Chapter 23
Integrated Water Resource Management in Isfahan: The Zayandeh Rud Catchment

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Abstract The river Zayandeh Rud is the most important surface water in central Iran. The catchment area has been affected by two drought periods within the last 15 years. Decreasing surface and groundwater availability has been accompanied by an increase in water withdrawal for irrigation, domestic uses, industry, and water transfers to neighbouring provinces. This has led to severe ecological and social consequences. While the Iranian government is officially committed to the IWRM idea, water management decisions have still been based on supply-driven strategies, and supply and demand have mainly been balanced by water transfer projects. Existing simulation models have not been used for management decisions because their development lacked participatory elements and therefore they are considered as being biased. The aim of the project IWRM Isfahan was to develop a locally adapted IWRM process for the catchment area which integrates organisational, participative and technical measures. To this end, three different simulation models have been developed and merged into a Water Management Tool (WMT). WMT serves as the main instrument for a better understanding of water management processes within the catchment area and it provides the authorities in charge with a decision support tool. In order to achieve ownership and acceptance of the results and recommendations, accompanying measures like reforms in water governance or the establishment of WMT commissions need to be realized. The first steps in this direction have already been taken applying participatory methods. Initial estimations show that the implemented measures as a whole carry the potential for successful conflict resolution.

Keywords IWRM process · Water management tool · Zayandeh Rud dam · Gavkhuni · Stakeholder involvement

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23.1 Introduction: Current State of IWRM in Iran and in the Zayandeh Rud Catchment Area

Iran's water resources and their ecology have been under pressure because of climatic conditions as well as their heavy overuse in many regions of the country. To date parts of the population suffer from water shortages particularly during the dry summer months. The drinking water supply and also water supply to the agricultural sector and the environment are in danger in the long-term (Foltz 2002).[1] There exist usage conflicts between single sectors as well as conflicts among water policy objectives, for example between resource use and resource protection.

The Iranian government has long since recognised the need for action and officially there is a willingness to reform the water sector (Bertelsmann Stiftung 2012). At the world summit for sustainable development in Johannesburg in 2002 the Iranian government had already committed to the IWRM idea and had produced a strategy paper in 2003 which takes up IWRM as the leading approach (UN DESA 2008). There are some international projects which work on regional IWRM strategies on behalf of the government and in summer 2013 the Iranian commission to UNESCO applied for an "international centre for integrated management of water and natural resources".[2]

Even 12 years after the Johannesburg summit fundamental institutional problems remain unresolved. There is still a lack of experience, operational organisations and effective instruments for implementing IWRM. Water agencies, provincial administrations and environmental agencies still lack the human and financial resources they would need to manage integrated cross-sectoral tasks. Moreover they focus too much on their respective interests and until now the Ministry of Energy has taken the main political decisions concerning water management. This results in short and long-term goals being very much focused around technical solutions like the regulation of water resources through dams or expensive water transfer projects[3] (Mohajeri et al. 2009a).

Reactions to droughts have been short-sighted, like the prohibition of surface water withdrawal for agricultural purposes (Safaei et al. 2013). This again led to an increase in groundwater extraction and a lowering of groundwater levels. Moreover, social unrest and the destruction of pipes for water transfers to other provinces by protesting farmers were consequential events (Al Monitor 2013, France24 2014).

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[1] The German broadcaster Deutsche Welle Farsi alone released nine articles in July 2013 with headlines like "Water shortage in Iran reaches critical levels", "Water shortage and pollution from North to South" or "Save the Ourmiyeh Lake".

[2] The centre is supposed to be one of 81 international and regional centers under the auspices of UNESCO. The costs are to be assumed by the Iranian government.

[3] For example a transfer from the Persian Gulf to the province Fars. See Tehran Times July 8th 2013.

The Zayandeh Rud is the most important and at the same time most endangered river of central Iran (see Sects. 23.2.1–23.2.3). Institutional and organisational weaknesses (Sect. 23.2.4) and the lack of water simulation models that can be accepted by all stakeholders were the starting point of the IWRM Isfahan project which seeks to initiate an IWRM process in the Zayandeh Rud catchment. Economic losses, increased uncertainty among investors in the industrial sector, social unrest and protests by environmentalists are direct consequences of incorrect policy and water management decisions. Therefore, in the course of the project instruments and procedures were developed, which allow for the promotion and support of an IWRM process and measures for conflict resolution at the same time. The first phase of the project has been finished, and initiated processes still have to be pursued in the future.

In order to initialise this IWRM process a Water Management Tool (WMT) has been developed together with the relevant local actors. With this WMT the consequences of political decisions regarding water resources can be visualised. For the development of the WMT quantitative data about the water resources in the catchment area have been used (see Sect. 23.3.1).

The lack of availability of surface water in the catchment area has been compensated particularly through overuse of groundwater during the last 15 years. Therefore, in Sect. 23.3.2 the results of the calculations of the FEFLOW groundwater model as part of the WMT will be described. FEFLOW is the main tool to describe the complex interaction of surface and groundwater and therefore provides vital data for water management decisions in the catchment.

Following the subsidiary principle of IWRM, the aim of the WMT is that visioning and strategic planning follow an iterative process (see Fig. 23.1): National, regional and local stakeholders should deliver inputs for the definition and

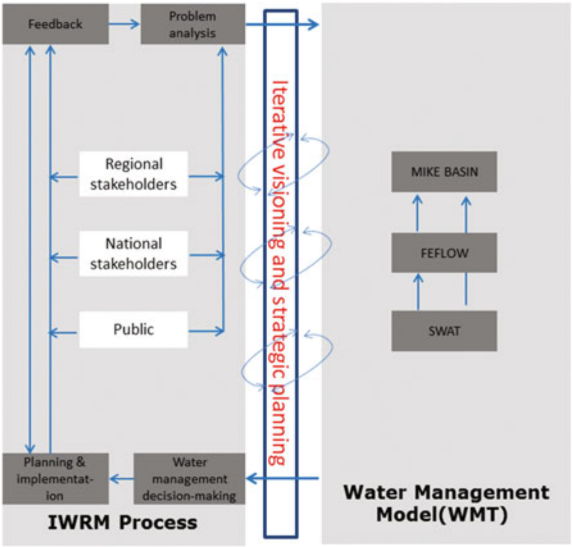

Fig. 23.1 Visioning and strategic planning as iterative process using the WMT. *Source* inter 3

description of water problems and the resulting consequences. Using the WMT the responsible actors should take joint decisions, plan and implement the respective measures and obtain feedback from all stakeholders on how far measures have led to solutions to water related problems.

A kick-off for the establishment of respective responsible organisations for carrying out these iterative processes as well as the technical responsibility for the WMT took place in the form of an interactive workshop (see Sect. 23.4.1). In the next project phase, questions concerning the institutional and organisational implementation shall be clarified and the WMT shall be handed over to the Iranian stakeholders. Section 23.4.2 describes the necessary steps towards sustainable and effective use of the WMT as well as towards a comprehensive implementation of IWRM in Iran. This involves the institutional, legal and organisational framework conditions, but also the capacity development of WMT users and actors who promote the IWRM process in general.

23.2 Zayandeh Rud—The Research Area

The research area is located in central Iran (see Fig. 23.2), in the province of Isfahan, with Isfahan City nearly in the centre. The river Zayandeh Rud, which gives its name to the region (the catchment area) is the most important surface water in central Iran. The catchment area stretches across two provinces, covering a total area of 26,000 km^2. The river originates in the province Chaharmahal-va-Bakhtiary

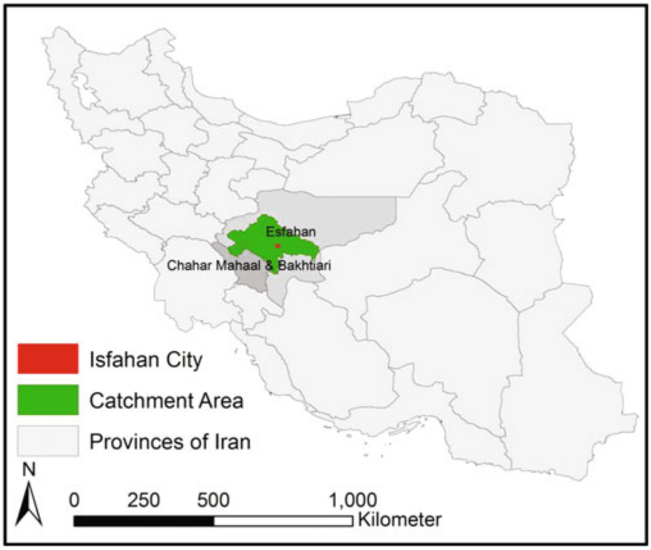

Fig. 23.2 The Zayandeh Rud catchment area. *Source* DHI-WASY

in the area of the Zāgros Mountains in the north-west of the catchment area. However, most of the river lies in the province of Isfahan. It ends in a seasonal salt lake and marsh in the south-east of the catchment area. On its way the Zayandeh Rud passes through fertile regions, large industrial settlements as well as the important city of Isfahan whose historical buildings were declared UNESCO world cultural heritage sites. The salt lake Gavkhuni became one of the first internationally recognised marshlands at the UN Ramsar convention (Nadjari 2004).

After the Islamic revolution in 1979 and at the beginning of the Iran-Iraq war in 1980, the Isfahan province attracted thousands of people from other provinces. The heavy population increase was accompanied by the rise of Isfahan as an important industrial and agricultural centre. As a result the city of Isfahan today is the 3rd most populated city in Iran and the province is the second largest industrial area in the country.

23.2.1 Characteristics of the Catchment Area

On its 405 km course the Zayandeh Rud runs through extremely different climatic and natural conditions (Shafaghi 2003; Hossaini Abari 2000). The area of its headwaters in the Zāgros Mountains, at an altitude of 4,000 m, is dominated by a cold and humid climate. At the river's estuary, the salt lake Gavkhuni at an altitude of approximately 1,500 m, the climate is arid. Thus, the average precipitation decreases from 1,500 mm at the source to only 80 mm at the mouth. Moreover, the average monthly air temperatures that differ between 1 to 24 °C and a potential evaporation of up to 3,100 mm/a suggest the particular challenges of managing these water resources.

In order to achieve controlled management of the water resources, a dam with an average inflow of 40 m^3/s was built by a French-Iranian consortium in 1972. For the purpose of covering the increasing water demand, three tunnels were built in 1954 and later in 1985, through which water is being rerouted from the neighbouring province toward the Zayandeh Rud dam. The demand driven water management led to the building of two more diversions that are supposed to redirect additional water towards the catchment within the next 7 years.

On its way from the dam to the salt lake the Zayandeh Rud can be divided into three main parts (see Fig. 23.3). In the first part the water flows in what can be described as quite good quality around 100 km from the Zayandeh Rud dam to the Chamaseman dam, the extraction point of Iran's biggest water works (Mohajeri and Dierich 2008). During the last few years, the region around the Chamaseman dam lake has become a famous destination for families and anglers from the city of Isfahan. Here, the drinking water for the 4.5 million citizens of the Isfahan province and other cities outside of the catchment area—like Yazd, Kashan or Nain—is being extracted. Additionally water is used for agricultural purposes.

In the second part of the river further downstream up to Isfahan, a number of agricultural businesses as well as big industrial sites (oil refineries, steel industry)

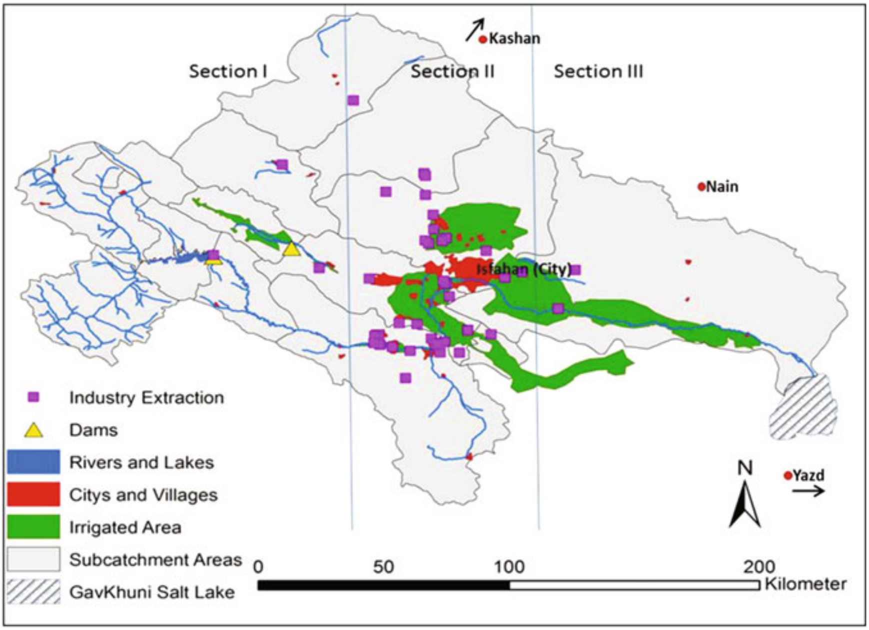

Fig. 23.3 The Zayandeh Rud catchment. *Source* DHI-WASY and inter 3

are located. Here the river water is heavily polluted through waste water and agricultural drainage water. In the last part of the river, water is used mainly for irrigation. In the last 15 years the water arriving at the Gavkhuni Lake has been almost only agricultural drainage water, heavily polluted by pesticides (Soltani 2009).

23.2.2 *Water Availability*

The long term yearly discharge from the dam lake is 1314,7 million m^3 based on values from 1996 to 2012 (Source: Isfahan Regional Water Board). Also between 2000 and 2008, an average of 1,300 million m^3 water per year from the dam lake was available to cover the water demand within the catchment area. At this time, the water availability decreased to 533 million m^3 during the dry period at the beginning of the millennium, and had its peak of about 1,800 million m^3 in 2007 (Table 23.1).

As a result of the arid climate there is no significant groundwater recharge downstream of the dam. The results of the SWAT model—as a part of the Water Management Tool (WMT) (see Sect. 23.3)—show an average groundwater recharge of about 142 million m^3 for the entire area downstream of the dam. This is

Table 23.1 Yearly release from Zayandeh Rud dam (2000–2008)

Year	Release from dam (m^3/s)	Release from dam (million m^3/year)
2000	28.9	911.4
2001	16.9	533.5
2002	39.9	1258.3
2003	48.4	1525.2
2004	47.8	1506.2
2005	51.0	1608.3
2006	50.0	1576.8
2007	57.8	1821.7
2008	31.0	977.6
AVG	41.3	1302.1

Source Isfahan Regional Water Board

the main reason for the heavy overuse of groundwater resources especially during the dry years. The results have been considerably decreasing groundwater levels during the last 15 years by 20 m, in some parts by even 50 m (see also Sect. 23.3.2). This represents an overuse of groundwater resources of around 5 billion m^3 over a period of 15 years or an average of 315 million m^3/year.

23.2.3 Water Withdrawal

The biggest share of surface and ground water resources in the catchment area is being used for irrigation. For the distribution of surface water, irrigation systems with multiple distribution structures and channel systems were built in the 1970s and late 90s. Additionally a lot of ground water has been extracted from 35,000 wells for irrigation purposes.

Most of the irrigated area in the catchment is irrigated by flood irrigation like furrow irrigation. In 2006/2007, for example, all irrigated crops were supplied by flood irrigation while orchards were supplied by pressure irrigation (Felmeden et al. 2014).

From 2000 to 2008, the agricultural sector took an average of 787 million m^3 of water directly from the river. There were also about 391 million m^3 of groundwater as well as the illegal use of treated effluent from the sewage treatment plants with an estimated total of about 269 million m^3. The water that seeped away from the mostly traditionally irrigated farmland is available as return flow for the irrigation of further agricultural areas. This process of reuse is repeated throughout the entire basin up to 3.5 times. Through this return flow, the average available amount of water for agricultural use increases from around 1,450 million m^3 to around 5,000 million m^3. With this amount of water 230,000 ha of agricultural land is irrigated; this is equivalent to almost 5 % of the total irrigated land in Iran. In the course of the extreme dry periods over the last 3 years, irrigation of agricultural areas in the catchment area has been completely or partially banned.

While agriculture has suffered from serious supply problems recently, the number of industrial businesses, including the water demand for industry, has risen steadily. Today the amount of water used by industry in the catchment area is around 150 million m^3/year. About 25 % of this water is being shared among more than 3000 small scale industries within Isfahan municipal boundaries, 13,000 small and medium sized industrial units and 29 large industrial settlements and zones. In addition there are over 30 large individual industrial units like Mobareke Steel Co. which share approximately 75 % of the total industrial water consumption in the catchment area.

The average daily consumption of drinking water in rural areas measured by individual water meters stands at 150 and 230 l/capita in urban areas. These figures are significantly higher than the average use of 90 l/capita for rural areas and 160 l/capita for urban areas as envisaged by the Iranian Ministry of Energy. And they have to be complemented with water losses caused by network leakages of up to 50 % in rural areas and 25 % in cities. This means a total water consumption of 225 l for rural residents and 285 l per urban user. Today, about 350 million m^3 of water resources is required to supply drinking water. Additionally around 100 million m^3/year is taken from the Zayandeh Rud to supply the inhabitants and agriculture outside of the catchment area, like the city of Yazd.

Experts estimate the water requirements of the salt lake Gavkhuni as being between 70–150 million m^3/year, an amount which hasn't been reached in years. Quite the contrary, the high water consumption coupled with the growing length of recent dry periods have left the riverbed in the centre of Isfahan virtually empty (see Fig. 23.4).

Fig. 23.4 Empty Zayandeh Rud river bed in 2013. © IWRM Isfahan

23.2.4 Challenges in Water Governance and Management

The implementation of IWRM requires the creation of an enabling environment, supporting institutional and governance structures, adequate water management instruments, an infrastructure development that is adjusted to the defined IWRM objectives and, last but not least, profound financial backing (UNEP 2012). IWRM promotes the river basin as the proper scale for water governance (Global Water Partnership 2000) and requires stakeholder participation (see e.g. Mitchell 1990; Mostert 2006).

Although the Iranian government accepted the general idea of IWRM, water governance and management still face severe problems: Overall, a general master plan (and regional action plans accordingly) for the management of the national water resources is still missing. Moreover, despite a formally decentralized water governance structure, there is no actual decentralization of responsibilities with their respective rights and duties (NWWEC and inter 3 2009). This leads to non-transparent decision making processes and vague responsibilities.

In general, three dimensions of institutional and governance challenges appear in the management of natural resources (Young 1999) and thus in the implementation of IWRM processes (Moss 2004). First, it is assumed that environmental institutions work best if they match the boundaries of the ecological systems they refer to. In the case of the Zayandeh Rud, however, two province governments are responsible for decisions over one river. Second, the coordination and cooperation between institutions within the catchment area, i.e. between sectors at the same level, are of major importance in order to integrate different interests regarding the water resources. In Iran, and particularly in the case of the Zayandeh Rud, sector agencies pursue their own goals with regards to and compete for water resources. Third, the coordination between institutions at different levels, for example between national and regional levels, is crucial. Ideally, command-and-control approaches should give way to participatory, bottom-up decision-making and management procedures. Addressing these coordination problems would require a realignment of governance structures and respective institutions, as has been described for many other countries (Bandaragoda 2000; Saleth and Dinar 2000; Rogers and Hall 2003; Dombrowsky 2005; Horlemann and Dombrowsky 2012; Huitema et al. 2009). The realignment of institutions and organizations along the scales of river basins in a water sector reform, however, is highly political because it would inevitably shift decision-making powers currently in place (see e.g. Schlager and Blomquist 2008; Saravanan et al. 2008).

It is obvious that a perfect fit and interplay of institutions can never be reached at the same time, and sometimes it is not even desirable, e.g. when newly established organizations at river basin level replace regional organizations that worked well (Moss 2003). For Iran, a breakdown of the water sector into a clear-cut regulative pillar, an executive or operational pillar and a control pillar to enhance coordination could also be an option (Mohajeri et al. 2009b).

The integration of interests concerning the water resources but also with regards to political and individual influence has been a main working point of the IWRM Isfahan project. So far, the Ministry of Energy and its subordinated entities at national and provincial level are responsible for water management. The ministry presides over (inter-provincial) water transfer measures which are a delicate political and social issue in the face of conflicting water usage. While the provincial government possesses the formal power of decision over water management issues, the ministry oversees the distribution of financial resources. This means that formal decentralization is not yet backed by financial autonomy of the provinces. The different entities and administrations would rather act as competitors and negotiators than pursuing the goal of sustainable water resources management.

The lack of cooperation and coordination is also reflected in the absence of water management simulation models that are accepted by all stakeholders and that are used by the responsible authorities. Several models have been developed during the last years, many of them by universities. These models, however, have not been applied in practice since they are considered as being biased. The reason is that they were developed without involving the relevant actors with their respective stakes in the water resources. It is important, though, that the data used in a model are agreed upon by all stakeholders to make the model a neutral knowledge base on which generally accepted decisions can be taken. Usually, the data available from different sources in Iran are not consistent, calculated at different scales (e.g. provincial level, catchment scale) or collected in non-transparent ways. The creation of a widely recognized data base and jointly developed water management tool was therefore the main objective of the IWRM Isfahan project.

23.2.5 Interim Conclusions

- An analysis of the extracted water volumes and their consumption in different sectors for the years 2000–2008 is shown (see Table 23.2).
- Each year an average volume of 2,026 million m^3 of water was consumed by various sectors in the catchment, including 269 million m^3 of treated municipal waste water (see Table 23.2).
- More than 70 % of the used (sewage) water resources were used for irrigation.
- The internationally recognised wetland Gavkhuni did not receive any water from the Zayandeh Rud during this time.
- At the same time groundwater resources were overused by 315 million m^3/year.
- Despite the overuse of groundwater resources and the extreme deprivation of the Gavkhuni, there were repeated protests by farmers and a virtually empty river bed in the centre of Isfahan city on eight occasions.
- Despite the official commitment of the Iranian government to IWRM there is still no water management master plan.
- Due to non-transparent, top-down decision making specific regional challenges in water management are allowed for insufficiently.

Table 23.2 Withdrawn water resources and water use in different sectors (2000–2008)

(Sewage) water resources in million m^3 as average value for the years 2000–2008	
Dam discharge[a]	1300
Overused groundwater[b]	315
Groundwater recharge in the catchment area after the dam[c]	142
Treated municipal wastewater[d]	269
Total	2026
Water withdrawal of different sectors in million m^3 as average value for the years 2000–2008	
Transfer to Yazd[e]	49
Transfer to Chaharmahal	50
Urban and rural Water and Waste Water Co.[f]	350
Industry[g]	130
Gavkhuni Lake	0
Agriculture[h]	1447
Total	2026

[a] Observed data
[b] Analytical result of the FEFLOW model
[c] Analytical result of the SWAT model
[d] Information from Isfahan Water and Waste Water Co
[e] Information on water transfers are from the Isfahan Water Board Co
[f] Information from Isfahan Water and Waste Water Co
[g] Own research. See Mohajeri et al. (2013)
[h] Calculated and observed data have been compared and revised

- A realignment of water institutions, an adjustment of institutional fit and interplay and the introduction of participative procedures are necessary steps towards IWRM.
- Existing simulation models lack acceptance by stakeholders from different sectors because they are based on data considered as being biased.

23.3 Water Management Tool as a Tool to Build an IWRM Process

The aim of the IWRM Isfahan project is to develop a locally adapted IWRM process for sustainable water management in the Zayandeh Rud catchment area, together with the Iranian stakeholders. To this end, three different simulation models have been developed and merged into a Water Management Tool (WMT).

The WMT is the main instrument for a better understanding of the hydrological process in the catchment area on the one hand and on the other as a decision-support tool. In this way the tool can be used as a decision support system in the IWRM process. It can be used to justify and legitimise water management decisions in advance, to show possible alternatives and to assess the consequences. Thus, decision makers are able to develop concrete goals and action plans including the necessary measures for sustainable resource management in the catchment area Zayandeh Rud.

23.3.1 Description of the Water Management Tool (WMT)

The WMT combines the simulation results of all three models (MIKE Basin, FEFLOW and SWAT) and calculates the amount of available water and the supply for each individual user.

23.3.1.1 Water Management Tool—MIKE Basin

The Water Management Tool is a GIS-based decision support tool built on MIKE Basin. In MIKE Basin the use of available water resources can be mapped taking into account technical, ecological, economic and social conditions (DHI-WASY 2013). The aim of the WMT is to picture all anthropological impacts on water resources in the catchment area in space and time. This includes the inflow into the dam, the discharge of surface water in the southern part of the Zayandeh Rud and all natural and artificial inflows (caused by irrigation), effluents and groundwater extraction along the river.

The strength of the model is to determine the water needs of all defined users and to contrast them with the actual water resources available. The MIKE Basin model represents the intersection of all three software-based models and accumulates the results (see Fig. 23.5).

MIKE Basin imports the natural runoff and climatic data on a monthly basis from the SWAT. The exchange between surface water and groundwater along the Zayandeh Rud is calculated as a function of groundwater extraction from the FEFLOW model and also imported by MIKE Basin. The model covers the entire catchment area, a region of about 26,000 km^2. The Isfahan province is divided into 21 sub catchments (4201–4221), of which only the sub catchments 4201–4216 are part of the Zayandeh Rud catchment. The FEFLOW model is limited to the province of Isfahan aquifer below the dam and considers the sub catchments 4201, 4202, 4203, 4205, 4206, 4207, 4208, 4209 and 4217 and extends over an area of approximately 10,500 km^2. The spatial extent of the three models is shown in Fig. 23.6.

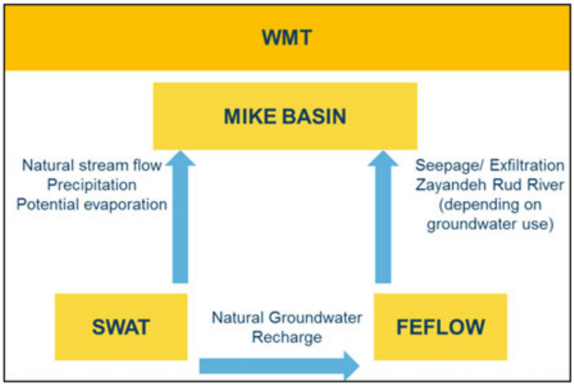

Fig. 23.5 Conceptual information exchange between the three software-based models. *Source* DHI-WASY (2013)

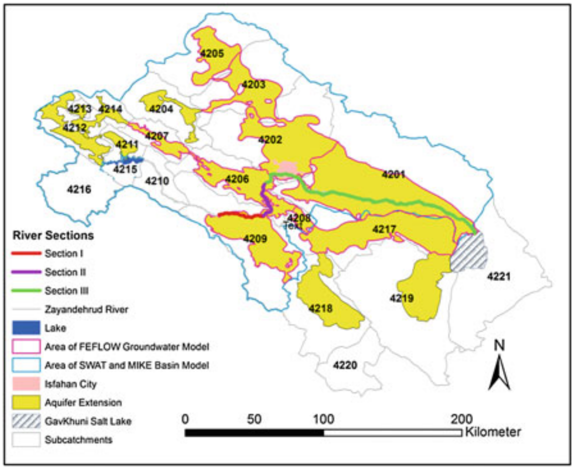

Fig. 23.6 Overview of the extension of the three models, the extent of the aquifer, and the division of flow sections for the exchange between MIKE Basin and FEFLOW. *Source* DHI-WASY (2013)

23.3.1.2 Groundwater Model—FEFLOW

The groundwater model was built up with the groundwater simulator FEFLOW—a software package that calculates water flow, mass and heat transport in porous media (Diersch 2012, 2014).

The aim of the FEFLOW model was to calculate the water exchange between the surface water in the Zayandeh River and groundwater in space and time for the simulation period 1995–2009 and to transfer the exchange rates to the MIKE Basin model. FEFLOW was chosen because it is professional software for small to large scale groundwater modelling. The option of local mesh refinement, powerful pre- and post-processing methods and several links to other software systems makes it a good choice for realizing the project aims.

23.3.1.3 Hydrological Model—SWAT

The hydrological model (SWAT—Soil and Water Assessment Tool) calculates the natural runoff based on simulation of hydrologically relevant processes that take place in the soil zone (Arnold et al. 2012). It covers the entire catchment area of the Zayandeh Rud aboveground (see Fig. 23.6). The calculation takes place on the basis of about 360 sub-basins. Within the project area-wide soil mapping was carried out for the entire SWAT model area in which the first 2 m of the surface in up to five different layers were separated. Each layer has been assigned with specific physical parameters that influence the impact of the soil zone on hydrological processes.

23.3.2 Results of the FEFLOW Model

In the article the groundwater model FEFLOW will be used as an example to describe technological procedures for several reasons. First, the FEFLOW model is at the utmost stage of development. Second, groundwater is the most important water source for the different uses in the catchment. Third, groundwater modelling can be regarded as the core function of the WMT because the interaction of groundwater and surface water is an important process in the catchment area.

However the surface water represents only 26 % (1237 million m^3) of the water used within the catchment area, the largest part of 74 % (3460 million m^3) comes from groundwater (data by Water and Sustainable Development). The steadily declining groundwater levels over the last 15 years have recently developed a legal, economic and environmental focus for the regional authorities. Some regions have been declared protected zones into which no new permits for groundwater withdrawal may be issued. In the future, significant socio-economic changes in these regions are expected with regards to agriculture and industry. For this reason, the partial results of the FEFLOW model are described herein. In order to sufficiently determine the water resources with regards to the groundwater in the catchment area, hydrological and hydrogeological issues have been considered and will be explained below.

23.3.2.1 Method

The model was built transiently for the period 1995–2009 and calibrated, mainly for a zone of 5 km around the Zayandeh Rud river. As the aquifer was already partially dry during the simulation period, an unsaturated model approach was chosen. The model consists of five layers, which divide the otherwise unconfined aquifer in the western part by a layer of clay into stressed and unstressed conditions.

The natural groundwater recharge as calculated by the SWAT model was divided into two streams. The lateral inflow was implemented using well boundary conditions while the vertical flow was implemented as ‘in/out flow’ on ‘top/bottom’.

In order to accurately depict the almost 40,000 wells, qanats[4] and natural springs with the different extraction rates in the model, the groundwater discharges were applied to grid squares of 1 km in length each. The proportion of the groundwater discharge to the total discharge per sub-catchment was determined and divided into deep and shallow discharges. The implementation in the model was carried out through 'in/outflow on top/bottom' on slice 5 and 'source/sink' in layer 3. The applied groundwater discharge in the model corresponds to the average discharge of the period 1999–2009.

The river was integrated with a third kind boundary (Cauchy) vertically and with half of the average breadth of the river between the first two slices. For the river, which is considered as being well connected, 'in/out transfer rates of 5,000' were estimated which correspond to a colmation layer of 0.5 m with a k-value of 0.03 m/s.

For the calibration, 311 observation wells were available of which 55 are located within a distance of 5 km from the river and therefore were considered as relevant for the model's goal. For the relevant observation wells which show a lowering of up to 50 m within 15 years, an average deviation of 5 m between the measured and calculated groundwater levels was identified.

23.3.2.2 Lowering of Groundwater Levels

The groundwater levels in the catchment area have diminished by approximately 20 m and in some parts even 50 m over the last 15 years. The lowering of groundwater levels varies a lot. The closer in proximity to the river, the less it decreases. This fact can be mapped by the current FEFLOW model. Figure 23.7 shows the vertical cross-section through the sub-basin Najafabad.

The blue line marks the measured groundwater level at the beginning of the model run (January 1995). Even at this time the groundwater level in the left north-western part of the cross-section does not show any natural conditions (no more discharge to the receiving stream). The green line shows the measured groundwater level at the end of the simulation period (December 2009). The groundwater level calculated by FEFLOW is indicated by the red line.

For this part the FEFLOW model provides a good depiction of the declining groundwater level. It becomes obvious that within a period of only 15 years the thickness of the aquifer has been reduced significantly. Only the river on the right side supports the groundwater levels through infiltration in its immediate vicinity. Under natural conditions rivers carry a combination of rainwater inflow and groundwater outflow. This means that under natural conditions groundwater flows in the direction of the receiving stream. As Fig. 23.9 shows, the overuse of groundwater affected the natural groundwater flow more than 15 years ago.

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[4] An ancient technology used to extract ground water.

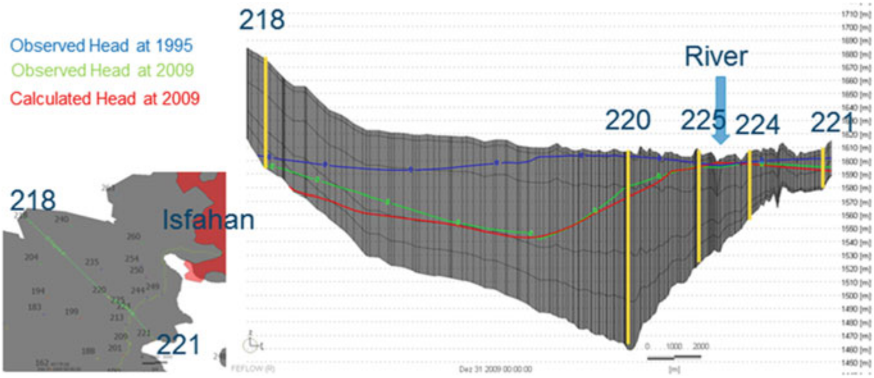

Fig. 23.7 Cross section views through sub-catchment 4206 (Najafabad) with observed heads at 1995 and 2009 and calculated heads at 2009; 50 times vertical exaggeration. *Source* DHI-WASY (2013)

23.3.2.3 Groundwater Budget

The basic water balance is crucial for sustainable water management. The natural groundwater recharge rate (calculated by the SWAT model) of 0 to locally 77 mm/a is comparable with the data from other authors like Nikouei et al. (2012) who presented average recharge rates of 12 mm/a and Gräbe (2012) who presented average recharge in arid environments of 8–71 mm/a). Additional inflows into the groundwater occur as surface/groundwater exchanges along the river as well as the anthropogenic-driven return flow.

The return flow was assumed using a local variable coefficient adopted for local groundwater use. The resulting ratios and volumes were in the range of previous investigations like those by Water and Sustainable Development, who presented a Return Flow of 1867 million m^3 for the 9 sub catchments covered by the Model area and Global Water Partnership (2012) quantified the additional groundwater recharge caused by irrigation in arid environments with around 300 mm which leads by an irrigated area of 3140 km^2 to 942 million m^3.

The resulting groundwater balance for the FEFLOW model is shown in Fig. 23.8. The natural groundwater recharge of 76 million m^3/year represents only 2 % of the total groundwater inflows. By far the major share (76 %) of the groundwater inflow is provided by the return flow of 1682 million m^3/year. The inflow of the Zayandeh Rud of 484 million m^3/year as calculated by the FEFLOW groundwater model represents 22 % of the total and thus must be considered an important amount of the groundwater budget. The average groundwater deficit is quantified as 379 million m^3.

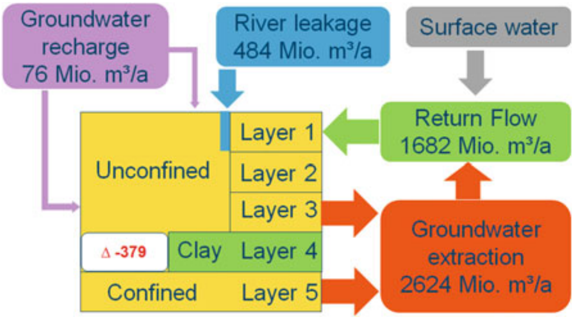

Fig. 23.8 Structure of the five-layer groundwater model which budgeted groundwater recharge, groundwater withdrawals, the return flow and seepage from the river into the groundwater. *Source* DHI-WASY (2013)

23.3.2.4 Exchange Between Groundwater and Surface Water

Analysis of the observed groundwater data showed that the water table has a hydraulically lower level than the surface water in the Zayandeh Rud River and hence the flow exfiltrates into groundwater.

The river was divided into three sections along which the temporal process of exchange was assessed. These sections were caused by level and flow monitoring stations and are shown in Fig. 23.6. The exchange rates for these three sections as calculated by the FEFLOW model are shown in Fig. 23.9.

Within the first 2 years the exchange rates in all sections increase severely. This is probably due to an overestimation of feed rates during the first years for which no data was available and therefore could not be included in the calculation of the long-term average. The exchange rate in Sect. 23.1 remains constant after 1996,

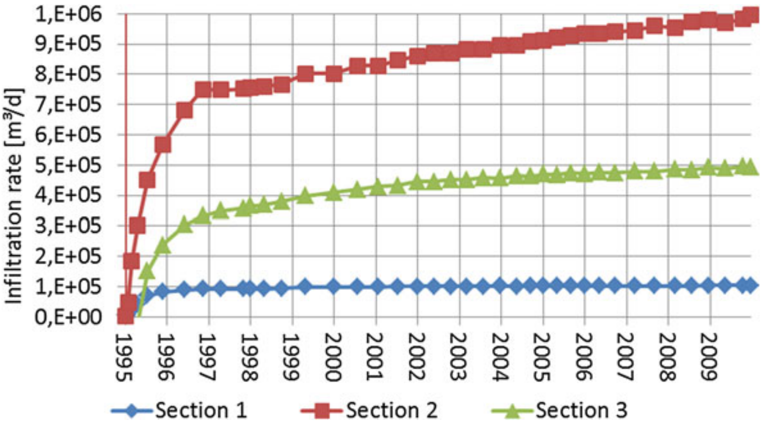

Fig. 23.9 Exchange rate between surface water and groundwater. *Source* DHI-WASY (2013)

while the exchange rates in Sects. 23.2 and 23.3 continuously increase after 1997. This effect can be explained by the partially severe lowering of groundwater levels in the surrounding aquifer. The drop in groundwater levels, again, is due to extensive groundwater withdrawal. Thus, there is a direct link between groundwater extraction and the exfiltration of the river into the aquifer.

23.4 Stakeholder Involvement for WMT Implementation

In theory, a decision support system (DSS) can provide the basis for successful participatory planning. However, in real life only few of the DSS developed for different countries and catchments have found implementation and experiences with water management models have shown that even a careful and practice-oriented development of a model does not guarantee that decision makers will actually use and further develop the model (see for example Jao 2011). This is not least because they are often designed by technocrats and lack adequate stakeholder input (Serrat-Capdevila et al. 2011). Successful implementation involves the participation of stakeholders from the earliest possible stage on. This way, the DSS can be adjusted to the needs of the end users. Moreover, not only the policy decisions based on the DSS models have to be taken in a coordinated way. The data fed into the data base also have to be agreed upon by all relevant stakeholders to guarantee maximal acceptance of the outputs. Only this can lead to a joint decision that can be fully acknowledged by all parties. Serrat-Capdevila et al. (2011) state that

> […] any decisions based on information provided by the models will not be considered sufficiently trustworthy if the models are perceived by the stakeholders as (a) not being transparent, and/or (b) if they are not convinced the model addresses their views and concerns, and/or (c) their input has not been requested or integrated into the development of the model.

23.4.1 Assessment of Needs and Demands

A major challenge of the project was to identify and harmonize the different interests and expectations of the decision makers towards the WMT. For this purpose, a participative, culturally adapted workshop was conceptualised and conducted, involving all relevant stakeholders.

The development of the methodology had to deal with two major challenges: In general, the implementation of a decision support system that puts previous forms of decision making into question. In Iran where hierarchical thinking prevails, the participative development of a tool means to negotiate classical working methods and principles of decision making (Ghanavizchian and Mohajeri 2013). Moreover, there are severe inter-sectoral conflicts of interest, particularly in the Zayandeh Rud catchment area, which have to be overcome. On occasion, these conflicts can be quite emotional.

These challenges could be resolved by addressing the problems in an open way. First, the problem of hierarchical thinking was discussed with the respective authorities and senior participants. Second, three small discussion groups were formed and participants were systematically chosen from different sectors, hierarchical levels and academia. The discussion groups were then chaired by an independent, unbiased person. The aim of the workshop was to clarify four main issues regarding the WMT:

- Current problems and future challenges of the WMT
- Advantages and expectations of WMT
- The issue of data collection, coordination and validation
- The question of WMT updating and availability

Regarding the current problems and future challenges of water resources management, the stakeholders mentioned both the decreasing availability of water and declining water quality. As a main cause and future challenge they highlighted the lack of integrated water management due, basically, to two factors. One is the lack of cooperation between sectors and other stakeholders (e.g. the public and decision makers) because of mistrust and opposing interests. The second factor is the lack of data management. On the one hand, data have never continuously been integrated into a data base; on the other hand decisions are rarely taken upon scientific data, leading to often ineffective or even wrong outcomes.

With regards to the assumed advantages of the WMT and the stakeholders' expectations of the tool, two main points were mentioned. First, stakeholders expect that the prediction and identification of their decisions' consequences will be improved. Second, this will help them to optimize their decisions. Since the tool is fed with scientific as well as socio-economic data, it is capable of analysing the impact of certain water allocation measures on water rights. While the tool is able to visualize how and where decisions may lead to changes in the catchment, it is also helpful in raising awareness for the different facets of water management among the stakeholders. Furthermore, it can assist in taking decisions about new technologies or the location of new industries. Eventually, the WMT may lead to a decrease of social conflicts about water resources in the region.

Regarding the question of who should be responsible for data collection and coordination some critical points have to be addressed. First, up to now data are collected within the single sectors, and there is no culture of sharing data. Second, in this atmosphere of mutual mistrust the stakeholders have to accept the actual data that are lastly fed into the WMT. Two proposals were discussed in this regard. The first proposal suggested that an independent committee consisting of experts of the respective regional organizations or sectors should be in charge of collecting the data. Being independent, the committee should at the same time be autonomous enough to be capable of collecting the required data, and it should have the actual mandate to claim due data from defaulting stakeholders. The second proposal suggested that a professional entity, i.e. the Isfahan Regional Water Board, should be responsible for data collection and coordination. The final decision on this question is still to be made.

However the collection and management of data does not only require a capable and acceptable organization. For providing valid data, standards for the measurement and for the data themselves have to be set. This may also require the introduction of new technologies and data collection techniques. Moreover, it was stated that questions of capacity building, adjusted legislation, feedback mechanisms and financing have to be further elaborated on. These points were also not decided on during the workshop.

The last question that was discussed in the working groups was about the responsible entity for WMT updating and its further development. New (social, environmental, political) trends and developments in the catchment have to be detected and translated into valuable data. The WMT has to be further developed accordingly. Here, three possible organizational solutions were discussed as well: transferring the tasks to a commission, an independent company or consultant, or to the Isfahan Regional Water Board. The final decision will also depend on the question, which organization is most likely to be trusted uniformly, and which is regarded as being most capable of balancing all interests.

The results of this interactive workshop were then presented in various rounds by different stakeholders. This led to a fruitful discussion within the region about the establishment of new necessary organisational units which are supposed to manage the IWRM process in the future (see also Sect. 23.4.2).

23.4.2 Establishment of WMT Commissions

The approach of the German-Iranian cooperation has been to accompany bargaining processes among stakeholders within the river basin which could eventually lead to the improvement of their coordination and cooperation. The joint development of new instruments like the WMT was a start, and vice versa the WMT is supposed to serve as an instrument to improve cooperation. The set-up of an adequate institutional and organizational framework that serves integrated water management needs to follow in due course (see also Sect. 23.4).

This will include the decision over, and appointment of, the responsible commission for data collection, adjustment and harmonization (Georgakakos 2007). Until now, not only between different agencies but even within agencies data has not been harmonized, so they cannot yet be used in the WMT. A second commission is needed that identifies and names water problems, applies the WMT, assesses the WMT output and translates it into a water management decision. In this commission, stakeholders of the different government levels, of the different sectors as well as of the civil society should be represented in order to achieve overall acceptance of the decisions taken. The involvement of representatives of the Ministry of Energy in such a commission is essential in the face of the current structure of the Iranian water sector. The participation of its representatives is particularly necessary in order to legitimize water management decisions within the ministry which require high investments. Moreover, the ministry representatives have the task of introducing necessary information from the neighbouring province into water management decisions. This is the only way that sustainable decisions can be taken for the entire catchment area. In the long run representatives of the neighbouring province will also become permanent members of the commission. Furthermore, representatives of the main actors responsible for water management in the region, like the regional Water Board, water and waste water companies, agriculture, environmental department, industry and municipality, have to become commission members. NGOs and environmentalists are supposed to speak for the needs of marginal groups and the environment.

The commission can, among other tasks, develop ideas for sustainable groundwater use in the catchment area. This could for example mean a change in the water use rights or modified land use (re-cultivation). The possible consequences of such decisions can be retraced by means of the WMT; the result can be discussed and finally be approved by the commission.

In periods of water shortages, e.g. because of droughts, the commission can also use the WMT to identify reasonable water use bans which can be assessed by means of their socio-economic consequences. To date, water use bans are only imposed on agriculture. This led to serious protests by farmers particularly in 2013 as they complained about inequality in the distribution of water.

23.4.3 Capacity Development

In general, the introduction of IWRM requires the development of respective capacities at the operational level as well as at decision making level. In the course of the project, both levels have been or will be addressed.

The WMT works with highly specialized models and can therefore only be used by experts. The Iranian Water Authority is the main user of the WMT. Therefore, experts will be trained on the usage of the WMT within the project. At the level of decision making, this could be addressed by a “German Iranian Competence Centre for Water and Wastewater Management (GICC)” where German and international experiences could be shared and where training in the field of IWRM could be merchandized and applied.

Project experiences have shown that the establishment of theoretical as well as practical knowledge transfer and exchange on the topic of IWRM between German and Iranian authorities, companies and scientists is of great importance (Mohajeri and Nuñez von Voigt 2011). At the GICC German experiences and knowledge about the implementation of sustainable water resources management can be exchanged and passed on. The GICC can also take up those standards which are lacking in the Iranian water sector. Next to its function as a training and technology transfer centre it can undertake the task of establishing German norms and standards as well as applying, adjusting and implementing German waste water regulations in Iran. In this way a permanent link between the German and Iranian water management sectors may be founded.

23.5 Conclusions and Outlook

The salt lake Gavkhuni, an internationally accepted marshland according to the Ramsar convention, and its valuable ecological habitat for migratory birds, has suffered the most as a result of the recent socio-ecological developments in the Zayandeh Rud catchment area. The intense use of groundwater in the Zayandeh Rud catchment area has led to a severe reduction of groundwater levels over the last 15 years. This change in natural conditions has led to a reversal of the hydraulic situation along the Zayandeh Rud River. Thus, according to the classification system of the Global Water Partnership it can be incorporated into the fourth level of water resources development which is called 'mining of aquifer reserves'. The two drought periods since 2000, which lasted 3 and 5 years, have reduced the availability of water in an unprecedented way. During the recent dry period (2008–2012) alone the amount of precipitation was 25 % below average. As a result, climate change has become an issue for water management decision makers but has not as yet led to actual operational developments.

Water management decisions are still based on supply oriented strategies. The balancing of the climactically induced decrease in water supply and increasing demand will mainly be addressed by transferring water resources from neighbouring regions. With the completion of two tunnels currently under construction, around 500 million m^3 of water per year will be redirected from the province Chaharmahal-va-Bakhtiary towards the Zayandeh Rud. This will result in unpredictable environmental and socio-economic consequences.

The fact that a master plan for the development of the individual regions as well as a political and legal framework are missing reduces hopes for sustainable urban planning and industrial development. There is evidence that the growing number of citizens who are connected to the drinking water supply system will lead to a rise in water demand by approximately 25 % to 450 million m^3 in 2025. Even though the impact of domestic water use on future water management is less important, saving potential has to be applied. Bringing down the current level of water use of 230 l/day and a reduction of network leakages of more than 25 % have to be promoted. Even more important are the extension of wastewater systems and an improvement of wastewater treatment in order to allow for a hygienic and ecological reuse of these water resources.

The stagnation of industrial development seems to be neither realistic nor economically judicious. The high number of well-educated experts, the strategic location of the province Isfahan in the centre of Iran and the available resources—except for water—make the region attractive for new industrial settlements. Estimates suggest that industrial water use in the catchment will increase by between 70 % (260 million m^3) and 140 % (370 million m^3) by 2025. Industrial development will depend heavily upon the political framework and the international standing of Iran. A successful change of the industrial development in the region is necessary: turning away from water intense industries like steel industry, to industries which do not depend so heavily on water, like the IT sector. Moreover, the implementation of eco-industry parks instead of unsustainable industrial settlements has to be promoted. Here, as well, the main focus will have to be on the lack of wastewater treatment and reuse.

Agriculture, as the main water user, will play the major role with regards to the restructuring of water resources distribution. Apart from Gavkhuni Lake and the groundwater resources, mainly the agricultural sector—in the eastern part of the catchment in particular—suffers from water shortages. It is assumed that on average up to 300 million m^3 or 20 % less water resources will be available for agricultural purposes. This is inevitably accompanied by a discarding of agricultural land. This decision, however, will create potential for socio-economic conflict. Next to the loss of income and an increase in unemployment, this could lead to the breakdown of regional ecology. An expansion of the desert towards the city of Isfahan will presumably become unavoidable. For this reason it will be important to plan and implement a slow and socio-ecologically compatible reform of the agricultural sector, while at the same time aiming at the greatest benefit for water resources. In this process the WMT will play an important role as a decision support tool.

The FEFLOW model shows a clear linear connection between exfiltration of the surface water and groundwater discharge at the river banks. It calculates that 20 % of the withdrawn water in the downstream catchment area are bank filtrates. This fact increases the importance of an optimized surface water management considerably. Due to the occurrence of longer dry periods where no water seeps into the ground, the inflow rate to the groundwater and thus the supporting property of the river on groundwater levels, will be further reduced. It is therefore to be expected that with the frequent occurrence of an empty riverbed the groundwater levels near the river will fall more in the future than they have been doing in the past.

In order to create a lasting IWRM process, the WMT is supposed to support decisions built on jointly developed and therefore a generally accepted data base. It is important that the WMT will be used in a routinized way and support the day-to-day work of responsible authorities developing political measures for IWRM.

Future steps will have to involve institutional and organizational changes at national and provincial level. Reforms concerning the enhanced intergovernmental interactions at national and provincial level will have to include changes within the water sector institutions, in order to create increased independency in decision-making at local levels, and law enforcement and monitoring. A next step would be the development of IWRM strategies for the national river basins and the establishment of respective organizations that are responsible for IWRM implementation in the long run. The first steps in this direction have already been taken and hopes have been raised for a permanently flowing Zayandeh Rud.

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