soils to gain the most beneficial agricultural water productivity. Further essential goals have to be considered and appreciated with the appropriate amount of water as well e.g. measures to improve the soil and/or environmental protection and counteract of desertification.

A generally accepted database should be created to support and facilitate the negotiations processes on issues like determination of water rights, agreeing upon the allocation formula, and compensation mechanism. It is seen as target-orientated development that the Iranian government takes already action in establishing river basin organizations (RBOs), starting with the RBO Zayandeh Rud as a pilot (EBRAHIMNIA, JAFARI BIBALAN, 2017). The RBO should be the central institution for the establishment of the database as well as for supervising research projects on the basin scale (**Table 6.24**). The data and information should be gathered in a way that is acceptable to all water users/stakeholders. Moreover, important data and information on water availability and distribution should be accessible and transparent for the public to increase their awareness and acceptance.

An important step for the realization of sustainable water resources management in the basin is to identify and stop illegal surface and groundwater extractions as soon as possible. This cannot be achieved without effective collaboration of farmers from upstream to downstream in the basin. Besides, all relevant authorities should build capacities in their institutions, such as training of personnel in the legal departments and enforcement officials, and organizing awareness raising campaign. A "Water Court" should be established to legally support successful enforcement of water laws and regulation of as well as prevention of illegal water extractions.

Table 6.24: Measures and activities for the impact FA3 S1 I2: Enforce water laws and regulations

No.	Measures	No.	Activity
M1	Establish a common database in the basin	A1	Establish a Work-Group in RBO to collect all relevant data and information in the local and basin levels
		A2	Discuss and modify the reliability of data with relevant institutions
		A3	Include the outcome of research projects and update the common database
M2	Upgrade monitoring system on surface and ground water extractions	A1	Investigate state and location of illegal water extractions
		A2	Install adequate technological system for monitoring
		A3	Build capacity for effective cooperation of farmers
M3	Establish "water courts", and prevent illegal surface and ground water extractions	A1	Build capacities for personnel in the legal departments and enforcement officials in all relevant authorities
		A2	Establish "water courts" with regards to current capacities
		A3	Modify existing legislations to get adapted with role of Water Court
		A4	Facilitate and organize awareness raising campaign
		A5	Take action to stop the illegal water extractions

Table 6.25: Measures and activities for the impact FA3 S1 I3: Coordinate and implement

No.	Measure	No.	Activity
M1	Empower River Basin Organization	A1	Establish a Regional Coordination Council for all irrigation networks in the basin
		A2	Refine the managing and organizational structure of the basin RBO
		A3	Involve affected stakeholders in an effective way
		A4	Organize awareness raising campaign
M2	Facilitate, coordinate, operationalize and continuously improve the execution of transformational strategies	A1	Connect local affected stakeholders with decision-makers at different levels
		A2	Carry out and supervise research projects
		A3	Discuss and refine the transformation strategies with local experts, farmers and other water users
		A4	Coordinate and implement transformation strategies
		A5	Capacity building, development of public participation and social engagement strategy

Considering growing conflicts on water allocation between farmers and government, the presence of a mediator institution is crucial in the Zayandeh Rud Basin (**Table 6.25**). Additionally, successful implementation of all above measures on transparent water rights and enforcing water laws and regulations urgent requires the empowerment of current River Basin Organization, called “Coordination Council of Integrated Water Resources Management in the Zayandeh-Rud Basin”. Besides, Regional Coordination Councils should be established in every district or irrigation networks. These institutions would facilitate, coordinate, operationalize and continuously improve the implementation of transformational strategies at different levels in the Zayandeh Rud Basin.

6.3.2 FA3 Strategy 2: Increase proper use of urban wastewater for crops

One of the broad strategies to satisfy increasing irrigation water demand is to tap uncommitted flows such as using urban wastewater resources in agriculture (**Figure 6.7**). For closed basins such as the Zayandeh Rud, real basin-wide water savings cannot be expected. The major benefit from wastewater reuse comes from the recovery of water in open river basins that discharge to oceans. Streams that are normally “lost” to oceans can be used for irrigation, and real water savings can occur in the basin. For inland urban systems that discharge to rivers, local reuse of wastewater can be provide a reliable source of water for selected applications or be stored regionally (i.e. through groundwater recharge) from winter months into the next growing season. The regional system experiences a benefit, though the impact on the basin must be determined. In the Zayandeh Rud Basin, wastewater is reused – either as irrigation water or as environmental flow. Instituting regulations for the treatment and wastewater quality would, however, improve the quality of the surface and affected groundwater, and the water quantity can be included in water distribution plans.

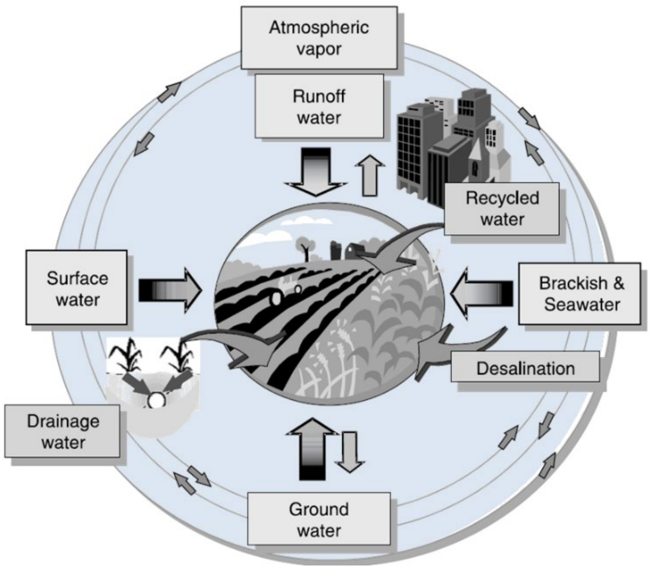


Figure 6.7: Irrigation cycle and its integration into the natural water cycle (Source: LAZAROVA, BAHRI, 2005)

Many countries allow the reuse of wastewater for irrigation purposes that fulfills certain regulations (e.g. Australia, Jordan, Israel, Tunisia, and the United States) or treat the wastewater for groundwater recharge to meet standards for drinking water. The majority of water reuse projects developed all over the world are for agricultural irrigation (LAZAROVA, BAHRI, 2005). The three targeted impacts recommended in the stakeholder workshops in **Table 6.26** focus on improving the allocation and quality of the wastewater as well as increasing the knowledge base so that farmers can determine appropriate uses of the wastewater for regional agricultural practices: 1) Capacity building for efficient use of wastewater, 2) Upgrading infrastructure, 3) Management and quality monitoring of wastewater.

Table 6.26: Targeted impacts and measures for the strategy FA3 S2: Increase proper use of urban wastewater for crops

No.	Impact	No.	Measure
I1	Capacity building for efficient use of wastewater	M1	Develop practical guidelines in the field of cropping pattern tailored to the wastewater
		M2	Implement research projects in the form of pilot projects
		M3	Train farmers to use wastewater efficiently
I2	Upgrade infrastructure	M1	Develop and upgrade wastewater treatment plants according to existing needs.
		M2	Encourage private sector investors to build a wastewater treatment plant.
		M3	Use wastewater in agriculture by considering allowed quality
I3	Management and quality monitoring of wastewater	M1	Supervise the unauthorized extractions from wastewater with the cooperation of the government and the agricultural union.
		M2	Allocate and distribute wastewater through a coordinated and integrated management.
		M3	Monitor the quality of waste water and water and soil resources.

One of the most challenging issues in using treated wastewater is the potential to spread pathogenic diseases through urban wastewater and its potential to contaminate aquifers and surface water with persistent organic chemicals, and inorganics such as nutrients or heavy metals (ELBAN et al., 2014). Two recent studies indicate that the treated Isfahan wastewater can be used in agriculture based on FAO criteria for salinity (MOHAMMADI MOGHADAM et al., 2015) and the impact on the microbial quality of soil and crops (FARHADKHANI et al., 2018). Both came to similar conclusions: that with proper operation of treatment plants and use of an appropriate disinfection process, an effluent quality suitable for agricultural purposes can be met. This has also been found for most other regions of the world, where the stress is laid on reliable operation of the wastewater treatment plants (WWTP) and monitoring of wastewater effluents.

The list of measures and activities from the stakeholders in the following tables centers on gathering more information on impacts of long-term use of wastewater, improving treatment facilities to ensure the quality and reliability of the treated wastewater, and on developing and disseminating guideline for its safe use to the stakeholders. Long-term studies from similar case studies like transfer of wastewater from Tehran's southern wastewater treatment to the Varamin, Pakdasht and Shahr-Rey plains (KHEIRKHAH RAHIMABAD et al.,

2015) should be evaluated to produce guidelines for the basin. The construction of decentralized smaller scale WWTPs to make treated water accessible in priority areas has been suggested. That entails setting and meeting the standards for reuse water quality (e.g. from the Iranian Environmental Protection Organization (EPO) and world health organization (WHO)) as well as monitoring each of these units. Indeed, improved measures to increase the quality of discharges or return water flows in general are needed so that cross-contamination of water resources does not take place. Training farmers (end users) to use the wastewater safely is strongly recommended as crucial part of using urban wastewater resources in agriculture strategy (**Table 6.27**).

The next steps in the process would be to review each of measures and activities for their efficacy and impacts with stakeholder participation, bringing in expertise on the topics. Select and prioritize the measures in order to develop an implementation plan (**Table 6.28** and **Table 6.29**).

Table 6.27: Measures and activities for the impact FA3 S2 I1: Capacity building for efficient use of wastewater

No.	Measure	No.	Activity
M**1**	Develop practical guidelines in the field of cropping pattern tailored to the wastewater	A1	Collect relevant information and guidelines and scientific papers (overview of existing guidelines)
		A2	Provide instructions for using wastewater and irrigation method according to the type of wastewater use and the permissible limits of contaminants
		A3	Report a list of arable plants in the region according to the characteristics of wastewater and health and environmental considerations
		A4	Identify lands with susceptible soil for irrigation with wastewater
		A5	Observe the quality of the products that irrigated by wastewater to maintain food security
M**2**	Implement research projects in the form of pilot projects	A1	Assess soil quality in long-term use of wastewater
		A2	Study of the status of microbial load of plants that irrigated with wastewater
		A3	Investigate the chemical quality of plants that irrigated with wastewater
		A4	Support research project in this area by government financial assistance
		A5	Assess the impacts of wastewater on groundwater resources
M**3**	Train farmers to use wastewater efficiently	A1	Hold training courses for farmers in the region on the disadvantages and advantages of using wastewater in agriculture
		A2	Prepare programs and brochures on the optimal and safe use of wastewater in agriculture by all executive stakeholders
		A3	Publish and distribute monthly journals related to the use of wastewater in the agricultural sector
		A4	Hold joint meetings with the presence of managers of relevant executive organizations and farmers

Table 6.28: Measures and activities for the impact FA3 S2 I2: Upgrading infrastructure

No.	Measure	No.	Activity
M1	Develop and upgrade wastewater treatment plants according to existing needs.	A1	Review the status of existing wastewater treatment plants according to the technology used and the quality of wastewater
		A2	Promote wastewater treatment technology in priority treatment plants
		A3	Decentralize input wastewater into wastewater treatment plants and construct smaller scale wastewater treatment plants in priority areas
		A4	Monitor quality of wastewater from wastewater treatment plants
		A5	Reduce the microbial load of the wastewater by supplementary treatment, considering the allowed limit for different uses of wastewater
M2	Encourage private sector investors to build wastewater treatment plants.	A1	Allocate treated waste water to the agricultural sector with considering the standards of using reuse water in agriculture
		A2	Formulate policies to provide guarantees to the private sector for the construction of supplementary treatment plant and its use in agriculture
		A3	Provide incentives to encourage the private sector to build WWTP
		A4	Establish a task force wastewater allocation with the participation of all stakeholders
M3	Use wastewater in agriculture by considering required quality	A1	Monitor wastewater quality of the wastewater treatment plants in basin
		A2	Formulate wastewater quality guidelines for use in agriculture with a view to minimizing damage to water and soil resources.
		A3	Implement research projects to identify areas susceptible to wastewater use in agriculture
		A4	Implement water cycle-related projects in areas intended for wastewater in agriculture
		A5	Investigate vulnerability of aquifers at basin level

Table 6.29: Measures and activities for the impact FA3 S2 I3: Management and quality monitoring of wastewater

No.	Measure	No.	Activity
M1	Supervise the unauthorized extractions from wastewater with the cooperation of the government and the agricultural union.	A1	Establish a monitoring mechanism for wastewater extraction in partnership with the government and agricultural union
		A2	Establish patrol and inspection groups to monitor unauthorized wastewater extraction
		A3	Raise level of awareness of farmers and water right holders in using wastewater
		A4	Assign Mirab to distribute wastewater in smaller scale among farmers
M2	Allocate and distribute wastewater through a coordinated and integrated management.	A1	Design and organize allocation and distribution of wastewater and monitoring of distribution according to the type of consumption
		A2	Clarify the distribution of wastewater according to the needs and coordination with relevant organizations
		A3	Share wastewater with stakeholders in all sectors
		A4	Replace wastewater for unallocated water rights to agricultural sector
M3	Monitor the quality of waste water and water and soil resources.	A1	Establish quality monitoring stations at the outlet of the WWTP
		A2	Monitor chemical quality of soils irrigated by wastewater periodically
		A3	Monitor chemical and microbiological content of groundwater resources in areas that irrigated with wastewater
		A4	Monitor microbial and chemical quality of products that irrigated with wastewater, periodically
		A5	Monitor the health of farmers that use wastewater, periodically

6.4 Focus Area 4: Land management and soil fertility

The successful transformation of agriculture within the Zayandeh Rud Basin must include measures to manage the land and to conserve and enrich the soil fertility. Since soil is the basis of all agriculture, it needs a special awareness. The resource soil must be recognized as a dynamic living system that is characterized by a balanced interaction of its biological, chemical and physical components (KAREN et al., 1995). It is highly recommended to consider soil as one of the key factors to improve the agricultural productivity or to enhance the sustainable implementation of environmental protected areas in the Zayandeh Rud Basin. Fertile soils have an effect like a water reservoir and a water filter. Fertile soils absorb rainwater well. The absorbed rainwater can be emitted slowly from the soil to the plants, the soil life and the ground water. Improper cultivation of the soil leads to damage of the soil, which might be accelerated by the consequences of irrigation with too little water for proper leaching, or poor water quality. For instance, intensive irrigation and over-fertilization are responsible for damages caused in several parts of the basin. The high salinity of irrigation water and resulting soil salinity are leading to a decrease in the fertility of the soils of especially the eastern part of the basin. The unreliability of surface water resources in terms of quantity and time forestall the proactive planning of irrigation and therefore a sustainable management of the resources.

To develop appropriate strategies for land improvement and soil fertility, the focus of numerous participatory activities and analyses within the framework of the project was to figure out how the farmers can be enabled to work on the improvement of the soil under these challenging conditions. A lack of regulations to maintain and to increase soil organic matter was found. Additionally it was found that no target-oriented coordination of the relevant governmental institution in decision-making on agricultural sector exists. Working on land improvement and soil fertility is a highly holistic task. Measures and activities of an interdisciplinary nature are proposed for the strategy “Improve and increase soil fertility and water holding capacity” that take these problems into consideration in the first section below.

Furthermore, a major factor for the transformation of agriculture will be developing policies for land management and the change of land use throughout the basin. In most of the stakeholder discussions and activities, the importance of “adapting land use to the water supply situation” as a strategy has been stressed. Related impacts such as preparing appropriately for water scarcity conditions and the need for adaptable allocation for water distribution have already been discussed in detail in Focus Areas 2 and 3. In the second section below, measures and activities to adapt land use are proposed. In some areas of the basin, this may mean changing or adapting agricultural activities to use saline water supplies. In others, adaptation may require a reduction in agricultural land use and restoration of natural ecosystems.

6.4.1 FA4 Strategy 1: Improve soil fertility and water holding capacity

The targeted impacts of this strategy focus on directly influencing the soil quality and developing capacity among the stakeholders to address the complex challenge in the water scarce region (**Table 6.30**). An overlapping task between the two impacts is that an association should be established which focuses on the coordination among participating sectors involved in the soil improvement. This newly developed soil association should provide appropriate programs for the stakeholders as well.

Many specific measures and activities were suggested to improve soil quality (**Table 6.31**). The majority focus on improving the organic matter in the soil by expanding the knowledge base for the farmers and improving agronomic techniques. For example, research and scientific institutions are asked to create a soil database to provide site specific knowledge about the condition of the soil. In addition, a regular control measurement of the soils in a multiannual cycle to check the influence of changing management on the soil fertility is recommended. Further recommendations for changes have already been made in the section on agricultural management.

In order to bring together the diverse activities that are involved in soil improvement under such challenging conditions, an association should be developed to provide capacity development and coordination between the relevant stakeholders. It should develop strategic programs and funding for the holistic use of resources, provide appropriate training to enable farmers to try out new techniques and disseminate the results (**Table 6.32**).

Some ideas for programs that specifically address the enormous challenge of improving soil quality in regions where the scarcity of water limits biomass production are also found in **Table 6.32**. Promising holistic solutions for soil improvement and the reduction of evaporation not mentioned previously come from the agroforestry sector. Diverse practices such as, assisted natural regeneration need to be evaluated by local experts for their effectiveness for various regions in the basin. The combination of woody perennials with forage and food crops can increase the resilience of arid and semi-arid regions. Furthermore, systems have been developed to arrest the spread of desertification (KRISHNAMURTHY et al. 2019).The benefits from combining trees and shrubs with crop or rangeland are manifold: i) reduced erosion from wind and water - the roots and fallen leaves help stabilize the soil, the above-ground structures break the wind; ii) reduced evaporation - the shade lowers the soil temperature, and the wind speed is decreased; iii) increased soil fertility - the type of woody perennial can be chosen to have a fertilizing effect on the soil e.g. legumes species. The reintegration of trees and/or shrubs into an ecosystem is known for its positive ecological effects and its contribution to biodiversity. Besides the ecological benefits, the farmer can also make use of products and by-products of the trees, such as fruits, wood and leaves (GIZ, 2012). Agroforestry can be combined beneficially not only with crops, but also with livestock production (MUSCHLER, 2014).

Table 6.30: Targeted impacts and measures for the strategy FA4 S1: Improve soil fertility and water holding capacity

No.	Impact	No.	Measure
I1	Improve soil quality	M1	Improve soil quality by applying appropriate technical measures.
		M2	Prevent burning of crop residue in fields to increase soil organic matter.
		M3	Improve cropping pattern, observance of crop rotation and maintenance of permanent cover of soil surface through cooperation with rural cooperatives to increase soil quality.
I2	Capacity development to improve soil management	M1	Coordinate soil improvement among relevant sectors and provide appropriate programs.
		M2	Develop strategic programs and funding for the holistic use of resources: land, water, fertilizers and pesticides.

Table 6.31: Measures and activities for the impact FA4 S1 I1: Improve soil quality

No.	Measure	No.	Activity
M1	Improve soil quality by applying appropriate technical measures.	A1	Create soil databases and conduct soil quality monitoring studies
		A2	Determine the soil quality classes using the created database
		A3	Improve soil texture through: Improvement of organic matter; Improvement of sub surface layer; Construction of drainage channels
		A4	Improve chemical content of soil: decrease soil salinity (EC); deficiencies in essential chemical elements
		A5	Improve biological content of soils: improve the population of bacteria, fungi and useful soil organisms
		A6	Modify conventional tillage practices
		A7	Integrate organic and inorganic fertilizers
M2	Prevent burning of crop residue in fields to increase soil organic matter.	A1	Train farmers to not burn the crop residue or encourage them to sell the crop residues
		A2	Implement governmental laws to monitor and carry out preventive actions in this regard
M3	Improve cropping pattern, observance of crop rotation and maintenance of permanent cover of soil surface through cooperation with rural cooperatives to increase soil quality.	A1	Train farmers to raise their awareness on the importance and ways to implement crop pattern plan
		A2	Preserve and develop indigenous vegetation in on arable lands
		A3	Insure proper distribution of required inputs (water resources and other inputs) according to cropping pattern and crop rotation.

The controlled implementation of livestock in the lower reaches of the basin may be a wide-reaching measure to obtain higher levels of soil organic matter and a further income source for farmers. Controlled implementation means that adapted grazing plans in the rangelands will be developed to avoid over-grazing. Through integrative approaches, such as versatile livestock systems, which combine shrubs and native plants in silvopastoral systems with strategies for careful selection of animal genotypes (especially of regional breeds), sustainable livestock production may be achieved in drylands (Blache et al., 2016). This can be considered as a chance to move towards a closed-loop agriculture, recycling nutrients and organic matter back to the soil. Often this idea is brought together with organic agriculture, but it can be nevertheless advantageous in conventional agriculture, resulting in comparatively higher yields. The development of programs in this area has to be discussed in multi-stakeholder-groups including local experts.

Table 6.32: Measures and activities for the impact FA4 S1 I2: Capacity dvelopment to improve soil management

No.	Measure	No.	Activity
M1	Coordinate soil improvement among relevant sectors	A1	Establish a single association to coordinate among relevant sectors and provide appropriate programs
		A2	Obtain the necessary permissions from the governor and organize budget for the formation of the associations
M2	Develop strategic programs and funding for the holistic use of resources: land, water, fertilizers and pesticides.	A1	Evaluate the controlled implementation of livestock (especially of regional breeds) to improve soil quality and reactivate a closed-loop agriculture system
		A2	Evaluate agroforestry technology, e.g. assisted natural regeneration, for cropland and livestock production
		A3	Provide educational services to farmers and producers and sellers of pesticides and fertilizers
		A4	Supervise the use of fertilizers and chemical pesticides in line with the application of existing standards
		A5	Determine how to use urban wastewater for irrigation of farmlands and forest and industrial and environmental purposes

6.4.2 FA4 Strategy 2: Adapt land use to water supply

The over-all integrated basin management plan will have to match the limited and variable available water resources with an appropriate and flexible cultivation area and pattern. The solutions to adapt land use will be intricately interwoven with those to reduce agricultural water use, respond flexibly to changes in water resources and distribute them equitably between the water users (domestic, industrial, environment, agriculture). In the preceding sections, the focus was more on the resource water which has historically been redistributed throughout the basin, overcoming the unequal spatial distribution. The previous strategies and measures related to land use change that were proposed have concentrated more on matching the irrigation demand with the water supply through changes in crops.

Here the focus of the targeted impacts is on managing agricultural land use in conjunction with water quality as well as adapting land use to the water quantity (**Table 6.33**). The implementation of agricultural practices that utilize the available water quality (haloculture) while protecting the land and water resources, and the restoration of wetlands and natural ecosystems are highlighted as important measures to improve the land management in the basin. Furthermore, many measures that have been discussed previously are essential to achieve the targeted impact of land use change. Some measures and activities that support this impact are repeated in this section.

Table 6.33: Targeted impacts and measures for the strategy FA4 S2: Adapt land use to water supply

No.	Impact	No.	Measure
I1	Adapt agricultural practices to water quality	M1	Develop agricultural haloculture practices in the region.
		M2	Develop and apply conservational policies for protecting the local surface and groundwater resources.
I2	Develop plans for land use change	M1	Draft action plans for wetland rehabilitation and prevent micro-dust from dried surface of Gav Khuni
		M3	Develop coordinated land use and water distribution plans with stakeholders taking the current and changing situations into account

The influence of soil and water salinity is well known as major limiting factors to the agricultural productivity within the basin. The cultivation of salt tolerant crops and halophytes is recognized as a practically feasible and economically viable measure to use saline water and soil resources (KHORSANDI, 2016). A number of measures and activities that utilize the available saline water or land quality are listed in **Table 6.34** that can be evaluated for their feasibility for the region. The evaluation must consider not only the economic benefits, but also the possible environmental impacts from the use of saline water or other unconventional water resources such as wastewater. Therefore, accompanying measures to develop policies for protecting the local surface- and groundwater resources are proposed.

Table 6.34: Measures and activities for the impact FA4 S2 I1: Adapt agricultural practices to water quality

No.	Measure	No.	Activity
M1	Develop agricultural haloculture practices in the region.	A1	Identify saline lands that are not arable.
		A2	Introduce different methods to use saline water resources (haloculture)
		A3	Develop saline water aquaculture, algae, artemia, shrimp
		A4	Develop cultivation of forage and halophytes
		A5	Develop cultivation of oilseed crops
		A6	Develop suitable crops for biofuel production and bio-fertilizer
		A7	Develop guidelines for use and disposal of saline water resources
M2	Develop and apply conservational policies for protecting the local surface and groundwater resources	A1	Provide educational and information services on optimal use (and disposal) of available local water resources
		A2	Prevent unauthorized withdrawals from surface and groundwater resources as well as wastewater of East Isfahan
		A3	Avoid any new pressures on the available water sources in the area
		A4	Install intelligent measuring equipment for controlling the extraction of water resources
		A5	Carry out studies on the artificial recharge of aquifers using unconventional water resources.
		A6	Encourage agricultural cooperatives and NGOs to create a protective unit for groundwater

Besides the improvement of the agricultural use of land, changes in land and water use for environmental protection or restoration especially of the Gav Khuni wetland is also included as an important goal in the basin. A basin-wide plan must be developed to decrease agricultural irrigated land to support the restoration process of Gav Khuni. Some measures and activities to achieve this goal have been discussed above for the targeted impacts, transparent water rights and appropriate preparation for water scarcity conditions. Moreover, extensive recommendations to restore the Gav Khuni wetland were suggested in the vulnerability analysis and action plan (RABER et al., 2018a and b). These have been summarized shortly in **Table 6.35** with the measure to draft action plans for wetland rehabilitation. More comprehensive measures are to be found in the action plan. In essence, the implementation of measures for the restoration of the Gav Khuni wetland in Roodasht is dependent on additional water to the wetland. This can only be realized if this water will be taken from agricultural use. This requires the development of coordinated land use and water distribution plans with all stakeholders, which take the current and expected changes into account. The agricultural sector has to deal with changes in land use in conjunction with a changing water allocation in the future. The activities listed in **Table 6.35** overlap with those already discussed in the section on agricultural management.

Table 6.35: Measures and activities for the impact FA4 S2 I2: Develop plans for land use change

No.	Measure	No.	Activity
M1	Draft action plans for wetland rehabilitation and prevent micro-dust from dried surface of Gav Khuni	A1	Coordinate with all competent authorities to develop and implement the master plan for the restoration of Gav Khuni wetland and closure of mines
		A2	Determine the seasonal water requirements for ecological demands in the different regions of the basin
		A3	Determine minimum water for Gav Khuni wetland with stakeholders
		A4	Reduce extraction from the Zayandeh Rud River appropriately
M2	Develop coordinated land use and water distribution plans with stakeholders taking the current and changing situations into account	A1	Evaluate potential reductions in the area of irrigated farming
		A2	Negotiate for normal and minimum water requirements on the scale of districts and basin
		A3	Develop an algorithm for water distribution agreed by all water users
		A4	Investigate whether reductions in water consumption in one part of the basin can make water available for other parts of the basin (e.g. transfer water use through purchase from relevant water users) with the Water Management Tool

A major factor for the implementation of these measures will be the change in land use throughout the basin. The spatial distribution of land and ecosystems should play a large role in developing plans for land use change. Plans have to take into consideration that the effects of different land uses vary across ecosystem types (GARCÍA-VEGA, NEWBOLD 2020). The potentials of various agro-ecological approaches must be evaluated in terms of maintaining drylands' biodiversity.

In expert workshops to develop scenarios for land use change for use in the WMT, the comparatively deepest cuts in agricultural land use were suggested for the Roodasht region (Zare, Libra, 2018). These are summarized in **Table 6.36**. On average a 40 % reduction in cultivated area for the whole basin was suggested for the scenarios, corresponding to historical reductions in land area in the last decade. Besides a definite reduction in agricultural land, changes in cultivated area of some crops within the districts were suggested.

The need to reduce agricultural area and adapt cropping patterns demonstrates the narrow leeway of action for adapting the region to the changing climate and site conditions. The results of the scenario calculations in the WMT must be discussed in a broad circle of stakeholders in the future. The development and evaluation of further scenarios in the WMT, as a basis for an implementation plan, requires a strong transdisciplinary and well-organized communication between the multi-stakeholders in the basin. But the final discussion has to be made considering, not only the simulated impacts on water use, but also the further environmental and social and economic impacts for the stakeholders across the basin.

Table 6.36: Proposed changes for the scenario analysis in terms of reduction in cultivated area for each district (Zare, Libra, 2018)

Districts	Proposed reduction	District	Proposed reduction
Abshar Left	40%	Faridan & Fereydoon	25%
Abshar Right		Karvan Up	
Borkhar		Karvan Down	
Chadegan		Kordolia	
Lenjan Down		Mahyar & Jarghoye	60%
Lenjan Up		Roodasht North	
Nekoabad Left		Roodasht South	
Nekoabad Right		Average (Total)	40%

7 Evaluation of the participatory approaches and lessons learned for the future

The development of the agricultural transformation strategies in the Zayandeh Rud Basin is an on-going and interdisciplinary process which benefits from participatory approaches as described in this report and other project documents (e.g. HORLEMANN et al., 2017a und b). In the following sections some lessons learned from using a participatory strategy development approach are given and the results are presented, along with an outlook on recommended future activities for preparing the implementation of IWRM in the basin.

7.1 Lessons learned for future participatory approaches

The use of participatory methods is very context specific and experiences need to be reflected on against the background of the specific conditions in which the methods were applied. The following list of lessons learned from the application of participatory methods in the project are meant to inform the general discussion about the usefulness of such methods for providing a basis for the monitoring, management and evaluation during the continued implementation of IWRM in the Zayandeh Rud Basin.

The application of participatory methods for developing transformations strategies for agriculture in the basin contributed to the following results:

- Better access to in-practice knowledge and local information of representative and pioneer farmers from upstream to downstream of basin.
- Gaining knowledge of local experts with different background and expertise who have been closely involved with water and agricultural issues in the basin.
- Creation of a common understanding of different issues in a negotiable platform.
- Increased participants' ability to take part in productive dialogue on key issues of sustainable water and land management in the basin.
- Opportunities for co-learning and reflection to build capacity to support current and future initiatives.
- Evaluation of recommendation and possible solutions with experts to get a deeper knowledge of what are most appropriate strategies.
- Creation of networking opportunities for further steps of IWRM.
- Bring the expectation of affected stakeholders closer to feasible measure that can be done by affecting stakeholders.
- Discovering the cooperation potentials of conflicting affecting and affected stakeholders.
- Adapted and improved strategies by getting ideas and recommendations of a wider range of stakeholders.
- Wider involvement of stakeholders in formulation of solution might create a sense of responsibility to call for action, or get better understood by government.

7.2 Analysis of the SPA results

The strategies and measures developed through the Strategic Pathway Approach were evaluated for their expected impact by experts and stakeholders in the basin who were involved in the participatory processes. The methodological procedure is described in **Chapter 3.1.** Selected attendees of the workshop were sent a questionnaire to rank the named strategies according to their expected impact on the transformation process. The participants had the opportunity for a ranking between very low, low, medium, high and very high impact (**Figure 7.1**). Only a small number participated in the questionnaire; future steps would be to evaluate the responses from a larger number of participants as well as from experts who here not involved in the participatory process (i.e. workshop) themselves.

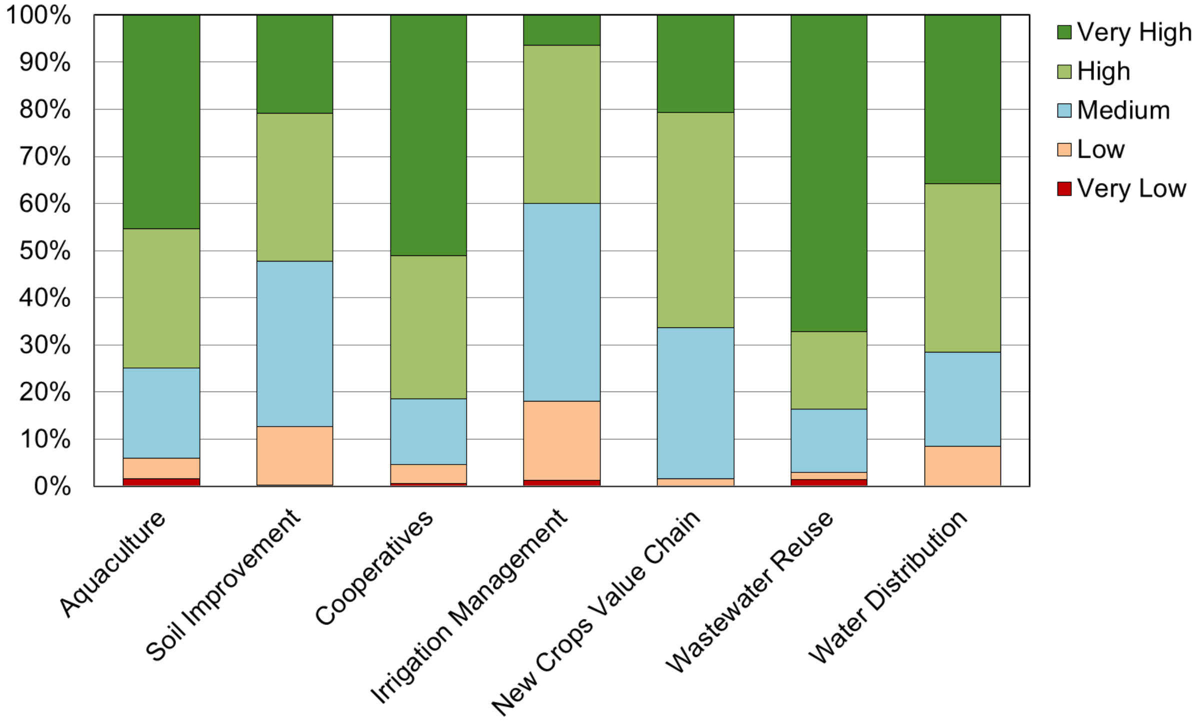


Figure 7.1: Evaluation of the expected impact of the transformation strategies considered within the Zayandeh Rud Basin

The results from the evaluation of the transformation strategies indicate that the impact criteria for the strategies 'Implementation of cooperatives' and 'Reuse of wastewater' were rated by the largest proportion of evaluating participants with the score *very high*, followed by aquaculture and water distribution. 'Soil improvement', 'Irrigation management' and 'New crops value chains' were rated with the score *very high* by a lower proportion of evaluators. The impact criteria received the rating *high* for all the strategies from about the same proportion of evaluators. The impact criteria for the strategies 'Soil improvement', 'Irrigation management' and 'New crops value chains' where rated with the score *medium* for by a larger proportion of evaluators. This is an indication for potential barriers related to these strategies, which need to be addressed previous to the implementation of the strategies. A higher proportion of evaluators rated the strategies ‘Soil improvement’, ‘Irrigation management’ and ‘Water distribution’ with the score *low* for all impact criteria, indicating the possible existence of severe threats for the successful implementation of these strategies. Even the percentage of evaluations with the score *very low* for the impact criteria is low in the case of the strategies ‘Aquaculture’, ‘Cooperatives’, ‘Irrigation management’ and ‘Wastewater reuse’, this clearly points towards some serious concerns regarding these strategies. These results are of relevance for prioritizing strategies e.g. where the impact criteria were rated by larger proportions of evaluators with the score *very high* against strategies with the scores *high*, *medium*, *low* or *very low*. Further, these results were important for the design of the strategy roadmap (in **Chapter 8**), and they should be taken into account when planning future actions previous to the implementation of the strategies. **Table 7.1** gives further insights in the quantitative assessment of the described measures related to the transformation strategies.

Table 7.1: Synopsis of the results from the SPA-Analysis for the transformation strategies.

Focus Area 1. Capacity building	
Cooperatives	The measures received the *very high* and *high* scores for impact criteria by the majority of the evaluators. The only measure receiving the *very low* score of impact criteria is: • The level of knowledge and expertise of members and staff of agricultural cooperative companies will be enhanced (Measure 2.1).
Focus Area 2. Agricultural management	
Irrigation management	Four measures received a *very low* score for impact criteria including the outcomes: • Improve irrigation practices to increase water use efficiency (Measure 1.3), • Stop or reduce extraction from the Zayandeh Rud River (Measure 2.2), • Create integrated service for farmers including software/database/web accessibility with participation of all relevant institutions (Measure 3.1), and • Develop educational programs for changing crop pattern and irrigation management for relevant stakeholders (Measure 3.2). Measures the received the *very high* score for impact criteria by few evaluators include: • Stop or reduce extraction from the Zayandeh Rud River (Measure 2.2), • Create integrated service for farmers including software/database/web accessibility with participation of all relevant institutions (Measure 3. 1).
New crops value chains	None of the measures received the *very low* score for impact criteria. The measures that received *very high* ratings of impact criteria by most evaluators are: • Financial incentives and credits are granted for crops with high added value (Measure 2.2), • Training and knowledge transfer to farmers (Measure 1.1), • Building trust in the accuracy and applicability of research results to farmers (Measure 1.2), • Financial resources will be provided to explore the potential for the development of new plantings (Measure 2.1), and • The cultivation of new high value added crops will be developed based on the government landscape design plan (Measure 2.3).
Aquaculture	Two measures received the *very low* rating of impact criteria including: • Required technical and scientific training and guidance will be introduced to licensed ponds (Measure 1.1), and • The formation for establishment of aquaculture associations will be provided (Measure 2.2). Some measures with the *very high* rating of impact criteria include: • Environmental considerations will be taken into account to establish and develop sustainable aquaculture ponds and healthy production (Measure 3.1), • Required permits will be granted to develop and establish aquaculture ponds (Measure 2.1), • The necessary facilities to maintain production and improving the performance of aquaculture ponds will be provided (Measure 2.3).
Focus Area 3. Water distribution	
Water distribution	None of the measures received a *very low* rating of impact criteria, but all measures were received nearly the same *low* and *medium* ratings of impact criteria. One measure received most *very high* ratings of impact criteria: • "Water courts" and "water mediation" groups will be established (Measure 2.2)
Wastewater reuse	Four measures received a very low as rating of impact criteria including: • Farmers are trained to use wastewater efficiently (Measure 1.3), • Private sector investors build wastewater treatment plant (Measure 2.2), • Wastewater is used in agriculture by considering allowed quality (Measure 2.3), • The unauthorized extractions from wastewater will be supervised (Measure 3.1). The rating very high of impact criteria predominates in the measures related to wastewater reuse, while the ratings low and medium of impact criteria were given by a lower proportion of the evaluators.
Focus Area 4. Soil improvement	
Soil improvements	The measures received *high* and *medium* ratings of impact criteria from most evaluators, especially: • Improve soil quality by applying appropriate technical measures (Measure 1.1), • Improve cropping pattern, observance of crop rotation and maintenance of permanent cover of soil surface through cooperation with rural cooperatives to increase soil quality (Measure 1.3), • Develop and apply conservational policies for protecting the groundwater resources and recharge them in the region through the exploitation of unconventional water resources (Measure 2.5). However, the measure 2.5 is the only one with a *very low* as rating of impact criteria.

7.3 Future work in participatory approaches

For a consistent formulation of transformation strategies it is essential to consider the interdependences existing between the expected impacts, outcomes from measures and activities. These interdependences can be described in an impact model, i.e. a systemic process model that maps out the entire progressive sequence of change processes in a sector or for a specific purpose, and which provides negotiable entry points at various levels of strategic planning (**Figure 7.2**).

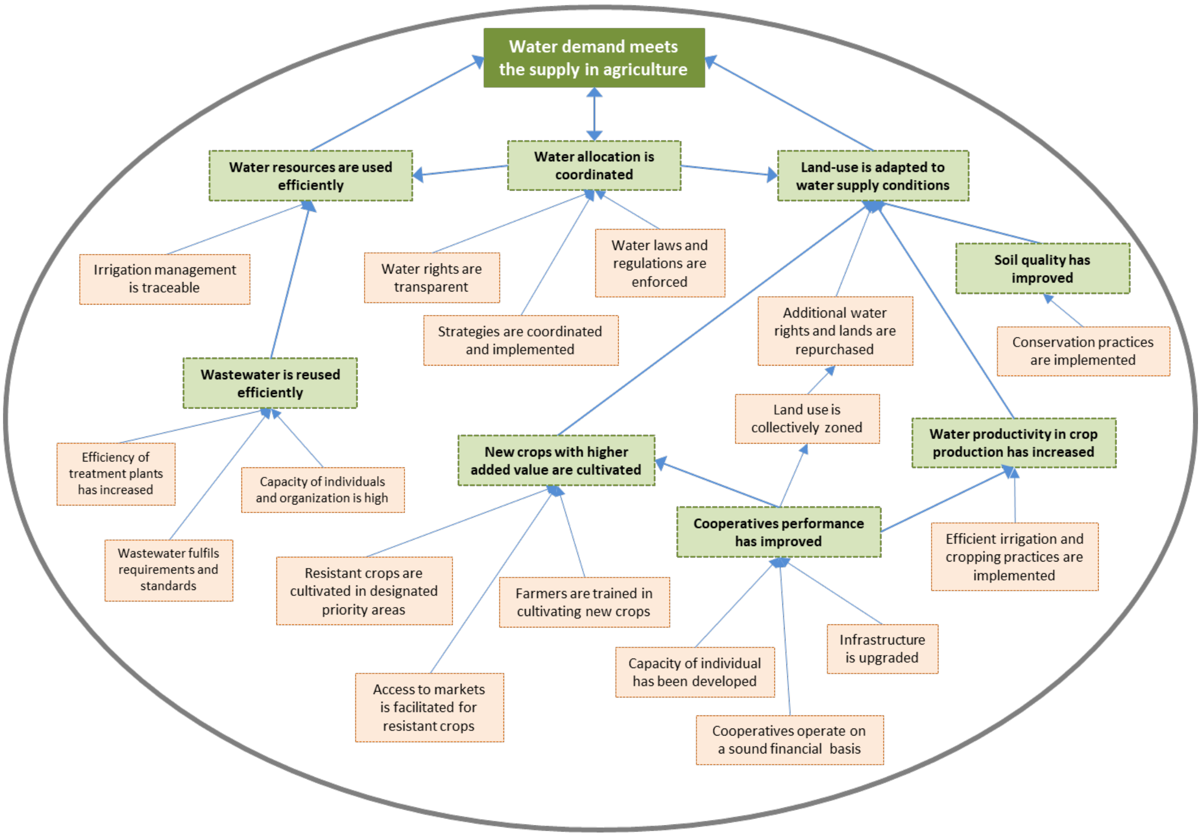


Figure 7.2: Mapping interdependences of transformation strategies

The impact modeling approach shown in **Figure 7.2** is an adaptation from REIMERS (2016) with the aim of assuring quality during strategic planning with involved stakeholders, and providing a basis for results-based monitoring, management and evaluation during implementation of respective strategies. Furthermore, the impact model (or results model) can be employed for better determination of main objectives and results of a nested strategy development, identification of hypotheses and preconditions for successful achievement of objectives in agricultural transformation in the Zayandeh Rud Basin. The approach is based on Theories of Change and Theory of Action, and it requires ongoing participatory development and validation during the continued implementation of IWRM in the Zayandeh Rud Basin.

8 Conclusions and Outlook

Agricultural transformation in the Zayandeh Rud Basin is more than just implementing technical solutions or changing farming practices for better crop productivity and water efficiency. It is more about catalyzing transformation of its rural livelihoods and economy. As such, more than agricultural trade and funding policies are involved. Multi-stakeholders are in play and influence important decisions on, for example, access to water, infrastructure, labor, laws and regulations that influence banking, land ownership, taxes and insurance. The challenge for policies is to act dynamically, adapting over time to react flexibly to changing situations, and, therefore, to find solutions which directly support development within the rural areas.

Effective policy making for agricultural transformation should be evidence-based over time. The policy makers should invest in gathering or making use of trustworthy common data and analytics to comparatively assess the costs and likely outcomes of different potential transformation programs. For the specific situation in the Zayandeh Rud Basin, both the economic costs as well the environmental costs of the policies must be considered. The project results show that the rural sector already deals with marked changes and a diminishing quality of life. The climate change and especially the water scarcity sustainably affect the people's livelihood.

Important for the success of the agricultural transformation is the willingness of governments, farmers, donors, companies and civil society organizations to assume responsibilities, take risks and change behaviors at the level of individuals, organizations and society to pursue an accepted solution within the basin. The Iranian commitment to implementing IWRM in the Zayandeh Rud Basin and the two phases of the BMBF-funded project "IWRM" have been crucial steps towards the path to enhance the socio-economic and environmental situation in the Zayandeh Rud Basin. The comprehensive, deep and partially difficult but target-oriented discussions of the multi-stakeholders during the participatory workshops have been valuable contributions to improve communication and, therefore, the understanding of the diverse perspectives on the same challenging need for transformation. To succeed, the transformation process requires continuous work with stakeholder engagement on a common development and understanding of an implementation plan. There is crucial need for such a mediator institution to manage the implementation of the transformation strategies over a long period of time. Therefore, the further empowerment of the current River Basin Organization (RBO), called "Coordination Council of Integrated Water Resources Management in the Zayandeh Rud Basin" will be indispensable. Additionally, as an initial step for agricultural transformation in the basin, new local Coordination Councils shall be established in all districts or irrigation networks of basin. These councils would be expected to facilitate, coordinate, operationalize and continuously improve the implementation of transformational strategies at the local level.

In the Zayandeh Rud Basin, the agricultural transformation strategies have to tackle short-term, mid-term and long-term goals (**Figure 8.1**). The availability of water throughout the basin has changed drastically over the last decades. Major action has to be taken in the field of water allocation. A paradigm shift from supply-side to demand-side water management is needed. A strong RBO and a stakeholder platform as bridging institutions between the various groups of stakeholders in the basin for supporting this change are imperative.

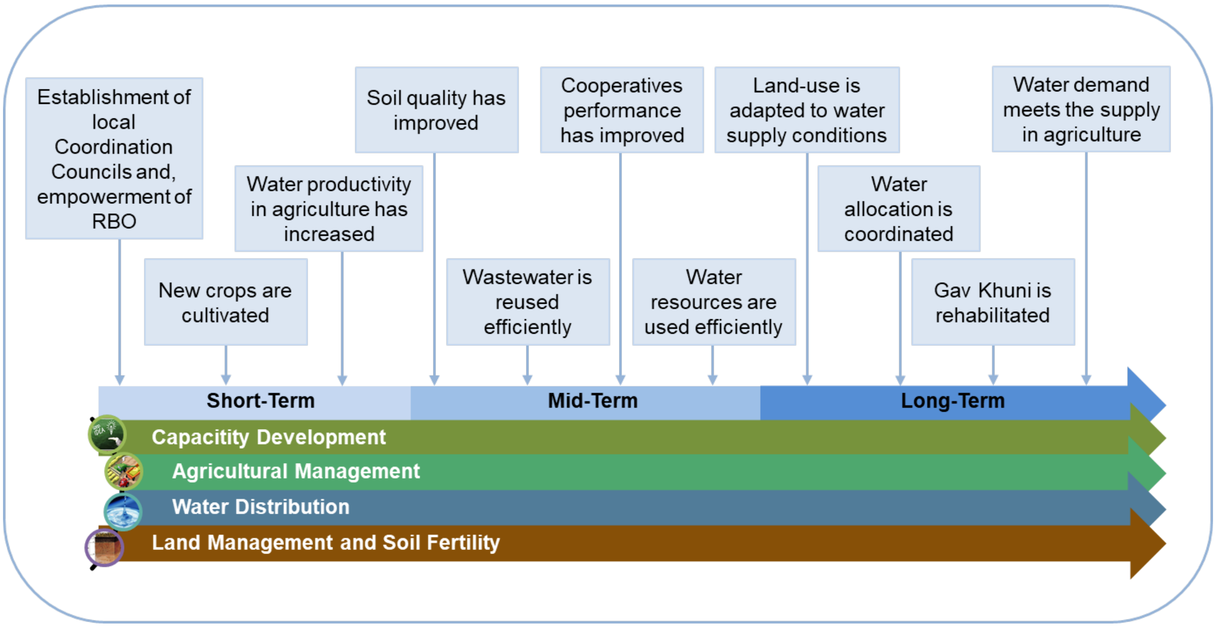


Figure 8.1: Key milestones on agricultural transformation in the Zayandeh Rud Basin

Developing the implementation plan demands prioritization of the strategies and resulting measures and activities, since the first plan cannot cover everything. Through the participatory approaches used in this project, four focus areas were determined: Capacity Development, Agricultural Management, Water Distribution and Land Management and Soil Fertility and ten strategies with measures were described. Key to all strategies are activities to continue the development of a common knowledge base and set of tools, so that integrated resource management plans can be put forward and evaluated. Also emphasized is the need to involve all stakeholders to prevent fear of bias from hindering general acceptance of the tools. This is essential since none of the strategies can be expected to reduce basin-wide agricultural water use by themselves if the overall area of irrigated cultivated land area is not reduced. A transparent basin-wide water accounting system needs to be developed based on the water consumed by agriculture, not on the water applied or diverted. Innovative schemes need to be applied, mixing technical improvements with policy to create real water savings and increase the amount of water available for the environment. Tools such as the Water Management Tool must be used to evaluate whether or not the strategies will translate into real water savings at a basin scale, or just in the local farming systems.

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Appendix

Appendix 1: About the research partners

The **Leibniz Institute for Agricultural Engineering and Bioeconomy (ATB)** is a European research centre at the nexus between biological and technical systems. It develops highly innovative and efficient technologies for the use of natural resources in agricultural production systems. Research is aimed at the sustainable intensification of bio-economic production. Its research approach is to analyze, model and evaluate bio-economic production systems focusing on examples in the fields of “precision crop production”, “livestock systems”, “biomaterials” and “biochar”. In summary, ATB develops and integrates new technologies and management strategies - for a knowledge-based, site-specific production of biomass, and its use for food, as raw materials and fuels - from basic research to application.

runlevel3 has been active since 2003 in the area of hard- and software development as well as network and system support. Customers include small and medium-sized companies as well as broadcasting corporations. Applying unconventional solutions based on our broad experience, we are able to respond to the needs of our customers, offering individual solutions for special problems. We support small office communities as well as larger companies with Europe-wide networked locations.

Final Project Report

Libra, J. A., Kraatz, S., Grundmann, P., Hunstock, U., Zare, M., Zamani, O., Reyhani, M. N., Jacobs, H., Gebel, R. (2019). IWRM Iran - Verbundprojekt Isfahan: Integriertes Wasserressourcenmanagement im Einzugsgebiet des Zayandeh Rud - Teilprojekt 3. Schlussbericht nach Nr. 3.2 BNBest-BMBF 98 : Projektlaufzeit: 1.3.2015-31.12.2018. Leibniz Institut für Agrartechnik und Bioökonomie e.V. (ATB). https://doi.org/10.2314/KXP:1671692810

Cooperation partners within the BMBF “IWRM Zayandeh Rud“ project

German Partners
inter 3 Institute for Resource Management, Berlin.
abc GmbH - advanced biomass concepts, Köln.
DHI WASY GmbH, Berlin
German Association for Water, Wastewater and Waste (DWA), Hennef
German Water Partnership e.V. (GWP), Berlin
Leibniz-Institute for Agricultural Engineering and Bioeconomy (ATB), Potsdam
p2mberlin GmbH, Berlin
PASSAVANT & WATEC GmbH, Aarbergen/Kettenbach
Technische Universität Berlin. Kartographieverbund, Fachgebiet Umweltverfahrenstechnik

Iranian Partners
Isfahan Regional Water Board Company (provincial authority of Ministry of Energy, project coordinator in Isfahan)
Isfahan Agricultural Organization (provincial agricultural authority)
Mirab Zayandeh Rud Company (responsible for water transfer and monitoring, operation of water supply networks)
Isfahan University of Technology
Iranian Federal Ministry of Energy (responsible for water, energy, wastewater services nationally)
Iran Water Resources Management Company (agency of the Ministry of Energy)
National Water and Wastewater Engineering Company (responsible for organizing official activities of the Ministry of Energy)
Governor General of Isfahan Province (responsible for implementation of general national policies)
Isfahan Water and Wastewater Company (local authority for drinking water supply, wastewater treatment)
Environmental Protection Organization of Isfahan (local authority for human and natural environments)
Zayandab Consulting Engineers (water infrastructure)
Zayandeh Rud Urban Development Organization (tourism)
Industrial Settlements Organization of Isfahan (responsible for policymaking and strategic planning)
Isfahan Higher Education and Research Institute in Water & Power (practical research and training)

Appendix 2. Irrigation water demand module (IDM) booklet

in Kraatz et al. (2021) Transformation strategies in agriculture. Project report: Integrated Water Resource Management in the Zayandeh Rud River Basin.

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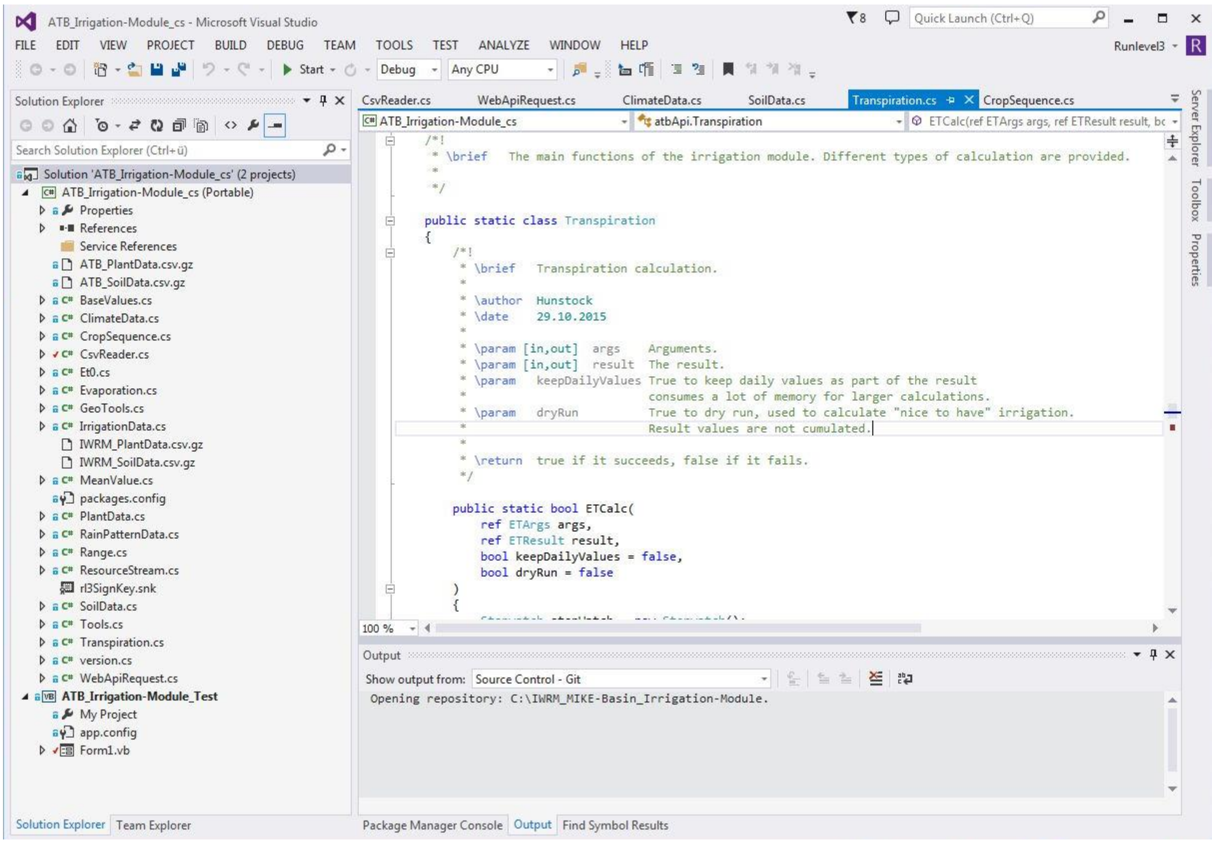
Leibniz-Institut für
Agrartechnik und Bioökonomie

Irrigation water Demand Module (IDM) booklet



Uwe Hunstock

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Leibniz Institute of Agricultural Engineering and Bioeconomy

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Content

Abbreviations and symbols

Term	In AHFM /IDM	Units	Description
IDM		-	Irrigation water Demand Module
FAO56		-	Allen, Richard & Pereira, L & Raes, D & Smith, M. (1998). FAO Irrigation and drainage paper No. 56. Rome: Food and Agriculture Organization of the United Nations. 56. 26-40.
ZR		-	Zayandeh Rud

Introduction to the IDM

The IDM is a software module that was developed to calculate the irrigation water demand for agriculture in the IWRM project. The module is an implementation of the ATB AgroHyd Farmmodel in a different programming language. The source code of the IDM is published to public domain at Github:

https://github.com/ATB-Potsdam/IDM

The relation between the AgroHyd Farmmodel, MIKE-Basin and the IDM is illustrated in the following picture. The algorithms were developed with AgrHyd and translated to the IDM.

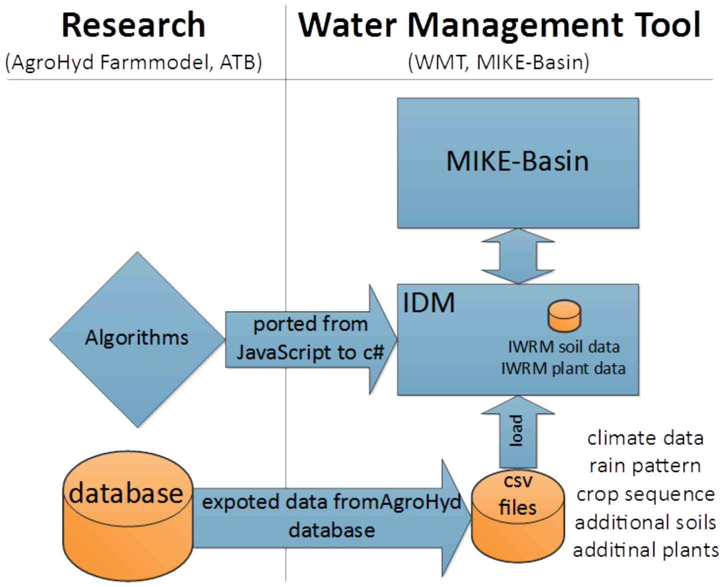

Figure 1 - Relation and Datasources AgroHyd - IDM

Use the IDM

Prepare Visual Studio

To use the IDM with a C# or VB .net Project you need only one file that has to be added as a reference to the project. To do so open the “Add Reference” dialog and browse to the directory which contains the file “ATB_Irrigation-Module_cs.dll”. The latest compiled Version can be downloaded here:

https://www.runlevel3.de/atb/irrigation-module/

The username is iwrm, password atb.

Additionally a package is required for Visual Studio. The Newtonsoft.Json package can be installed in Visual Studio with Tools -> NuGet Package Manager and this command line:

Install-Package Newtonsoft.Json -Version 9.0.1

As an alternative the source code of the IDM may be used for better debug opportunities. The source code is published at GitHub and can be loaded with git:

git clone https://github.com/ATB-Potsdam/IDM.git

Documentation

The programmers reference is built directly from the source code and is available online here:

https://www.runlevel3.de/atb/irrigation-module-docs/

The username is iwrm, password atb. In this documentation you can find all classes, data structures etc. with descriptions.

Initialize and Load data

After adding the "ATB_Irrigation-Module_cs.dll" to the project references, the namespace atbApi is available in the project. Before starting any calculation, the IDM data store has to be initialized and climate, rainPattern and cropSequence data must be loaded. Below is an example code snippet in c# to load the external data files.

```
var dataPath = "C:\\IWRM_MIKE-Basin_Irrigation-Module\\testDataSent\\";
var cropSequenceFile = "C:\\IWRM_MIKE-Basin_Irrigation-Module\\testDataSent\\cS_IWRM_Sce-
nario_1.csv.gz";

//create CultureInfo for english ans german formatted csv data
var cultureInfoEn = new CultureInfo("en-US");
var cultureInfoDe = new CultureInfo("de-DE");

//create empty climateDb
var climateDb = new atbApi.data.ClimateDb();
//load climate stations which are referenced in the cropSequence
foreach (String climateFile in Directory.GetFiles(dataPath, "*ClimateData*", SearchOp-
tion.TopDirectoryOnly)) {
    climateDb.addClimate(File.OpenRead(climateFile), atbApi.data.TimeStep.day, cultureIn-
foEn);
}

//create empty rainPatternDb
var rainPatternDb = new atbApi.data.RainPatternDb();
//load rain pattern which are referenced in the cropSequence
//only needed with monthly climate data
foreach (String rainPatternFile in Directory.GetFiles(dataPath, "*rainPattern*", SearchOp-
tion.TopDirectoryOnly)) {
    rainPatternDb.addRainPattern(File.OpenRead(rainPatternFile), cultureInfoDe);
}

//create cropSequence, use builtin plant and soil db and before created climate db
var cropSequence = new atbApi.data.CropSequence(
    File.OpenRead(cropSequenceFile),
    atbApi.data.LocalPlantDb.Instance,
    atbApi.data.LocalSoilDb.Instance,
    climateDb, rainPatternDb, cultureInfoEn);
```

cropSequence dry run and real calculation

The cropSequence contains all data regarding fields, seed- and harvest dates, climate and soil references. For more details of this data structure refer to the documentation:

https://www.runlevel3.de/atb/irrigation-module-docs/classat-bApi_1_1data_1_1CropSequence.html

The calculation will be done in two operations. At first a time step is calculated using the model argument "dryRun = true". This calculates the irrigation water demand for this time step and returns a list of all demands for all fields in all districts.

The demand will be adjusted in the MIKE-Basin Script according to the available water. The changed amounts are fed into the IDM for the second operation, the calculation with "dryRun = false".

The time step is variable and can be at least one day up to years. The result is always cumulative so a time step of more than one year doesn't make sense in general.

The list of the irrigation demands is sorted by irrigation network id, water rights and field id. So MIKE-Basin Script can sort out the networks, rights and fields, build sums and apply the irrigation water.

```
//create common arguments for all calculations
var etArgs = new atbApi.ETArgs();
//create autoIrrigation parameters unnessecary if contained in cropSequence
etArgs.autoIrr =
    new atbApi.data.AutoIrrigationControl(level: 0, cutoff: 0.15, deficit: 0.2);

//loop from 1996 to 2010 in monthly steps
var loopDate = new DateTime(1996, 1, 1, 0, 0, 0, DateTimeKind.Utc);
var loopEnd = new DateTime(2010, 12, 31, 0, 0, 0, DateTimeKind.Utc);
atbApi.data.CropSequenceResult result, nullResult = null;

do {
    //set endDate of one loop to last day of month
    var endDate = new DateTime(loopDate.Year, loopDate.Month,

        DateTime.DaysInMonth(loopDate.Year, loopDate.Month), 0, 0, 0, loopDate.Kind);

    //calculate irrigation demand but don't cumulate results
    //and plant development -> dryRun: true
    result = cropSequence.runCropSequence(start: loopDate, end: endDate,
        etArgs: ref etArgs, irrigationAmount: ref nullResult, dryRun: true);

    //modify irrigation demand, here just divide by 2 as an example
    foreach (String resultKey in
        new List<String>(result.networkIdIrrigationDemand.Keys)) {
        result.networkIdIrrigationDemand[resultKey].
            irrigationDemand.surfaceWater.amount /= 2;
    }

    //calculate again with real irrigation amount -> store in result, dryRun: false
    result = cropSequence.runCropSequence(start: loopDate, end: endDate,
        etArgs: ref etArgs, irrigationAmount: ref result, dryRun: false);

    //calculate next timestep
    loopDate = loopDate.AddMonths(1);
} while (loopDate < loopEnd);
```

Data sets included

The "ATB_Irrigation-Module_cs.dll" itself has compiled in resources. All ATB and IWRM plant parameters and the soil data from the ZR basin are included. To access the data programmatically two statically instantiated classes are available:

```
atbApi.data.LocalPlantDb.Instance
atbApi.data.LocalSoilDb.Instance
```

Because of size and change of data, some data sets are provided separately. In this booklet is an USB-stick included which contains several data sets in the folder "scenario_data".

- Daily climate data from 7 stations in the basin from around 1990 to around 2015
- Rain pattern extracted from the 7 stations in the basin
- Monthly climate data from the Climatic Research Unit, University of East Anglia, built from long term mean values
- cropSequence for scenario 1, 3 and 4

Integration into MIKE-Basin

The IDM can be integrated into MIKE-Basin. This can be done within the MIKE-Basin Script. The code to use the IDM instead of the built in FAO56 module has not yet been implemented.

Further Development

Everybody is invited to participate in the further development of the IDM. The project is living as an Open Source project on Github. The ATB will manage the "master branch". To improve the IDM you can:

- create your own Github account
- fork the project and create a new branch
- develop with Visual Studio, add or improve functions
- send a pull request to ATB-Potsdam to merge your branch into the master project
- or use your own new branch
- report bugs and issues at https://github.com/ATB-Potsdam/IDM/issues

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Heft 104	Transformation Strategies in Agriculture Project Report: Integrated Water Resource Management in the Zayandeh Rud River Basin	2021

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