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IWRM
Zayandeh Rud

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Sector Overview and Case Study on Collective Resource Efficiency

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Preface

This report presents two main results of the German-Iranian research cooperation "IWRM Zayandeh Rud", concerning the Industry sector in the Zayande Rud catchment. The first part of this document presents and justifies data on industrial water consumption in the whole catchment area. The data have been composed by inter 3 GmbH in order to serve as a database for the Water Management Tool developed by DHI-WASY. Hence, an important goal of the report at hand is to deliver comprehensible overview on industrial water use and data for the water management tool. Additional information on the industrial sector in the catchment may be found in Raber and Mohajeri (2017). The potential benefits and constrains for implementation of a collective approach for more resource efficiency "the Eco Industrial Park Concept" is being presented in form of a case study in the Zayandeh Rud basin.

After a (1) short summary, the (2) structure of the database will be presented briefly, followed by a discussion of (3) large industrial units, (4) industrial settlements and zones as well as (5) industrial agriculture, being closed by (6) conclusions and (7) recommendations. In the last chapter (8) and the second segment of this report, the case study on the "Eco Industrial Parks" approach is beeing presented.

1. Summary

The use of water resources in the Zayandeh Rud catchment is characterized by water use of different stakeholders. Next to the agricultural and urban sector, industry is consuming a proportion of the surface- and ground water resources of the Zayandeh Rud catchment. This report focuses on the industrial water consumption.

The study is based on data received by close collaboration with (1) local institutions like: Regional Water Company, Water and Wastewater Company, Industrial Organization and Industrial Settlement Organization, as well as (2) Interviews with large Industrial Units and quantitative Questionnaires sent to the largest industrial water consumers and (3) literature review of the Reports on water consumption in the Zayandeh Rud catchment of Zayandab Consultancy Co. (2009) and Yekom Consultancy Co. (2013a and b).

Data presented in this report is selected and formatted according to available data and the specific requirements of the IWRM research project. The database is limited to the most relevant industries from an integrated water management perspective which comprises over 13.000 industrial units. Hence, the document has following characteristics in comparison to other works on industrial water use in the Zayandeh Rud catchment:

- Only the largest industrial water consumers with defined water extraction points are included in the report, in order to serve the Water Management Tool of the IWRM Zayandeh Rud research project as a database;
- Figures on water consumption of the largest industrial units are based on their current water consumption instead of the water extraction licenses which these units hold;
- Future increasing water demand of large single industrial units in the most cases is assumed to be managed by the application of modern technology and wastewater recycling, and not by increased water extraction from fresh water sources. Nevertheless, water extraction will increase in a few cases as discussed in two future scenarios in Chapter 3.1.3.
- Future water consumption of small industrial units is based on the information of the Industrial Organization that new industrial development will be restricted to the already existing industrial settlements. Consequently, the existing settlements can only be developed to maximum capacity. This approach does not take into account requests from investors posed to the Regional Water Company for new water licenses (approximately 500 M m^3/a) which are not approved yet.

The figures in this report cover the most relevant industrial water consumers, which are over 13.000 industrial units in the Zayandeh Rud catchment. We find that the total industrial water consumption in the catchment is approximately 200 M m^3/a (reference year: 2006) including 48 M m^3/a industrial agriculture water consumption (reference year 2012). Next to a large quantity of small industries, with only little share of the overall water consumption, few large water consumers, mainly from the metal, petrochemical and power generation sector, have a very high water consumption. Giving consideration to the diversity of Industrial Units in the catchment, we divided the industrial water consumers in the following four groups:

- The 30 largest single industrial units with a unit consumption larger than 500.000 m^3/a, which have a share of approximately 60% of the total industrial water consumption in the catchment;

- Over 10.000 small and medium sized industrial units are clustered in 29 large industrial settlements and zones. Each is expected to have a consumption larger than 500.000 m^3/a in the year 2025. These industries account for approximately 15% of the industrial water consumption in the basin.

- About 3.000 small scale industries within Isfahan municipal boundaries are supplied with approximately 10 M m^3/a by the Water and Wastewater Company with a proportion of approximately 5% of the industrial water consumption in the basin.

- Industrial agriculture with livestock and poultry farms, aquaculture and greenhouses account for about 25% of the industrial water consumption in the basin.

Large single industrial units and the industrial settlements and zones are presented separately since the respective data sources, analysis and management followed different concepts. The water consumption of small industries within Isfahan municipal boundaries are expected to be stable for the next years and are not presented in detail in this report. These small industries as well as industrial agriculture are supplied mainly from the drinking water network of the Water and Wastewater Company; hence there might be overlaps with the water balance of urban water use.

The report presents the selected industries with a set of interlinked data. Furthermore, the origin of the data and taken assumptions are discussed.

2. Structure of data base

For each analyzed unit, information is collected and merged together in a table in the appendix. The head line of the data table (Table 1) shows the type of collected data which are presented briefly in the following (from right to left). In the data table for industrial settlements, additionally the currently build and total surface of the industrial settlements is given (see chapter 4).

2.1. Specification on industrial unit or settlements/zone

The name for each industrial units and settlements/zones is given. To each industry unit, a number is linked in order to identify the industries on the maps in chapter 3 and 4.

2.2. Water Source and extraction points

Specifications on the locations of water extraction points for three possible water sources:

- Surface water (SW);
- Ground water (GW);
- Water supplied by the Water and Wastewater Company (WW).

The coordinates of the locations are given in the UTM (Universal Transverse Mercator) coordinate system and are all located in UTM Zone 39 N.

Next to the coordinates, the current, main water source is given in the column “Water Source” for each industry.

2.3. Water withdrawal in different years

The water extraction with a certain volume per year (m^3/a) is given for the different water sources (surface water, ground water, supplied water by Water and Wastewater Company) for three different years:

Table 1: Structure of data table in the appendix (Abbreviations: WW= Water and Waste Water Company; GW= Ground Water; SW= Surface Water).

Withdrawal (2025) [m^3/a]			Withdrawal (dry year) [m^3/a]			Withdrawal (normal & wet year) [m^3/a]			Water source and extraction point							Specifications	
									Wastewater Co. extraction point (UTM)		Location of the Wells/ Companies (UTM)		Surface water extraction point (UTM)				
WW	GW	SW	WW	GW	SW	WW	GW	SW	X coordinate	y coordinate	X coordinate	y coordinate	x coordinate	y coordinate	Water Source	Name	Number

- Normal & Wet year: current, climatically normal year with the reference year 2006;
- Dry Year: Typical dry years with little rainfall as for example 2010-2011;
- Prognosticated year in the future with an estimated normal & wet reference year in 2025. For large single industries two scenarios for future water consumption exist, which are introduced in chapter 3.1.3.

The quantities of water extraction from different sources could not all be based on measured data, since the coverage of installed water meters is not sufficient. Instead, a mix of methods as interviews, review of water licenses and calculation of extraction capacities as justified in the analogous passages in the text has been applied to collect the relevant data.

3. Large industrial units

In close collaboration with the Regional Water Company the 30 largest industries have been selected to be included in the database (see Figure 1). Each selected industry consumes currently a minimum of approximately 500.000 m^3/a. All selected large industries together consume approximately 114 M m^3/a freshwater.

The selected 30 industries with high water consumption are presented in the figure below. Four of these industries are named “other industries” and their location is not given. These virtual industries have been placed in collaboration with the Regional Water Company in order to represent not accounted for large water users in the catchment.

The Regional Water Company transferred data on name and address of all industries. In addition, the GPS coordinates for eight companies (Mobarakeh Steel Co., Esfahan Steel Co., Polyacryl Iran, Synthetic Fiber raw material, vegetable oil Industry Golbahar, Sepahan cement Co., Sarooj Cement Co. and Baresh Co.) have been communicated, are not displayed in this version of the report.

3.1. Data sources and assumptions

In the research project IWRM Zayandeh Rud, the main module “Water Management Tool” requests several detailed data on industrial

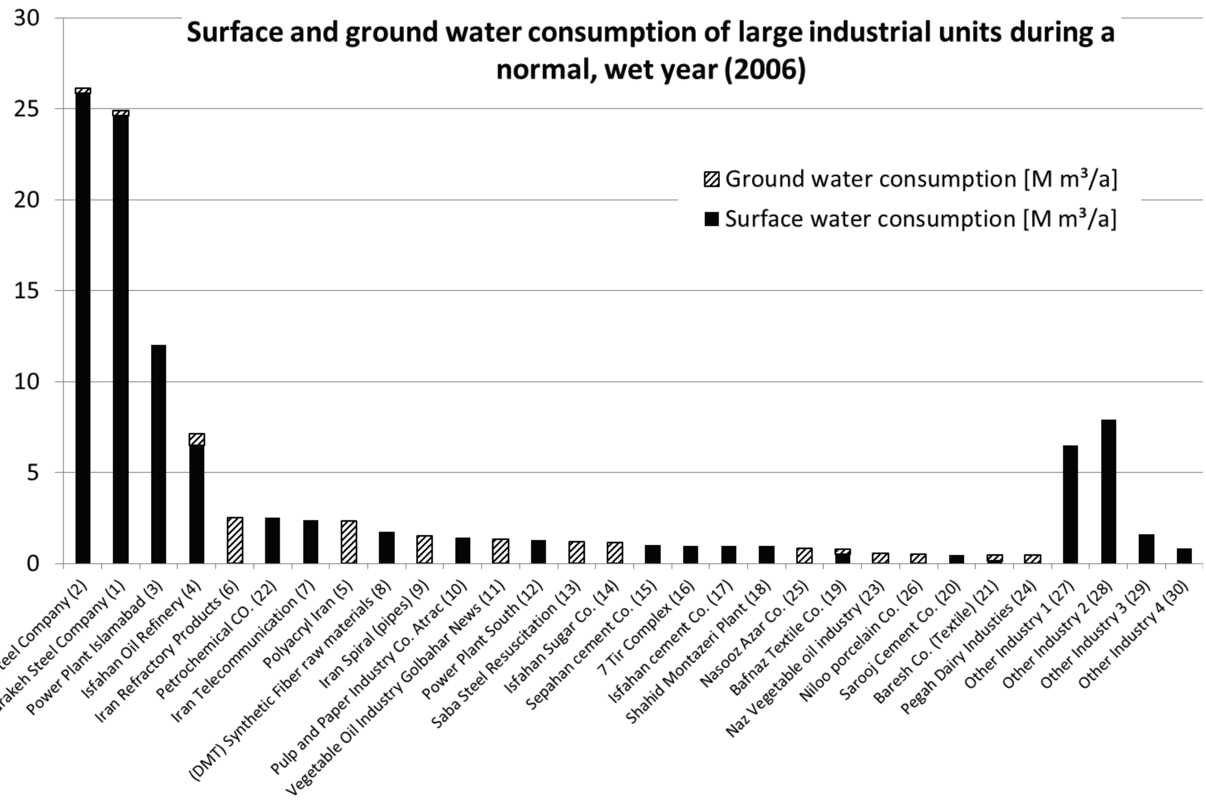

Figure 1: Water consumption patterns of selected large industrial units in the catchment area (reference Number in brackets)

water consumption to operationalize the model of the management tool. Next to exact locations for the withdrawal point from each water source, the tool requires a monthly water withdrawal rate for each industrial unit during wet and dry years for the past 10 years, as well as a prognosticated scenario for water extraction in the year 2025.

In the following, the data sources and assumptions taken to provide the requested data are presented. The assumptions are taken based on our knowledge of the situation in Zayandeh Rud catchment and should be verified by the Iranian institutions. The understanding of the water consumption patterns is based on provided data and communication with the Iranian Institutions as well as quantitative questionnaires and interviews with specific Industries. Quantitative questionnaires have been sent to the industrial units with the highest water consumption. Unfortunately, only 12 relevant industries out of 22 Industries replied, and the questionnaires were often incomplete. Consequently, the questionnaires only helped to gain a better understanding of water and wastewater management practices of the industrial units.

Information obtained by Interviews with selected Industries (Mobarakeh Steel Company, Esfahan Steel Company, Polyacryl Iran and Isfahan Sugar Co.) gave detailed information on water and wastewater management of these units.

3.1.1. Current water consumption

The current surface and ground water consumption of the large industries are established, based on the water licenses transmitted by the Regional Water Company, which are formatted in yearly water extraction.

During Interviews with the largest industrial water consumers, it has been found that three companies: Mobarakeh Steel Company, Esfahan Steel Company and Polyacryl Iran, use together currently approx. 24 M m^3/a less water than their licenses permits. Furthermore, the Regional Water Company communicated that the consumption of the Power Plant Islamabad is with 12 M m^3/a twice as high as their original water license.

Due to the limitations of received primary data, the following assumptions are taken based on our understanding of industrial water consumption in the catchment.

Requested monthly water withdrawal rates for the selected industries are not known. We assume that industry units have a constant water demand over the whole year (no seasonal variations) and that water use was constant for the past 10 years.

Drinking water supply for workers of industrial units, are already included in the calculations of the urban water sector, hence not considered in the industrial water balance and not further discussed in this report. Water supplied to small industries within the boundaries of Isfahan municipality are assumed to be constant and only represented in the overall conclusions (Chapter 6).

During dry years, the Water and Wastewater Company provides water only temporary to the four mentioned industrial units in the time where they don’t have access to surface water. All other industrial units use the same sources and amounts of water as they do in wet years. The overall water consumption of all industries is constant during wet and dry years.

Based on our questionnaires and interviews we learned that industrial waste water volumes and disposal are very complex and unexplored topics. Due to collected information we assume that no significant amount of wastewater is being produced in large industrial units and emitted to the water circle. All water is used in the production process or used in green space irrigation within the industrial unit. Consequently, we assume no wastewater is being recycled in the water balance.

3.1.2. Current water sources

Possible sources of water are:

- Surface water;
  - Extracted directly from the Zayandeh Rud river;
  - Extracted from one of the irrigation canal networks;
  - Extracted from shallow wells close to the river, marked as bank filtration;
- Groundwater from industrial wells;
- Water supplied by the Water and Wastewater Company.

The quantitative distribution of surface water and ground water extraction are specified by the water licenses communicated by the Regional Water Company.

By collaboration with the Regional Water Company and Water and Wastewater Company, it was found that during dry years, five large industries (Power Plant Islamabad, Isfahan Oil Refinery, Shahid Montazeri Plant, Petrochemcial Co. and Pegah Dairy Industries) compensate a temporal lack of surface water access by water supplies from the Water and Wastewater Company.

Also the coordinates for the water extraction point from the Zayandeh Rud River have been transmitted for the four largest companies: Mobarakeh Steel Co., Esfahan Steel Co., Power Plant Islamabad and Isfahan Oil Refinery.

To specify the locations of different sources of water extractions, the following assumption have been taken.

Four locations for surface water extraction have been communicated by the Regional Water Company. To identify the points of water extraction for the other industrial units, a Geographical Information System (GIS) with shape files of the location of river and irrigation systems in combination with the identified locations of the industries was used. The following approach and assumptions are taken to define the locations of water extraction points:

- Surface water extraction from the river and canals are as close as possible to the industrial unit;
- Ground water extraction is done from wells located in the area of the industrial unit itself;
- The locations of wells used for bank filtration are next to the River and as close as possible to the industrial unit;
- The extraction point belong to the Water and Wastewater Company was observed and detected with GPS device during our experts field visits to the region;
- The location of two units supplied by the Kashan Pipe are located at the water extraction point (headwork) of the Kashan Pipe (at the dam) and accounted for as surface water.

3.1.3. Future water consumption in 2025

Future industrial water consumption in the year 2025 is strongly dependent of the global and regional socio-economic and political development. Furthermore, the disposability and development of regional water resources and management of the relevant stakeholder are a key factor for possibilities to settle new, water intense industries in future.

As a result of the scarce water resources in the catchment, new industrial development is currently limited. New industrial developments are only exceptionally permitted though a complex administrative process between Industrial Organization and Regional Water Company, which has to be approved by a regional committee of authorities (Committee # 24).

During the research of the IWRM Project and constant communication and exchange with the Iranian partners, two different scenarios for future water consumption of large single units have been established. The two scenarios share a large part of the set of assumption but comprise some differences which result in 107 M m^3/a variance in future water consumption.

The first scenario represents the view of inter 3 and the IWRM research project. The outlook is based on a moderate expansion of new large industries, due to limited freshwater resources and moderate economic growth in the region.

The second scenario reflects the perspective of the Regional Water Company, based on regional and national development plans. The outlook assumes a stronger increase of water consumption of some existing industries as well as settlement of additional new large industries than the German colleagues in the first scenario.

In the following, both scenarios and assumptions are presented. The differentiation of the two scenarios can also be found in the overall conclusion in chapter 6. In the conclusions of this chapter, only Scenario 1 is discussed.

Scenario 1 (inter 3)

For the water extraction forecast for 2025, the research team assumes that in general no additional large industries will settle in the basin and withdraw water from the current water balance of the Zayandeh Rud catchment. Currently existing extraction licenses will not be increased until 2025. Disregarding the general assumption, the following four exceptions are taken into consideration:

- In interviews with the industrial organization it was supposed that four new large steel and petrochemical industries are to be developed in the eastern part of the catchment. These Industries are expected to consume together around 30 M m^3/a in 2025, but their location and sources of water extraction are unknown yet;

- Due to current limited production capacity, the Isfahan Oil Refinery will be expanded significantly. This will more than double the freshwater extraction with an increase of approx. 17 M m^3/a;

- Due to population growth and increased industrial activities all power plants will increase their water consumption with at least 10% by 2025. This applies also for the already increased consumption of the Power Plant Islamabad. The Shahid Montazeri Plant is directly connected to the Isfahan Oil Refinery and will increase its capacity and water consumption by almost 60%, equivalent to the expansion of the oil refinery. All development factors will increase the water consumption of power plants by 2 M m^3/a in total;

- The three in chapter 3.1.1 mentioned companies (Mobarakeh Steel Company, Esfahan Steel Company and Polyacryl Iran) that currently use less water than their license permits them; will reach extraction up to full license capacity in 2025.

Scenario (Regional Water Company)

For the water extraction forecast for 2025, the Regional Water Company also expects that most of the existing extraction licenses will not be expanded until 2025. Nevertheless, an increase of water extraction and new development for the following cases is predicted:

- 12 new large Industrial units will be developed within the Zayandeh Rud Catchment with a total annual water consumption of 98 M m^3/a.
- The four largest single industries (Mobarakeh Steel Company, Esfahan Steel Company, Power Plant Islamabad, Isfahan Oil Refinery) will consume 2025 in total approximately 39 M m^3/a water more than their current license permits.
- Due to current limited production capacity, the Isfahan Oil Refinery will be expanded significantly. This will more than double the freshwater extraction with an increase of approx. 20 M m^3, which is 3 M m^3/a more than expected in Scenario 1;
- Due to population growth and its direct connection to the Isfahan Oil Refinery and the Said Montazeri Plant, the power plants Islamabad and Sahid Montazeri Plant are expected to be expanded by 2025 and increase their combined water consumption by 11 M m^3/a.

Figure 2 shows a map section of the Zayandeh Rud Catchment. The current water consumption of large industrial units is split in four classes, from < 1 M m^3/a to > 10 M m^3/a, which are represented in different sized and colored circles on the map (see legend on the left side). Urban Settlements, the River and Irrigation Canals as well as the Zoning of the Catchment are also displayed on the map.

The map displays the locations of the large industrial water consumers (grey circles) with their reference number (red number) in the industry list in Figure 1 and the appendix. The map shows that the major water extraction is located upstream of Isfahan City along the Zayandeh Rud River or irrigation systems which have their headworks there. It is to be noted that the Borkahr irrigation system, which is located north-west of Isfahan city, is missing in the map.

Analyzing Table 3 one can see that currently the dominant industrial sectors of the large individual industries are steel, petrochemical and chemical industries as well as power plants. Regarding the consumption of the large water consumers in Table 2 one can see that the four largest water consumers (Mobarakeh and Esfahan Steel Company, Power Plant Islamabad and Isfahan Oil Refinery) consume 70 M m^3/a, which is over 60% of the water consumption of large industries. Table 3 also shows that water extraction for the steel and particularly the petrochemical sector in Scenario 1 is expected to grow till 2025. The total water consumption is expected to rise at 65% till 2025 to 187 M m^3/a.

3.2. Conclusions

Currently the total water withdrawal of the selected large industrial units is 114 M m^3/a.

The map in Figure 2 shows which Industrial units are expected to grow till 2025 according to Scenario 1. To the map that is shown and explained in Figure 1, a green figure is added.

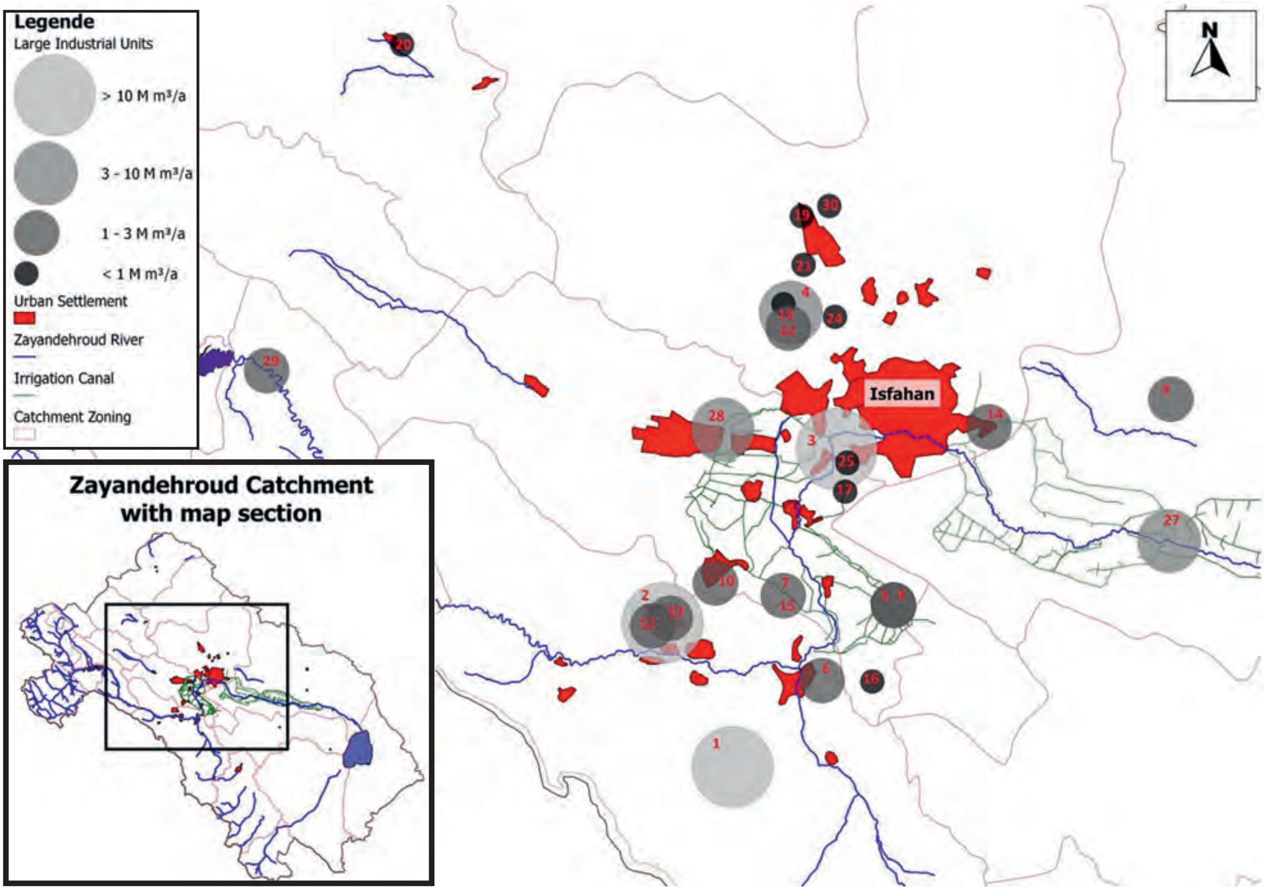

Figure 2: Location and classes of current water consumption (grey circles) of large industrial water consumers (red reference number to industry list) in the catchment

Table 3: Current and future water consumption of industrial sectors according to Scenarios

Sector of water consumption		Steel	Petro-chemical and Chemical	Power	Building Material
Current consumption (2006)	M m^3/a	54	17	14	3
	% of total water extraction (114 M m^3/a)	47%	15%	12%	3%
Future consumption (2025) Szenario 1	M m^3/a	89	53	16	3
	% of total water extraction (187 M m^3/a)	48%	28%	9%	2%
Future consumption (2025) Szenario 2	M m^3/a	151	89	25	3
	% of total water extraction (294 M m^3/a)	51%	30%	9%	1%

This green number is the expected percental growth of water consumption till 2025 of the industrial unit (grey circle) where the number is written on top. The map shows that few large industries that extract water upstream of Isfahan city are expected to grow moderately. In scenario 2 mainly the same industrial units will grow, but to a higher degree. The complete data table including expected growth till 2025 for large individual industry of both Scenarios can be found in the Appendix.

Regarding the sources of water, currently (2006) only nine large industrial units rely mainly on ground water and 21 companies rely mainly on surface water. The total groundwater consumption of large industries is only 14 M m^3/a, which is around 12% of the total 114 M m^3/a water extraction. The current surface water consumption of large industries is 100 M m^3/a (88% of total consumption). Regarding Figure 4 one can see that the largest industries withdraw water directly from the Zayandeh Rud River. It should be noted that the Borkhar Canal is directly fed from the "Nekroabad Canal left" and has only one extraction point from the Zayandeh Rud River.

In Scenario 1, the total water withdrawal of large industries is expected to grow up to 187 M m^3/a by 2025. The four new industrial developments in the east part of the catchment (see chapter: 3.1.3) are expected to have a total consumption of about 30 M m^3/a, whereas the source is unknown yet and not included in the following table. For the already established industries, the water sources are expected to develop towards higher surface water use. In the forecasted water withdrawal scenario in 2025, ground water is expected to stagnate at approximately 14 M m^3/a and water supplied by the Water and Wastewater company will rise up to 10 M m^3/a. The surface water extraction is expected to grow up to 133 M m^3/a (without the new developments) mainly due to increased extraction by large industrial units directly from the river (see Figure 4).

Analogue, the expected surface water extraction of large industry in 2025 according to Scenario 2 is presented in Figure 1.4. The planned 12 additional industries with approx. 98 M m^3, water consumption are not included in the figures due to unknown water source and location. Besides the 172 M m^3/a (without the new developments) expected surface water extraction, the amount of groundwater and water supply by the Water and Wastewater company is equal to Scenario 1.

Presented figures indicate that the high water consumption of large industries, particularly of the steel and petrochemical segment in the central part of the basin, are expected to grow even further in the near future.

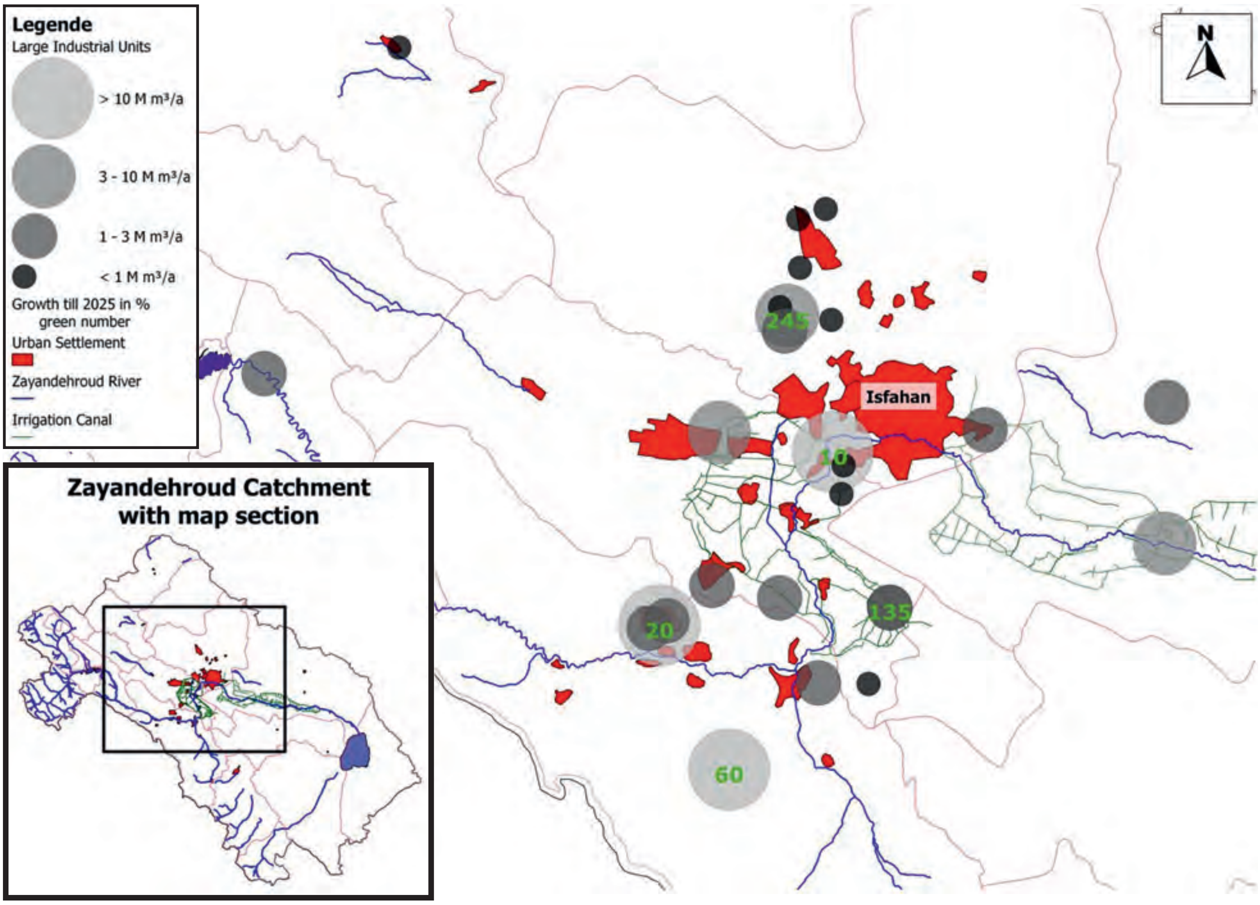

Figure 3: Expected growth in water consumption of units (green number as %) on the map of location and current water consumption of large industrial units (Scenario 1)

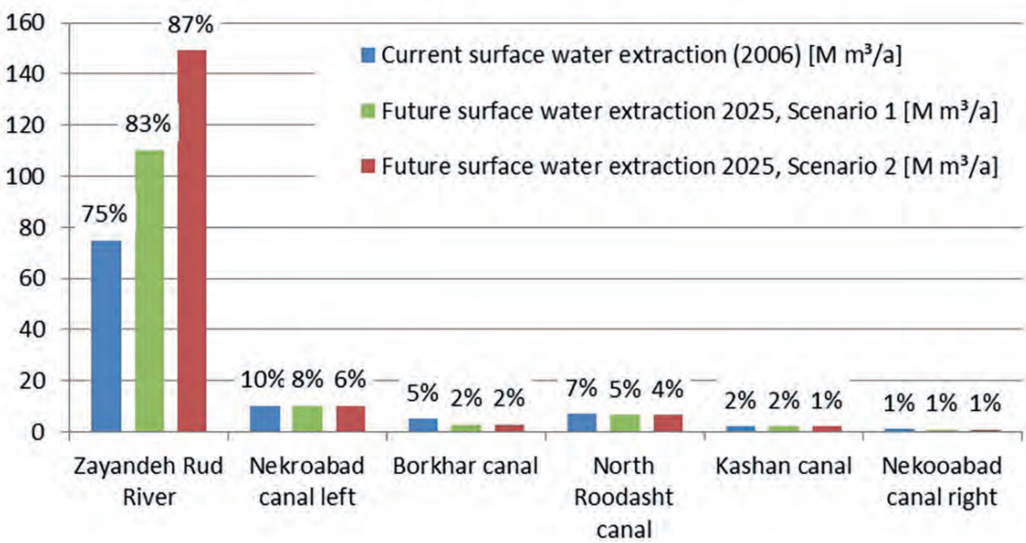

Figure 4: Sources of surface water extration in 2006 and in 2025 according to scenarios 1 and 2, including percentage of total surface water extraction of lage industries

4. Industrial settlements and zones

There are industrial settlements and industrial zones in the catchment. In the past, there have only been industrial zones, which are industrial units, clustered in one area. Industrial settlements also have several industrial units in the same area, but also have a common administration in terms of a management board and are handled as one legal entity in terms of distribution of water licenses etc. In future, all industrial development will be placed in industrial settlements; the only exceptions are very large or heavy polluting units. For simplification, in the subsequent document, the term industrial settlement will be used for settlements as well as for zones.

In close collaboration with the Regional Water Company, Industrial Organization and Industrial Settlements Organization, the 29 largest and most important industrial settlements with at least 10.000 single units have been selected. The entities either have already high water consumption or are expected to grow intensively until 2025, reaching a minimum of approximately 500.000 m^3/a, water consumption. Currently the 29 settlements consume together approximately 28 M m^3/a.

The following zones and settlements were selected: Khomeinishahr, Mahmoodabad, Dolatabad, Morchehkhort, Faridan,

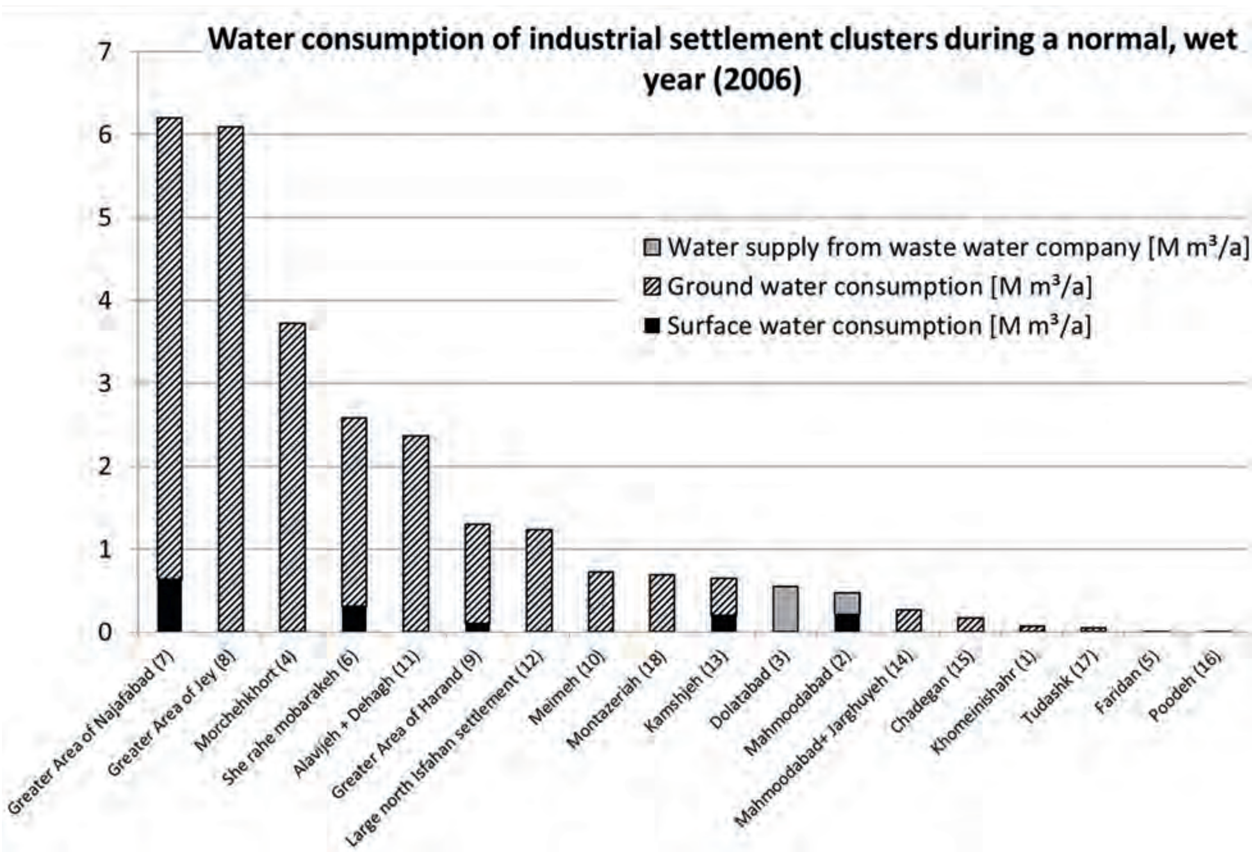

Figure 5: Selected industrial settlement clusters with water consumption (2006)

Se Rahe Mobarakeh, Tiran, Karvan, Esfidvajan, Oshtorjan, Najafabad1, Najafabad2, Jey, Segzi, Kohpayeh, Harand, Varzaneh, Ezhieh, Meimeh, Alavijeh, Dehagh, Large north Isfahan settlement, Komshecheh, Mohamadabad, Jarghuyeh, Chadegan, Poodeh, Tudashk and Montazeriah.

The locations of the industrial settlements have been communicated by the Regional Water Company.

Following the suggestion of the Regional Water Company we created the following five industrial settlements by clustering neighboring settlements: Great Area of Najafabad (Tiran + Karvan + Esfidvajan + Oshtorjan+ Najafabad1 + Najafabad2), Great Area of Jey (Jey + Segzi), Great area of Harand (Kohpayeh + Harand + Varzaneh + Ezhieh), Alavijeh + Dehagh, and Mahmoodabad+ Jarghuyeh settlements.

This approach results in totally 18 settlements, which are displayed in Figure 5.

4.1. Data sources and assumptions

4.1.1. Current water consumption

The water demand of each settlement is calculated according to a calculation formula (Formula 1) used and communicated by the Industrial Settlement Organization. The formula is based on the built/developed area of the industrial settlement in hectares. This way an estimated water demand of the settlement with the current developed area is calculated.

The developed surface times 0,3 equals the water demand of the settlement in L/s.

Formula 1

*current water demand of settlement [L/s]=build surface of settlement [ha]*0,3*

The above mentioned calculation is applied for each settlement without considering the branches and other criteria for water consumption of the industries in the settlement.

No quantitative data on wastewater production or management could be included in the database. However, it has been communicated by the Industrial Settlement Organization that five industrial settlements: Mahmoodabad, Se Rahe Mobarakeh, Oshtorjan, Najafabad1 and Alavijeh, have a wastewater treatment plant installed and constructions for a treatment plant are ongoing in Jey industrial settlement. Until 2025, 17 industrial settlements are planned to be equipped with a wastewater treatment plant. Runoff from wastewater treatment plants are used for green space irrigation and in Morchehkhort settlement and 50% of the treated wastewater is reused in the production process.

The ground water extraction of each settlement is assumed and calculated according to Formula 2 by adding the supplied surface water and urban water and subtracting it from the calculated water demand of the settlement.

Formula 2

Ground water extraction =water demand (Formula 1)-(supplied surfacewater+ urban water)

It is assumed that no wastewater flows back to the water cycle.

During dry years the Water and Wastewater Company provides water to more industrial settlements than in normal wet years. The overall water consumption of all industrial settlements is constant in dry and wet years.

The Mahmoodabad + Jarghuyeh settlement is geographically a few hundred meters out of the catchment, but since it's supplied by the Water and Wastewater Company, it is included in the water balance of the Zayandeh Rud catchment.

4.1.2. Current water sources

The surface water consumption of industrial settlements is based on surface water licenses received from the Regional Water Company.

Figures for water being supplied by urban water[1] have been communicated by the Water and Wastewater Company.

The locations of surface water extraction points for Se Rahe Mobarakeh, Great Area of Najafabad and Komshecheh where communicated by the Regional Water Company.

Analogue to large industrial units, the locations of water extraction are chosen using the following assumptions:

- Surface water extraction from the river and canals are as close as possible to the industrial settlements;
- Ground water extraction is done from wells located on the area of the industrial settlements;
- The extraction point of the Water and Wastewater Company is located at the Chamaseman Dam for drinking water extraction;
- The location of the Alavijeh + Dehagh settlement supplied by the Kashan Canal are located at the water extraction point of the Kashan line (at the dam) and accounted for as surface water. Its coordinates are at the headwork of the canal at the Zayandeh Rud River.

1. The water is usually treated and diverted from the urban drinking water supply network and as such called urban water.

4.1.3. Future water consumption in 2025

Future water consumption in 2025 was forecasted by taking the following approach.

For each settlement exists a total settlement area and a current build surface of the settlement. With the total settlement area and the following formula, the future water demand of settlements can be calculated.

Formula 3

*future water demand of settlement [L/s]=total settlement area [ha]*0,3*

Until 2025, all industrial settlements will develop their full surface and reach maximum water extraction.

Analogue to large industrial units in Scenario 1, development of new industrial settlements is currently not happening since the administration is limiting new development due to water scarcity in the catchment.

4.2. Conclusions

Figure 6 shows a map section of the Zayandeh Rud Catchment. The current water consumption of industrial settlements is split in four classes, from 20.000 – 100.000 m^3/a to 1,5 - 7 M m^3/a, which are represented in different sized and colored circles on the map (see legend on the left side). Urban Settlements, the River and Irrigation Canals as well as the Zoning of the Catchment are also displayed on the map.

The map displays the locations of the industrial settlements with their water consumption (grey circles) and their reference number (red number) in the industry list in Figure 5 and the appendix. The map shows that the settlements are distributed widely over the catchment and are not as oriented along the river as large industrial units. Compared to the large industrial units shown in Figure 3, the total consumption of each displayed industrial settlement (grey circle) is smaller than from large industrial units.

Currently the water consumption of industrial settlements is 27 M m^3/a, of which about 92% (25 M m^3/a) comes from groundwater. Till 2025 all industrial settlements are expected to be fully developed which will more than double the total water consumption up to 62 M m^3/a.

The map in Figure 7 shows which industrial settlements are expected to grow till 2025. A green figure is added to the map that is shown and explained in Figure 6. This green number is the expected percent al growth of water consumption till 2025 of the industrial settlement (grey circle) where the number is written on top. The map shows that particularly small settlements distributed widely in the catchment are expected to grow excessively till 2025. The complete data table for industrial settlements and its expected growth can be found in the Appendix.

In 2025 groundwater is expected to account for 83% (51 M m^3/a) of the total water consumption of industrial settlements.

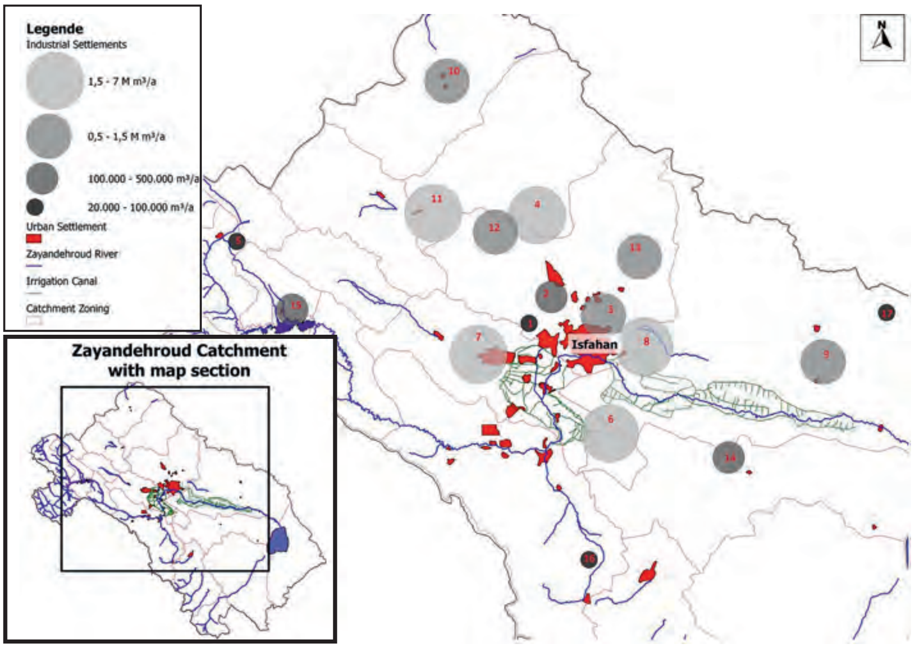

Figure 6: Location and classes of current water consumption (grey circles) of industrial settlements (with red reference number to settlement list) in the catchment.

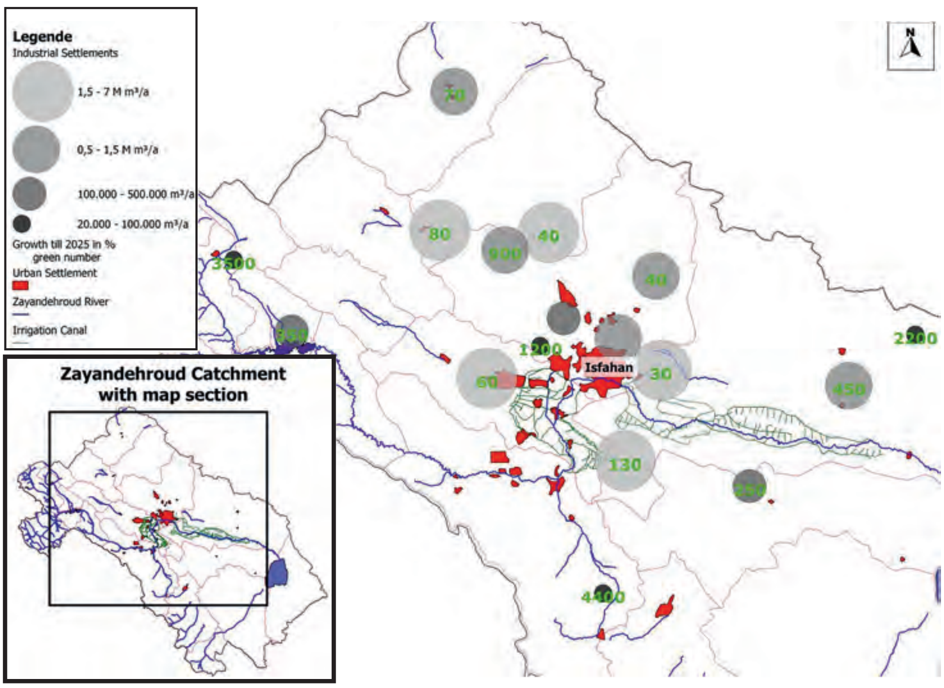

Figure 7: Expected growth in water consumption of industrial settlements (green number as %) on the map of location and current water consumption of large industrial units.

5. Industrial agriculture

Large agricultural production sites have been identified by Jihad Agriculture Organization and decided by the Regional Water Company to be included in this report due to their industrial water consumption patterns. Specifically, poultry farms, livestock farms (Cattle, calves, sheep, goats, camels), greenhouses (vegetables, nursery of flowers & ornament plants) as well as aquaculture production sites (cold and thermal water fish) are defined as industrial agriculture and presented in the following Tabel 7.

In contrast to the previously presented data, no specific units or exact locations are presented due to missing data. Nevertheless, water consumption of the reference year 2012 is allocated to the counties in the Zayandeh Rud Catchment.

Table 7: Water consumption (reference year 2012) of industrial agriculture by county (source: Jihad Agricultural Organization).

Aquaculture	Greenhouses	Livestock	Poultry	Secification	
Total water comsumption (m3/a)	Total water comsumption (m3/a)	Total water comsumption (m3/a)	Total water comsumption (m3/a)	County	
7760000	2300000	2920000	1040000	Isfahan	1
350000	190000	930000	210000	Borkhar	2
320000	560000	580000	430000	Tiran & Karvan	3
370000	10000	560000	50000	Chadegan	4
60000	1260000	640000	130000	Khomeynishahr	5
1100000	600000	760000	660000	Shahinshahr & Meymeh	6
0	590000	780000	470000	Shahreza	7
150000	20000	480000	110000	Faridan	8
3820000	30000	120000	20000	Freydoonshahr	9
370000	6390000	1080000	210000	Falavarjan	10
390000	30000	210000	120000	Lenjan	11
980000	2420000	600000	110000	Mobarakeh	12
1060000	380000	1160000	740000	Najafabad	13
0	1330000	0	0	Samiron (dehaghan)	14
16730000	**16110000**	**10820000**	**4300000**	**total**	

5.1. Data sources and assumptions

Displayed data origin from the Jihad Agriculture Organization and have been transmitted by the Regional Water Company. The received data has not been crosschecked or modified by our team.

The presented data are not included in the report of the agricultural sector of the IWRM research project, but are included in this report for the sake of completeness.

5.1.1. Current water consumption

According to the Regional Water Company, consumption data are based on existing water licenses and county based statistics. No information on the amount of agricultural units or wastewater production has been delivered. Nevertheless, it is assumed that the single units consume less than 500.000 m^3/a, and are by that of minor interest for the water management tool.

5.1.2. Current water sources

No data regarding water sources or geographic locations of extraction points have been transmitted. By communication with the Agricultural Organization, all industrial agriculture units, besides of Greenhouses, are supplied with water from the Water and Wastewater Company. Greenhouses cover their demand most likely by ground water extraction.

5.1.3. Future water consumption in 2025

For the water extraction forecast for 2025, the Regional Water Company communicated data on expected percental growth of the different types of industrial agriculture. The predicted consumption is presented in the conclusions.

5.2. Conclusions

Currently (2012), the overall water consumption of different sectors of industrial agriculture is 48 M m^3/a. According to the Regional Water Company, the water consumption will raise till 2025 with 55% up to 87 M m^3/a (Table 8).

The current and expected future water consumption of the industrial agriculture is significant. Particular aquaculture and greenhouses have very high consumption patterns and should be located and analyzed in detail.

6. Overall conclusions

Table 8: Current and future water consumption of industrial agriculture.

	Aquaculture	Greenhouses	Livestock	Poultry
Current water consumption (2012) in M m^3/a	16,7	16,1	10,8	4,3
Future water consumption (2025) in M m^3/a	30,0	30,4	19,3	7,7

The analyzed more than 13.000 industrial units consume currently (reference 2006) a total of approximately 200 M m^3/a, with an expected increase of consumption until 2025 of over 70% up to 347 M m^3/a in the future Scenario 1. In future Scenario 2, the industrial water consumption raises due to excessive growth of large single industries with 130% up to 454 M m^3/a. Current industrial water consumption origins to around 50% from surface water, 30% from groundwater and 20% from urban water supplied by the Water and Wastewater Company. In 2025 this proportion of water sources is going to stay similar. Current Industrial water consumption (reference year 2006) of approximately 200 M m^3/a in the Zayandeh Rud catchment is with 114 M m^3/a to 60% done by the 30 largest industrial water consumers. The four largest water consumers (Mobarakeh and Esfahan Steel Company, Power Plant Islamabad and Isfahan Oil Refinery) alone consume with 70 M m^3/a around 35% of the total industrial water used in the basin. Steel industry is with few large production entities the dominant water consumer in the catchment and sustains probably a large number of industrial units as sub-contractors or subsequent processers. Steel and Petrochemical Industries are most likely going to expand their dominance in water consumption in future (compare Table 3 and Appendix). The total share of single largest industrial water users on the total industrial water consumption is with 50% in Scenario 1 and 60% in Scenario 2 expected not to change significantly in 2025 (Table 9). The large Industries also withdraw water mainly directly from the river (Figure 4).

The approximately 10.000 small industrial units within settlements do with 14% not have a high share of the current overall water consumption. Also in future (2025) small industries are expected to increase their share only up to 18%. However, small industries share of groundwater extraction with current 45% and future around 55% can be considered as significant. Although the share of small industries extraction increase in future is not going to be high, the qualitative impact of their wastewater discharge on water resources could be considerable, especially noting the fact that most of the industrial settlements which embody the small industries, lack facilities for wastewater treatment.

The small industrial units within Isfahan Municipality are expected to have a stable water consumption supplied by the Water and Wastewater Company.

Regarding industrial agriculture, it is important to gain a deeper understanding of their water use and wastewater production, since a current and future share of 25% of the total industrial water withdrawal is significant.

Table 9: Summary of industrial water consumption in the Zayandeh Rud Catchment.

Summary of Industrial water users in the Basin	Withdrawal (2025)			Withdrawal (dry year)			Withdrawal (normal & wet year)		
	WW (m^3/a)	GW (m^3/a)	SW (m^3/a)	WW (m^3/a)	GW (m^3/a)	SW (m^3/a)	WW (m^3/a)	GW (m^3/a)	SW (m^3/a)
Single Industrial Units (Scenario 1)	10530000	13855000	163000000	6140000	13960000	93980000	0	14090000	99980000
	187000000			**114000000**			**114000000**		
Single Industrial Units (Scenario 2)	10530000	13860000	269930000						
	294000000								
Industrial Settlements (Scenario 1+2)	9100000	51650000	1240000	5400000	21690000	0	800000	24840000	1450000
	62000000			**27000000**			**27000000**		
Small Units in Isfahan municipality (Scenario 1+2)	10000000	0	0	10000000	0	0	10000000	0	0
	10000000			**10000000**			**10000000**		
Industrial Agriculture (Scenario 1+2)	56960000	30390000	0	31820000	16120000	0	31820000	16120000	0
	870000000			**48000000**			**48000000**		
Summed up consumption (Scenario 1)	86590000	95895000	164240000	53360000	51770000	93980000	42620000	55050000	101430000
	3470000000			**199000000**			**199000000**		
Summed up consumption (Scenario 2)	86590000	95900000	271170000						
	454000000								

7. Recommendations

Recommendations regarding industrial water consumption from the perspective of the IWRM Zayandeh Rud research project comprise the following two pillars:

Improved Monitoring

- The data recordings of industrial water users should be improved in order to gain a deeper understanding and more control of industrial freshwater consumption. The basin wide coverage with accurate water meters for ground and surface water extraction including a monitoring program would improve the database. The current database on industrial wells should be updated.

- Long term recordings of monthly water consumption and use of different water sources, should give an understanding on seasonal consumption dynamics and exploitation of different water sources. Future distribution conflicts in dry periods could be foreseen and appropriate distribution management strategies could be developed.

- The wastewater production and quality of industrial units needs to be monitored and recorded to enable us to include eventual wastewater backflow in the water cycle, wastewater reuse and water quality issues in management approaches.

Improved Collaboration

- A shared database and information platform should be installed among industry and water authorities. A common knowledge base would enable both sectors to foresee potential conflicts and improve coordinated planning.

- Also the collaboration among the industrial with the agriculture and urban water sector should be improved. Installing new mechanisms for collaboration could increase the overall water efficiency by enabling the trade and cross-sectoral use of wastewater for production purposes.

- An improved collaboration and coordination amongst small industrial units within industrial settlements could improve water and energy efficiency by trading and reusing wastewater and heat flows among units as seen in so called EcoIndustrial Parks (EIP). See the next chapter for the application of the concept.

Since the Zayandeh Rud Catchment is a closed basin, in general, no more water intense industry should be settled in the Catchment. The focus should rather lie on modern water efficient industry with high economic return and low water consumption.

8. Case study application of the Eco-Industrial Parks (EIP) Concept

Approximately 10.000 small industrial units in 29 settlements consume roughly half of the groundwater extracted by the industrial sector. Against this background, in this chapter an approach is being tested and presented with the aim to reduce the overall water consumption of industrial settlements. In the case study, the resource saving potential and possible drivers and constrains for application of an Eco-Industrial Parks (EIP) concept are analysed. EIP is an approach to increase resource efficiency by symbiotic sharing and reusing production means amongst industrial units. The focus was set on inter-industrial water reuse, targeting substitution of fresh water consumption and reduction of wastewater disposal. The presented approach is delimited from methodologies towards increasing water efficiency within one single industrial unit as well as approaches of water reuse amongst different sectors, e.g. industry, urban users and agriculture.

The Morche Khort industrial settlement in the north of Isfahan is one of the biggest in the catchment and was chosen as site for the case study. In Morche Khort, approximately 500 companies are contracted, out of which around 300 are already working in the food, metal, mineral, textile, plastics, paper and chemical sector (for impressions see Figure 8). The settlement stretches over 582 hectares, harbouring about 17,000 employees. The annual water consumption adds up close to 4 M m^3/a. Water supply in the settlement is mainly performed by individual wells tapping a shallow aquifer or to a minor extend, water supply from a central deep well. The deeper groundwater aquifer has, in contrast to the upper aquifer, a good water quality (particularly in regard to salinity). Industry representatives indicate that due to overexploitation groundwater level of the upper aquifer has declined by 20 m over the past five years, and the quality has deteriorated (von Koerber, 2016). The industrial wastewater is mainly used for green space irrigation, conveyed to the central wastewater treatment plant of the settlement or disposed by private service providers. The Industrial Settlement Organization is responsible for central water supply as well as for the central industrial wastewater treatment plant.

8.1. Introduction to the Eco Industrial Parks Concept

The Eco Industrial Parks (EIP) Concept utilizes the concept of industrial symbioses and origin from the scientific field of Industrial Ecology. It exploits the interactions between industry, local business and the environment to improve resource efficiency. The aim is to maximize the sharing and multiple use of production means like water, energy/heat and raw materials to reduce the amount of resources consumed and waste generated. EIP enables companies to develop multilateral solutions of industrial symbiosis for optimization of material and energy flows, thereby reducing the overall environmental footprint left by economic activity in a region (Hein et al. 2015; Chertow & Park, 2016). Chertow (2007) defines the approach as following: "Engaging traditionally separate industries in a collective approach to competitive advantage including physical exchange of materials, energy, water, and by-products. The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity ".

A prominent example can be found is the municipality of Kalundborg in Denmark (Hewes & Lyons, 2008; Massard et al. 2014), where the foundation stone for the first so-called Eco-Industrial Park was laid in the 1970s (Lambert & Boons, 2002). Typical and possible features of EIPs and industrial symbioses are (Boons et al., 2011; von Hauff, 2012):

- Sharing of residues: Residues/wastewater from company 1 is used as raw material/resource/process water in company 2;
- Sharing of emissions: Heat exchange between companies;
- Infrastructure sharing: Industry sites have a common water treatment, emergency power supply, rail connection, etc.;
- Sharing networks: Networks are shared through the formation of distribution networks, procurement communities, etc.

Reasons for industrial cooperative action are based in the principles of circular economy, creating win-win situations by increased resource efficiency. Drivers may be economic (monetary) advantages, improved environmental sustainability and public image, reducing dependencies of external resources and strengthening corporate cohesion (von Hauff, 2012).

Figure 8: Impressions from Morche Khort settlement (von Koerber & Raber, Site Visit, 31.7.2016).

8.2. Application of the Eco Industrial Parks Concept in Morche Khort

In this chapter, a systematic approach for testing and evaluating resource saving potentials for freshwater and wastewater along the EIP concept in the industrial settlement of Morche Khort is being presented.

In the first step, industries to be included in the case study have been selected and surveyed. Then industries have been characterized and grouped according to their water consumption and wastewater generation patterns, followed by a development and analysis of possible EIP scenarios.

8.2.1. Selection of industries and data collection

At the beginning of the study in 2015, availability of data with the industry and water authorities on industrial units in Mourcheh Khort settlement regarding their actual water consumption patterns has been poor, due to their mainly decentralized water supply systems. In close collaboration with the Industrial Settlement Organization 21 industries from the textile, metal, food, plastics, glass and stone industries have been identified for further investigation. Selection criteria have been (1) high wastewater production, according to service contracts with the wastewater treatment plant (see Figure 9), (2) a likeliness of high water consumption (evaporation), even though no or little wastewater is being disposed to the central sewer system, (3) a maximum diversity of industrial branches from typical industries for the settlement and the region.

For more in depth investigation of the water consumption and wastewater production pattern of the selected industries, a questionnaire survey and sampling campaign was carried out by the Industrial Settlement Organization from May to August 2016. By spot sampling and analysing industrial wastewater, quality parameters like Chemical Oxygen Demand (COD), Total dissolved solids (TDS), Total suspended solids (TSS), turbidity, hardness, Electrical Conductivity (EC) and temperature have been obtained. Due to the limited number and volume of samples, the campaign yielded only in a rough impression of water quality parameters. Due to the absence of water meters, quantitates of supplied, disposed and evaporated water of relevant industrial processes could only be estimated in questionnaire based interviews with industry representatives. The questionnaire comprised also questions on the minimum water quality requirements of the industry and its processes. Unfortunately, this question did

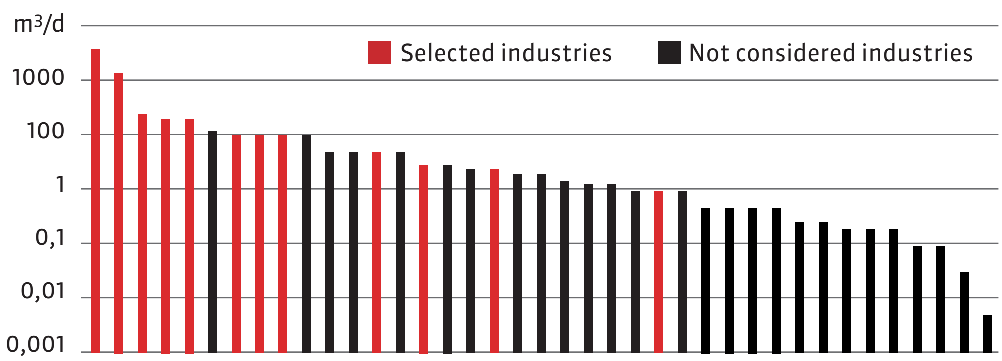

Figure 9: Selected industries for further investigation according to the highest licensed wastewater disposal contracts in Morche Khort settlement (Industrial Settlement Organization).

not yield usable information. Required information on minimum quality demands for process water had to be estimated by (1) analysing the water quality of existing industry internal return flows, (2) consultation of the industry representatives on the critical water parameters and (3) collaboration with German industry experts.

8.2.2. Characterizing and clustering of industries

From the collected data water balances and substances flow sheets for the respective industries were prepared and validated through comparison with Best Available Techniques (BAT) reference documents (BREFs) of the European Commission. For the prevalent small and medium-sized enterprises with partly outdated equipment however, comparability with European standards was limited or not available in the BAT.

To systematically document collected data for the different types of industry, the outlines of industry specific factsheets/characteristic papers have been developed. Next to general data on raw materials, products and production processes of the type of industry, the factsheet holds data on typical quantity and quality of water consumption and wastewater production patterns (example of industrial material flow chart Figure 10). Due to the limited database, factsheets could only be sketched, but in a workshop with representatives of the industrial organization the potential was highlighted by the Iranian partnerns, to extend the database and use them on the one had as benchmark for the water footprint of different industrial branches and on the other hand as tool to design innovative industrial water supply and disposal schemes such as Eco Industrial-Parks in Iran.

In the following step, the characterized Industries have been clustered in three classes according to their anticipated water quality demand and degree of wastewater pollution. In the primary class, industries with high water quality requirements (e.g. food industry) or industries which produce low polluted wastewater easy to reuse (e.g. yarn manufactures

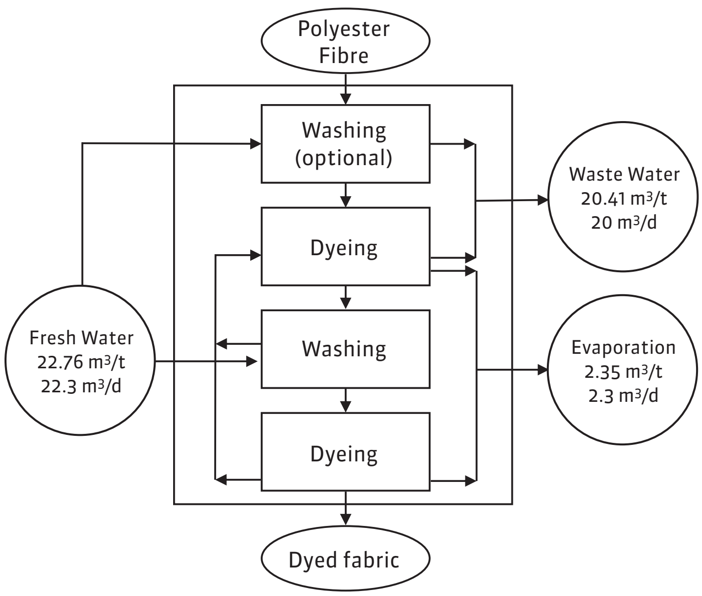

Figure 10: Example material flows chart (focus water) of the dying workshop without qualitative parameters.

and plastic pipe manufacturer) are assigned. In the tertiary, the last class, industries with expected low water quality requirements and small volumes of wastewater production (e.g. stone processing) as well as industry with highly polluted wastewater (e.g. Dyeing facilities and print shops) have been placed. The secondary class of industry served as intermediate category. Secondary users were mainly metalworking industries, such as producers of domestic components or tube manufacturers. In this work step the following simplifying assumption had to be taken due to shortage of data: the process with the highest water demand determines the required water quality for the whole site and distinct water quality requirements for minor processes (e.g. fluid for heating boilers, water for cleaning or sanitary wastewater) have been disregarded.

8.2.3. Development of EIP scenarios

In expert interviews the characterization and clustering of industries have been confirmed as valid assumptions to develop exemplary EIP scenarios. In EIP scenarios industries are aligned alongside a water flux, connecting the (low polluted) wastewater of one industry, with the water supply of a subsequent industry as presented in Figure 11. With the categorization of industrial units, a connection of the water fluxes along primary, secondary and tertiary users with increasing pollution of water ressources could be adopted. The higher the wastewater reuse rate, the higher are savings of freshwater and wastewater emissions in the industrial settlement. In the figure, partial flux of highly polluted wastewater of certain process leave the system but other partial fluxes are being reused. Due to the above mentioned poor information on water quality demand of industries, in the following scenarios a 100% reuse capacity of wastewater is being assumed.

By assessing different options of connecting the clustered industries under investigation, three principles could be derived (Figure 12). In the figure, the coloured arrows represent the water quality: from dark-green with very good quality to dark red with a high pollution. The bilateral principle connects two industries in a simple way. The wastewater from one industry is used as process water in another industry and then disposed as wastewater. The cascade

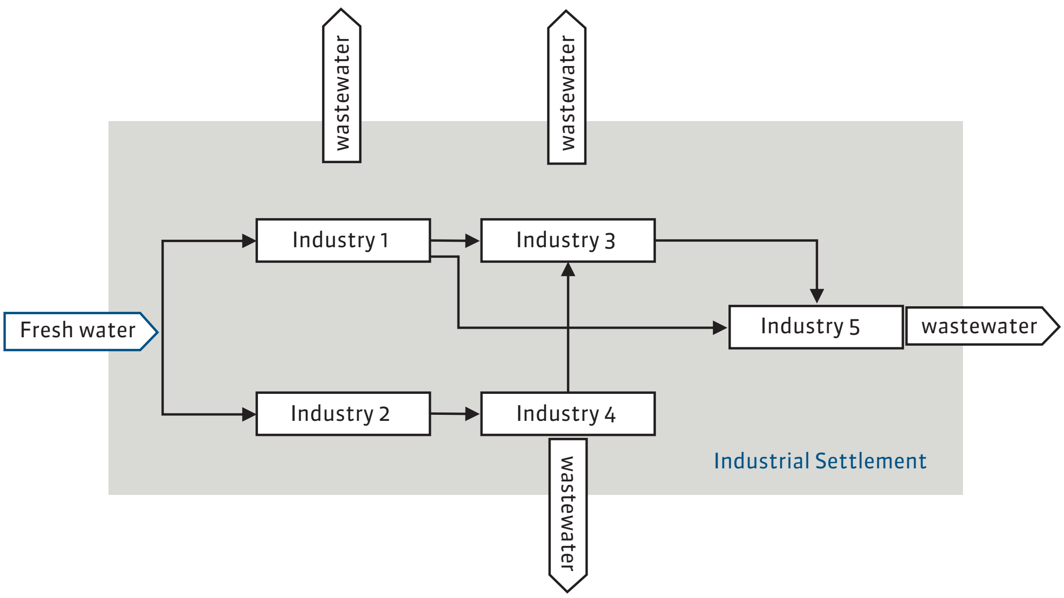

Figure 11: Example material flows chart (focus water) of the dying workshop without qualitative parameters.

principle is a sequence of the bilateral principle. The nucleus principle is an expansion of the bilateral principle where the wastewater of a water intensive industry is reused by several industries instead of one. In the nucleus principle with a large industry in the centre, also interposed wastewater treatment seems rational.

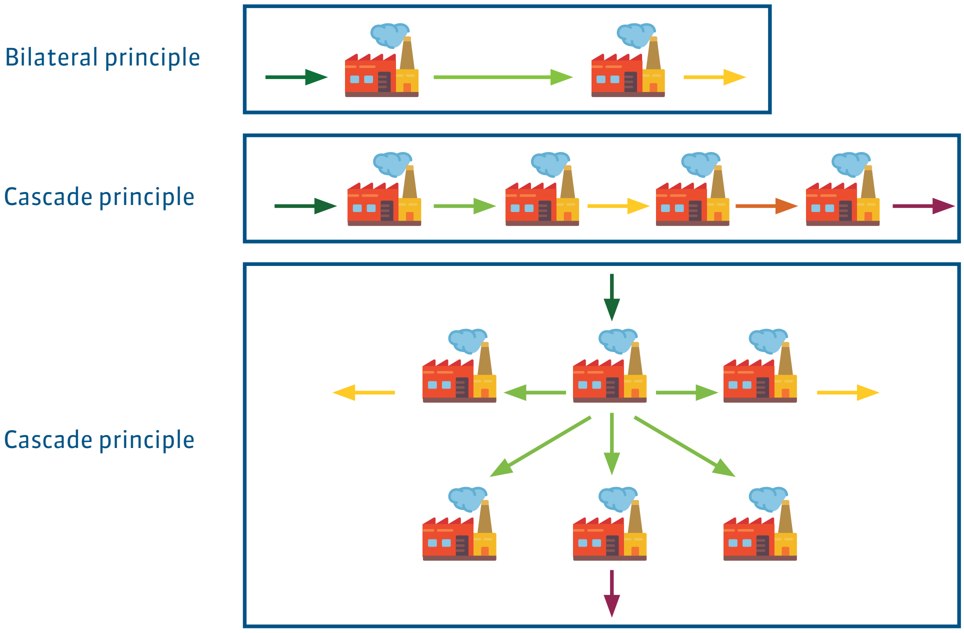

Figure 12: Illustration of three developed principles for EIP connections.

8.2.4. Results of EIP scenario case studies

Collected data on industrial water quality and quantity patterns and taken assumptions have been modelled according to identified connection principles by flux analysis with the STAN (subSTance flow ANalysis) software, a freeware tool for Material Flow Analysis (MFA) issued by Vienna University (Cencic & Rechberger, 2008). In the MFA, wastewater pollution adds up over subsequent reuse steps. The results are presented in the following:

As an example of the rather simple bilateral principle, a polyamide fibre production was selected as primary water user and process water supplier and connected to a dyeing workshop as consumer of the low polluted wastewater. Representatives of the dyeing workshop stated that critical factors for the dying process are hardness and total suspended solids (TSS). Both the hardness and the TSS of the polyamide thread wastewater are comparable low and meet the minimum requirements estimated by the dyeing factory. The heavily polluted wastewater of the dyeing workshop (tertiary water user category) is not fit for simple reuse.

To simplify the representation of water flows in Figure 13, the freshwater supply (input) was scaled to 100 m^3/d. All other values were scaled with the same factor, which may hypothetically be reached by connecting the several polymide fibre and nine dyeing factories located in Mourcheh Khort settlement (ISO, Site Visit Mourcheh Khort, 2016). Anyhow the connection of industries where the wastewater of one industry meets exactly the freshwater demand of another in terms of quantity, seems in practice unrealistic.

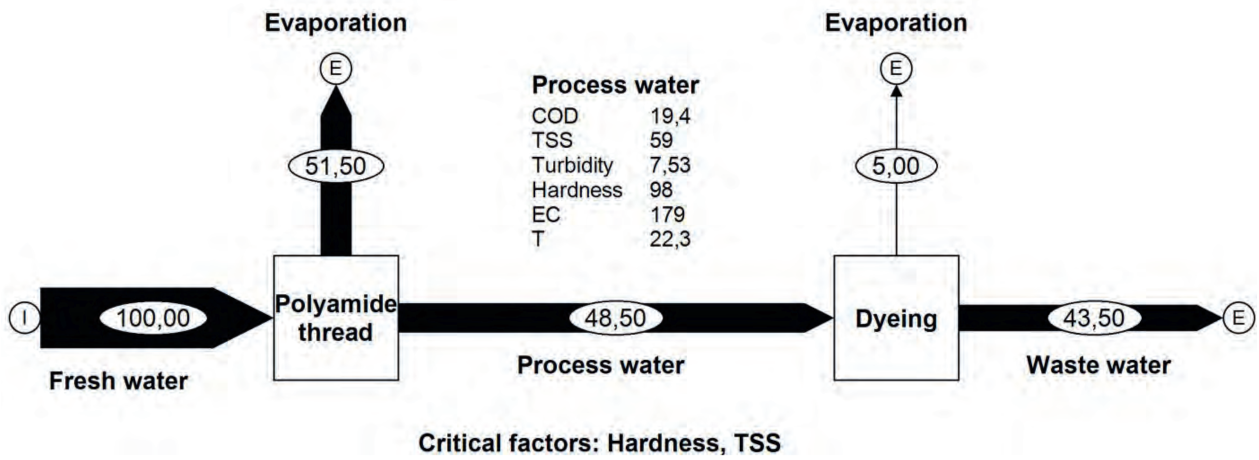

Figure 13: Example material flows chart (focus water) of the dying workshop without qualitative parameters.

The figure shows that the hypothetical connection of the polyamide fibre production and the dyeing workshop, may yield in a reduction of freshwater consumption of 48.5 m^3/d. This saving represents approximately 33% of the total water demand of the two industries. The use of the wastewater from the polyamide fibre production in the dyeing industry reduces the total amount of wastewater generated of both industries by about 53%. The higher percentages of the wastewater compared to the freshwater can be attributed to the high evaporation rate in the Polyamide thread factory.

In the example of the cascade principle, several industries are successively connected (Figure 14). As above, the polyamide fibre production was selected as primary water user. It transfers its wastewater to a polymer-pipe production site, which is also categorized in the primary category. The production of polymer pipes is relatively robust in terms of process water quality but requires low water temperatures for cooling. Since it impairs the wastewater quality only to a minor extend, the wastewater can be reused as process water in two different metal industries. Both industries have been classified as secondary users and identified total suspended and dissolved solids (TSS&TDS), turbidity and the conductivity as critical factors for their production. The wastewater of both primary users is evaluated as low, so that the wastewater may be reused as process water in both metal industries. As a tertiary user, the stone processing and the glass production were selected. The critical factor for the stone processing is stated the organic load (COD). TSS and turbidity are critical for the production of glasses. The use of sewage from both metal processing plants may be possible for both stone processing and glass production.

The water inflow was again scaled to 100 m^3/d. The complex, cascade-like arrangement of the industries and the associated use of the water may hypothetically save a total of approximately 56% of the freshwater demand and approx. 83% of the wastewater generated, but seems to be challenging to implement in practice.

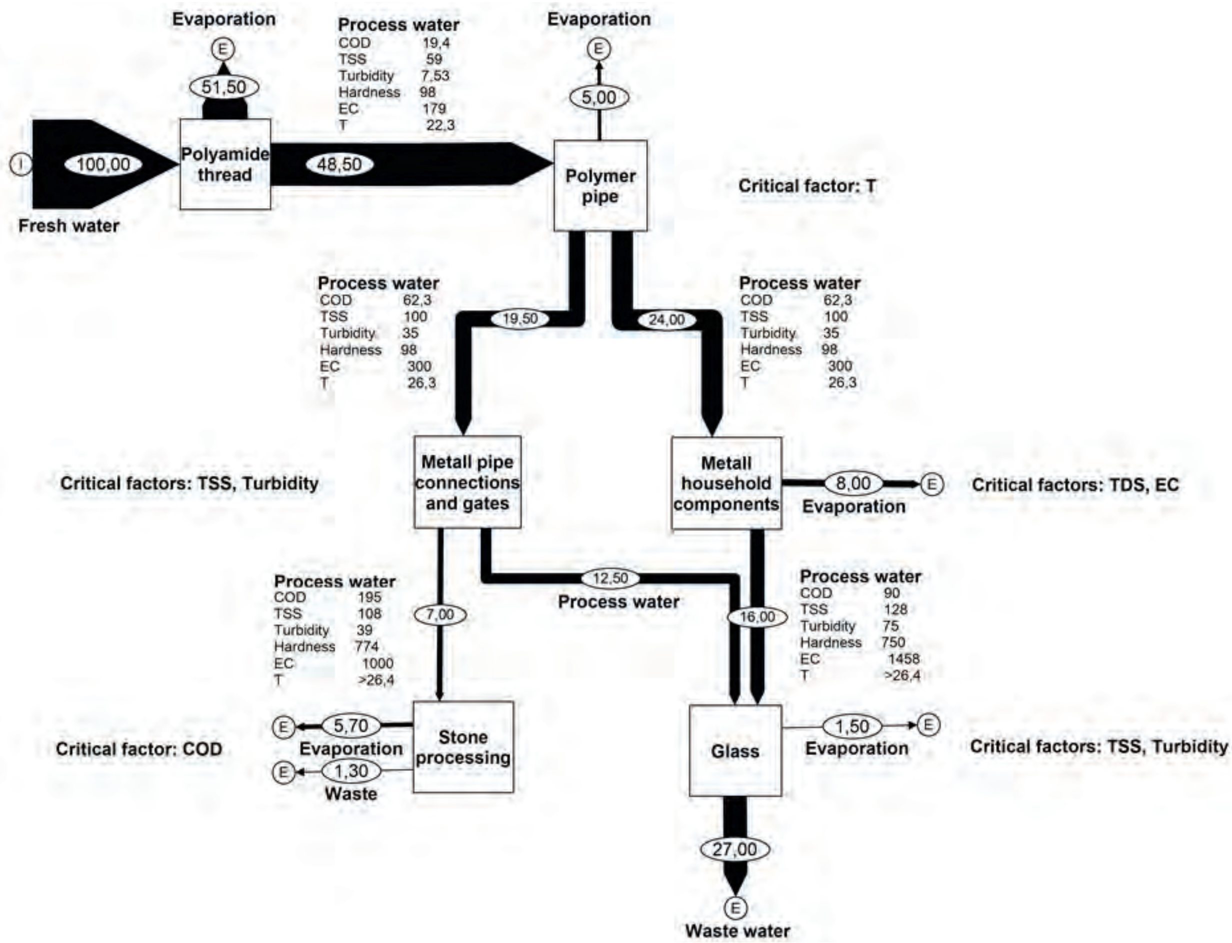

Figure 14: Cascade EIP scenario case study modeled with the STAN software.

In the example of the nucleus principle, the largest wastewater producer of the industries under investigation, the milk powder production, was selected as wastewater supplier. The peculiarity of the milk powder production is its amount of produced wastewater which is significantly greater than its freshwater consumption. Most of the wastewater is generated by the processing of the milk. Wastewater from the dairy industry carries high loads of organic material and nutrients, and must therefore be treated prior to further reuse. The first draft of the nucleus principle with the dairy industry in the centre is presented in Figure 15. The scenario presents hypothetical freshwater savings of in total 92% and wastewater reduction of 67%. If the volume of processed raw milk is added to the fresh water supply, the calculated freshwater savings still add up to 48%.

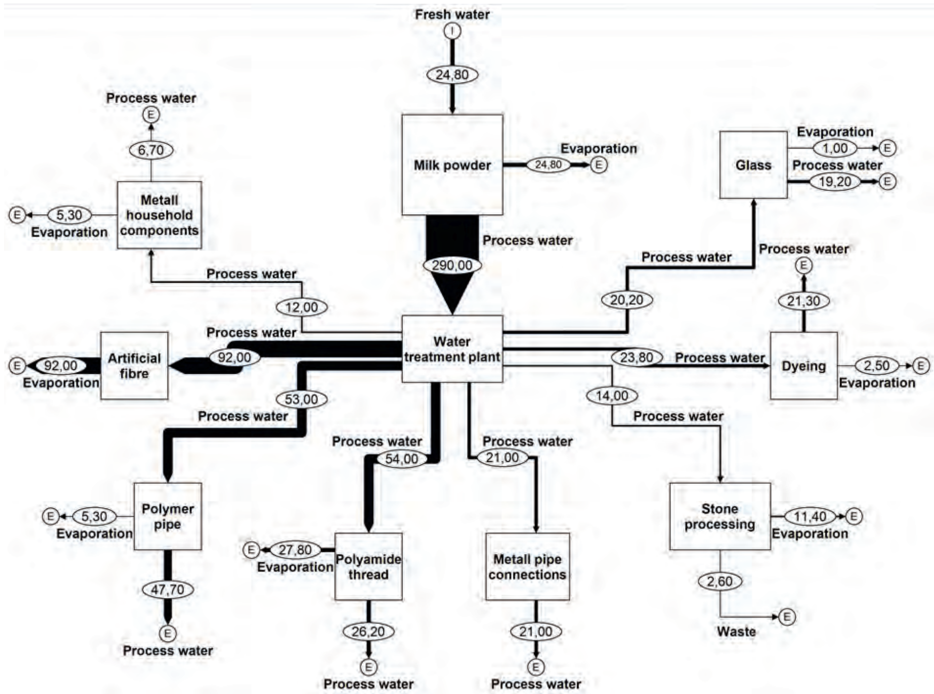

Figure 15: Nucleus EIP scenario case study modeled with the STAN software.

Further analysis of nucleus scenario

The nucleus principle with the dairy industry in the centre was analysed more in depth. The goal was to draft outlines of a possible wastewater treatment system and necessary infrastructure for reuse according to the EIP principles. For this end additional data on involved industries has been collected during a second interview campaign in cooperation with the Industrial Settlement Organization from April to August 2017.

Table 10: Random sampled wastewater characteristics of the milk powder industry (including cheese production) and figures on German wastewater quality of dairy industry (DWA-M 708, 2011).

Prozess	Volume [m^3/d]	COD [mg/l]	TSS [mg/l]	TDS [mg/l]	Turbidity [NTU]	Hardness [mg/l CaCO3]	Ec [µS/cm]	pH [-]	T [°C]	P [mg/l]	N [mg/l]
Cheese production	174	5030	566	5430	240	670	6728	11,91	23,4	1,5	5<
Milkpowder Production	116	3770	2660	1412	744	2<	3020	7,05	21,6	1<	5<
Sumed up, Total wastewater stream	300	4400	1430	3770	450	390	5200	10	22,7	1,3	5<
German reference figures for dairy processing	800	800 - 4500	--	--	--	--	--	6 - 11	12	20 - 100	20 - 230

According to collected data, it was found that wastewater production per m^3 of milk processed in the surveyed industry is in the upper norm of 1-2 m^3 wastewater produced per m^3 of processed milk, suggested by the German Water Association (DWA-M 708, 2011). Also the random sampled wastewater quality of the combined cheese and milk powder production dairy facility are similar to German reference values (see Table 10). However, the concentrations of nutrients (Phosphorus and Nitrate) seem to be particularly low in Iran. Also after several consultations on sampling and analytical methods, the reason for this difference could not be found.

In the second survey, the geographic location of industries has been identified. The industries are located between 800 m to 2.200 m distant with an average of 1.600 m from the dairy industry. High costs for pipe connections, pumps and earthworks may be expected for retrofitting the EIP concept with the establish nine selected industries in Morche Khort.

To determine the required reuse water quality, a choice experiment with the receiving industries has been performed. In a questionnaire a (worst case) future scenario was sketched, where no more groundwater would be available and industries need to buy alternative water resources (the higher the quality, the higher the price) to run their processes. Six qualities of water have been offered, with increasing purity from 1- wastewater from the dairy industry after screening, over 3- Quality after wastewater treatment in a Membrane Bio Reactor, to 4- Quality after Nano filtration up to 6- Quality after Reverse Osmosis (see Table 11).

Table 11: Offered water quality in choice experiment with selected industries.

Parameter	Quality 1	Quality 2	Quality 3	Quality 4	Quality 5	Quality 6
COD [mg/l]	3000	1500	< 30	< 5	< 5	< 5
N [mg/l]	<5	< 5	< 5	< 5	< 5	< 2
P [mg/l]	1,3	1,3	< 0,3	0,1	0,1	0
TDS [mg/l]	3770	3770	3770	1880	350	50
TSS [mg/l]	1430	600	<10	<10	<10	<10
EC [µS/cm]	5200	5200	3767	1883	550	<100
Turbidity [NTU]	450	200	<10	<10	<10	<10
Hardness [mg/l CaCO3]	390	390	390	178	50	<10

The results of the choice experiment revealed that the participating industries demand a rather high quality of process water (see Table 12), but are also willing to pay high prices for it (in average 0,66 € / m^3 for Quality 3, 1,36 € / m^3 for Quality 4, 3,26 € / m^3 for Quality 5 and 46 € / m^3 for quality 6). However, in personal communication technical managers of the industrial units stated that they don't know the pollution tolerance of their processes and that this information needs to be investigated by practical testing and on-site experiments. The stone processing industry did not contribute to the survey.

Table 12: Amount of water from different water qualities industries would demand in m³/d (choice experiment).

Parameter	Quality 1	Quality 2	Quality 3	Quality 4	Quality 5	Quality 6
Polymer Pipe				6		46
Artificial fibre			3			100
Polyamide thread			1,5			16,5
Metal household components			8	43		
Dyeing workshop			7	16	6	
Stone Processing	-	-	-	-	-	-
Glass				18	9	
Metal pipe connections			2	1	15	

Based on these presumptions, a possible wastewater treatment plant had been designed in a Master Thesis at the University of Applied Sciences Magdeburg-Stendal in Germany (Hennig, 2018) for application in the nucleus EIP scenario.

The design assignment yielded a sequence of treatment steps where water of different qualities may be withdrawn on demand (see Figure 16). The process steps are detailed with estimated costs (ideal conditions) for installation as well as operation and maintenance in Table 13. The design was performed for two design capacities. Capacity 1 – with 300 m^3/d similar to the dairy industry in Morche Khort and Capacity 2- with a higher volume per day of 1000 m^3 to increase cost efficiency. The complete design and extensive justifications for the derived figures may be found in Hennig, 2018. However, considering a service lifecycle of 20 years and 4% interest rate, the costs for treated wastewater have been estimated by cash-value-method. For water Quality 6: 0,56 € / m^3 with design capacity 1 and 0,25€/m^3 for design capacity 2 or for water Quality 3: 0,35 € / m^3 with design capacity 1 and 0,19 € / m^3 for design capacity 2 (Hennig, 2018). Even though these figures do not include required piping and pumps for connecting the facilities, prices for treated wastewater are significantly lower than the above identified willingness to pay. Although the presented example is purely theoretical, examples of dairy processing facility in Jalisco, Mexico with 1.600 m^3 daily water consumption and examples of dairy industry in Belgium show that nearly 100% reuse is in practice possible and economical rational (Möslang et al., 2017).

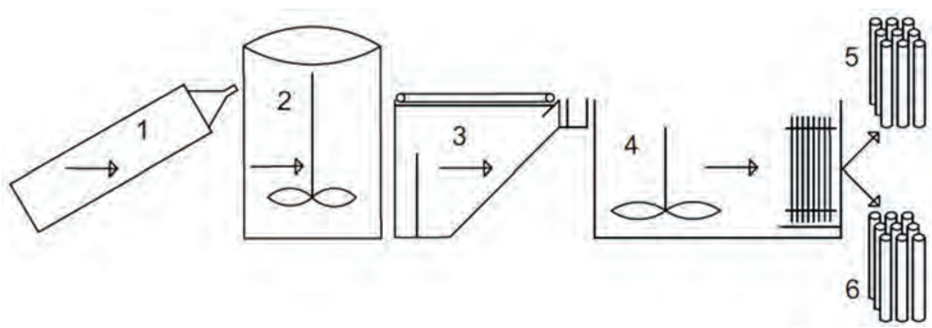

Figure 16: Treatment steps for purification of wastewater from the dairy industry and reuse in the EIP nucleus scenario (Hennig, 2018).

Table 13: Cost estimations on water treatment steps (Hennig, 2018).

	Investment Costs [€]		Operation and Mainainance Costs [€/a]	
	Capacity 1. (300 m^3/d)	Capacity 2 (1000 m^3/d)	Capacity 1. (300 m^3/d)	Capacity 2 (1000 m^3/d)
1. Screening plant	25.818	25.818	2.000	2.000
2. Mixing and equalizing	33.750	48.400	3.500	8.500
3. Flotation system	88.821	88.821	2.500	3.500
4. Membrane-Bio-Reactor	109.750	268.875	5.500	15.000
Sludge drainage	81.860	81.860	2.000	2.000
5. Nanofiltration	12.550		1.983	
6. Reverse Osmosis	61.300	89.350	6.000	11.000
Employees			10.000	15.000
Total costs [Euro]	331.989	521.264	33.483	57.000

8.3. Discussion of results, drivers and constrains for practical Implementation

The presented EIP scenarios show the result of a theoretical analysis under given assumptions. Each scenario has a distinct degree of complexity and hypothetical resource saving potential. It can also be observed that water conservation potential depends not only on the complexity of linkages, but also on industry specific water balances. Industries with low evaporation losses for example, may archive overall higher rates of fresh water savings.

The high hypothetical figures for potential saved freshwater (up to 92%) and avoided production of wastewater (up to 67%) by application of EIP scenarios, should be motivation to further investigate the potential of practical application of a EIP design philosophy particularly for the development of new industrial settlements. New settlements seem privileged, since proximity of symbiotic industries, geographic factors like landscape slope and necessary infrastructure and managerial adaptations of participating industries should be considered already in the planning phase for higher cost efficiency. If EIPs are on the long run more cost efficient than conventional industrial settlements in Iran, cannot be answered by this study. But rapidly declining groundwater resources increase the pressure for action in the sector.

Drivers and constrains for implementing the EIP design philosophy in new industrial planning has been discussed in a workshop with planners and operators from the industrial authorities and representatives of the environmental sector in Isfahan, Iran. Next to very positive feedback regarding the potentials of the EIP concept in Isfahan and Iran, the aspects below where raised and discussed. Economic incentives, business philosophy and image consider industries on a more individual level, whereas the other aspects below discuss obstacles and transaction costs for the interaction of industries.

- Business philosophy: The change of business philosophy is perceived as critical since it is assumed that industries focus on profit maximization, disregarding environmental impact of their action. Environmental sustainability may be brought more to the focus of management if (1) environmental regulations are implemented, (2) public interest stimulates environmental friendly products and/or (3) training and awareness rising campaigns are implemented with industry representatives.

- Image of wastewater use: The use of wastewater in production processes has the risk to lead to a negative public image of the industry and its products. The perception of low quality and contamination of products may be associated with water reuse. Awareness rising campaigns on the importance and means of environmental friendly industrial management on the general public, may prevent the possible image loss, and could even turn it in an image win.

- Conflicts in the exchange process: Critical conflicts are expected in the process and interface of resource exchange. Conflicts amongst industries may arise for example on fluctuations in quality and quantity of delivered process water or failure of shared infrastructure. Necessary problem solving strategies are the development of clear and reliable responsibilities, communication channels, installations of monitoring equipment and adapted contract models for industrial symbiosis. Capacity building measures should be implemented to increase trust and partnership amongst participating industries and to develop problem resolution capacity with the park management.

- Discontinuation or failure of a linked industry: Failure or decrease of production capacity of an industry that supplies one or more industries with its wastewater threatens the functional safety of the wastewater users. This issue starts already in the planning process of industrial settlements since there is no guarantee that an actor on the free marked will finally settle at the foreseen location. Therefore, it is likely that emergency water supply and sewage infrastructure must be provided which increases the overall costs.

- Distance between industries: The distance between the linked industries is a main critical factor, as infrastructure costs increases with higher pipe length. The feasibility of EIP concepts must be questioned at longer distances. To minimize the distance between industries, EIP linkages need to be considered already in the planning phase for new industrial settlements.

- Data for the planning process: The currently available data on small and medium sizes industries is considered as insufficient for the EIP planning process. A database on relevant types of industries, productions processes and industrial water flux (quantitative and qualitative) need to be developed, expanded and maintained over years. The above presented concept of industrial profiles is a practical tool to be implemented as way towards a solid database.

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Appendix: Water consumption of large industrial units

Withdrawal (2025) (Scenario 2)			Withdrawal (2025) (Scenario 1)			Withdrawal (dry year)			Withdrawal (normal & wet year)			Water sources and extraction points							Specifications	
												Wastewater Co. extraction point (UTM)		location of the Wells/Companies (UTM)		Surfacewater extraction point (UTM)		Water Source	Name	#
WW (m3/a)	GW (m3/a)	SW (m3/a)	WW (m3/a)	GW (m3/a)	SW (m3/a)	WW (m3/a)	GW (m3/a)	SW (m3/a)	WW (m3/a)	GW (m3/a)	SW (m3/a)	X coordinate	y coordinate	X coordinate	y coordinate	x coordinate	y coordinate			
0	270.000	55.500.000	0	270.000	40.000.000	0	270.000	24.600.000	0	270.000	24.600.000			540104	3568576	541636	3580448	Zayanderoud River	Mobarakeh Steel Company	1
0	270.000	43.000.000	0	270.000	31.000.000	0	270.000	25.830.000	0	270.000	25.830.000			531007	3587305	531372	3583121	Zayanderoud River	Esfahan Steel Company	2
2.220.000	0	20.500.000	2.220.000	0	11.000.000	1.280.000	0	10.730.000	0	0	12.000.000	552781	3611276	553614	3609884	552985	3610161	Zayanderoud River	Power Plant Islamabad	3
5.410.000	630.000	20.500.000	5.410.000	630.000	18.600.000	3.110.000	630.000	3.390.000	0	630.000	6.500.000	552781	3611276	547662	3627596	552781	3611276	Zayanderoud River	Isfahan Oil Refinery	4
0	2.340.000	3.160.000	0	2.340.000	3.160.000	0	2.340.000	0	0	2.340.000	0			560976	3589699	553329	3584476	Groundwater & future Zayanderoud River (BankFiltration)	Polyacryl Iran	5
0	2.500.000	0	0	2.500.000	0	0	2.500.000	0	0	2.500.000	0			551713	3579831			Groundwater	Iran Refractory Products	6
0	0	2.390.000	0	0	2.390.000	0	0	2.390.000	0	0	2.390.000			546677	3590883	547045	3591111	Nekooabad Canal Left	Iran Telecommunication	7
0	0	1.750.000	0	0	1.750.000	0	0	1.750.000	0	0	1.750.000			561038	3589552	553256	3584477	Zayanderoud River (BankFiltration)	(DMT) Synthetic Fiber raw materials	8
0	1.520.000	0	0	1.520.000	0	0	1.520.000	0	0	1.520.000	0			597008	3616321			Groundwater	Iran Spiral (pipes)	9
0	0	1.420.000	0	0	1.420.000	0	0	1.420.000	0	0	1.420.000			537869	3592520	535636	3582228	Zayanderoud River (BankFiltration)	Pulp and Paper Industry Co. Atrac	10
0	1.300.000	0	0	1.300.000	0	0	1.300.000	0	0	1.300.000	0			522173	3690088			Groundwater	Vegetable Oil Industry Golbahar News	11
0	0	1.260.000	0	0	1.400.000	0	0	1.260.000	0	0	1.260.000			529692	3586944	529370	3583844	Zayanderoud River (BankFiltration)	Power Plant South	12
0	1.200.000	0	0	1.200.000	0	0	1.200.000	0	0	1.200.000	0			532011	3587929			Groundwater	Saba Steel Resuscitation	13
0	1.130.000	0	0	1.130.000	0	0	1.130.000	0	0	1.130.000	0			573390	3612738			Groundwater	Isfahan Sugar Co.	14
0	0	1.000.000	0	0	1.000.000	0	0	1.000.000	0	0	1.000.000			548776	3585903	550295	3583903	Zayanderoud River	Sepahan cement Co.	15
0	0	970.000	0	0	970.000	0	0	970.000	0	0	970.000			558237	3579705	550213	3583176	Zayanderoud River	7 Tir Complex	16
0	0	950.000	0	0	950.000	0	0	950.000	0	0	950.000			554528	3604015	554498	3604430	Nekooabad Canal Right	Isfahan cement Co.	17
1.500.000	0	0	1.500.000	0	0	950.000	0	0	0	0	950.000	552781	3611276	546718	3628700	550260	3628525	Borkhar Canal, Urban water	Shahid Montazeri Plant	18
0	300.000	480.000	0	300.000	480.000	0	300.000	480.000	0	300.000	480.000			549091	3640143	549285	3639637	Borkhar Canal	Bafnaz Textile Co.	19
0	0	470.000	0	0	470.000	0	0	470.000	0	0	470.000			497188	3662457	479593	3620052	Kashan Canal	Sarooj Cement Co.	20
0	330.000	120.000	0	325.000	120.000	0	330.000	120.000	0	330.000	120.000			549326	3633816	548887	3633729	Borkhar Canal	Baresh Co. (Textile)	21
1.170.000	0	1.330.000	1.170.000	0	1.330.000	670.000	0	1.830.000	0	0	2.500.000	552781	3611276	547320	3625603	552781	3611276	Borkhar-Shahinshahr/ Urban water	Petrochemical CO.	22
0	560.000	0	0	560.000	0	0	560.000	0	0	560.000	0			520740	3692775			Groundwater	Naz Vegetable oil industry	23
230.000	210.000	0	230.000	210.000	0	130.000	310.000	0	0	440.000	0			553392	3627044			Groundwater	Pegah Dairy Industies	24
0	800.000	0	0	800.000	0	0	800.000	0	0	800.000	0			554996	3608111			Groundwater	Nasooz Azar Co.	25
0	500.000	0	0	500.000	0	0	500.000	0	0	500.000	0			540180	3610181			Groundwater	Niloo porcelain Co.	26
0	0	6.500.000	0	0	6.500.000	0	0	6.500.000	0	0	6.500.000					596792	3597748	North RooDashtein Canel	Other Industry 1	27
0	0	7.900.000	0	0	7.900.000	0	0	7.900.000	0	0	7.900.000					538809	3612387	Nekooabad Canel Left	Other Industry 2	28
0	0	1.580.000	0	0	1.580.000	0	0	1.580.000	0	0	1.580.000					479595	3620052	Kashan Canal (km 300)	Other Industry 3	29
0	0	810.000	0	0	810.000	0	0	810.000	0	0	810.000					552656	3641458	Borkhar Canal	Other Industry 4	30
					30.170.000	4 new large industries expected till 2025														
		98.340.000	12 new large industries expected till 2025																	
10.530.000	13.860.000	269.930.000	10.530.000	13.855.000	163.000.000	6.140.000	13.960.000	93.980.000	0	14.090.000	99.980.000								Sum	

Appendix: Water consumption of industrial settlements

Settlements area		Withdrawal (2025)			Withdrawal (dry year)			Withdraw (normal & we	
Total settlement area (ha) مساحت کل شهرک(هکتار)	build surface area (ha) مساحت زمین واگذار شده (هکتار)	WW (m3/a)	GW (m3/a)	SW (m3/a)	WW (m3/a)	GW (m3/a)	SW (m3/a)	WW (m3/a)	GW (m3/a)
95	7	0	900.000	0	0	70.000	0	0	70.0
		470.000	0	0	470.000	0	0	260.000	
		540.000	0	0	540.000	0	0	540.000	
562	393	0	5.320.000	0	0	3.720.000	0	0	3.720.0
98	2	0	730.000	0	0	20.000	0	0	20.0
377	272	0	5.620.000	310.000	0	2.580.000	0	0	2.270.0
1.080	655	3.130.000	6.460.000	630.000	1.800.000	4.400.000	0	0	5.570.0
860	643	3.000.000	5.130.000	0	1.550.000	4.540.000	0	0	6.090.0
736	136	860.000	6.000.000	100.000	470.000	820.000	0	0	1.190.0
130	76	100.000	1.130.000	0	40.000	680.000	0	0	720.0
460	249	150.000	4.200.000	0	100.000	2.260.000	0	0	2.360.0
1.280	130	0	12.110.000	0	0	1.230.000	0	0	1.230.0
95	67	350.000	350.000	200.000	190.000	450.000	0	0	440.0
95	28	300.000	600.000	0	130.000	130.000	0	0	260.0
74	17	0	700.000	0	0	160.000	0	0	160.0
95	2	0	900.000	0	0	20.000	0	0	20.0
95	4	0	900.000	0	0	40.000	0	0	40.0
88	72	200.000	600.000	0	110.000	570.000	0	0	680.0
		9.100.000	*51.650.000*	*1.240.000*	*5.400.000*	*21.690.000*	*0*	*800.000*	*24.840.0*

awal wet year)		Water sources and extraction points							Specifications	
'a)	SW (m3/a)	Wastewater Co. extraction point (UTM)		location of the Well / companies (UTM)		Surfacewater extraction point (UTM)		Water Source	Name	#
		X coordinate	y coordinate	X coordinate	y coordinate	x coordinate	y coordinate			
.000	0			543389	3621913			Groundwater	Khomeinishahr	1
0	210.000	552781	3611276	550489	3630282	549800	3630427	Surface water	Mahmoodabad	2
0	0	519970	3582084	567042	3624341			Urban water SW in Future	Dolatabad	3
.000	0			545971	3656384			Groundwater	Morchehkhort	4
.000	0			450355	3648035			Groundwater	Faridan	5
.000	310.000			569122	3587041	566319	3587238	Groundwater	She rahe mobarakeh	6
.000	630.000	519970	3582084	527277	3612084	534336	3602252	Groundwater & Urban Water in Future	Great Area of Najafabad(Tiran + karvan + esfidvajan + oshtorjan+ najaf abad1,2)	7
.000	0	519970	3582084	580044	3614532			Groundwater & Urban Water in Future	Great area of Jey (jey + segzi)	8
.000	100.000	519970	3582084	637029	3609846	630436	3590719	Groundwater	Great area of Harand (Kohpayeh + Varzaneh + Ezhieh+ Harand)	9
.000	0	519970	3582084	517289	3699141			Groundwater	Meimeh	10
.000	0	519970	3582084	512914	3657029	479593	3620052	Groundwater	Alavijeh + dehagh	11
.000	0			532712	3651023			Groundwater	Large north Isfahan settlement	12
.000	200.000	519970	3582084	578494	3643134	577598	3642487	Ground water	Kamshjeh	13
.000	0	519970	3582084	606925	3579328			Ground water	Mahmoodabad+ Jarghuyeh	14
.000	0			467992	3626300			Ground water	Chadegan	15
.000	0			562487	3546766			Ground water	Poodeh	16
.000	0			657212	3625331			Ground water	Tudashk	17
.000	0	519970	3582084	538506	3615577			Ground water	Montazeriah	18
.000	*1.450.000*								Sum	

This report presents two main results of the German-Iranian research cooperation "IWRM Zayandeh Rud", concerning the Industry sector in the Zayande Rud catchment. The first part of this document presents data on industrial water consumption in the whole catchment area.The data were composed by inter 3 GmbH in order to deliver a comprehensible overview over industrial water use and to provide a database for the Water Management Tool developed by DHI WASY. In the second part of the report potential benefits and constrains for the implementation of a collective approach for more resource efficiency, the "Eco Industrial Park Concept", is presented in the form of a case study in the Zayandeh Rud basin.

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