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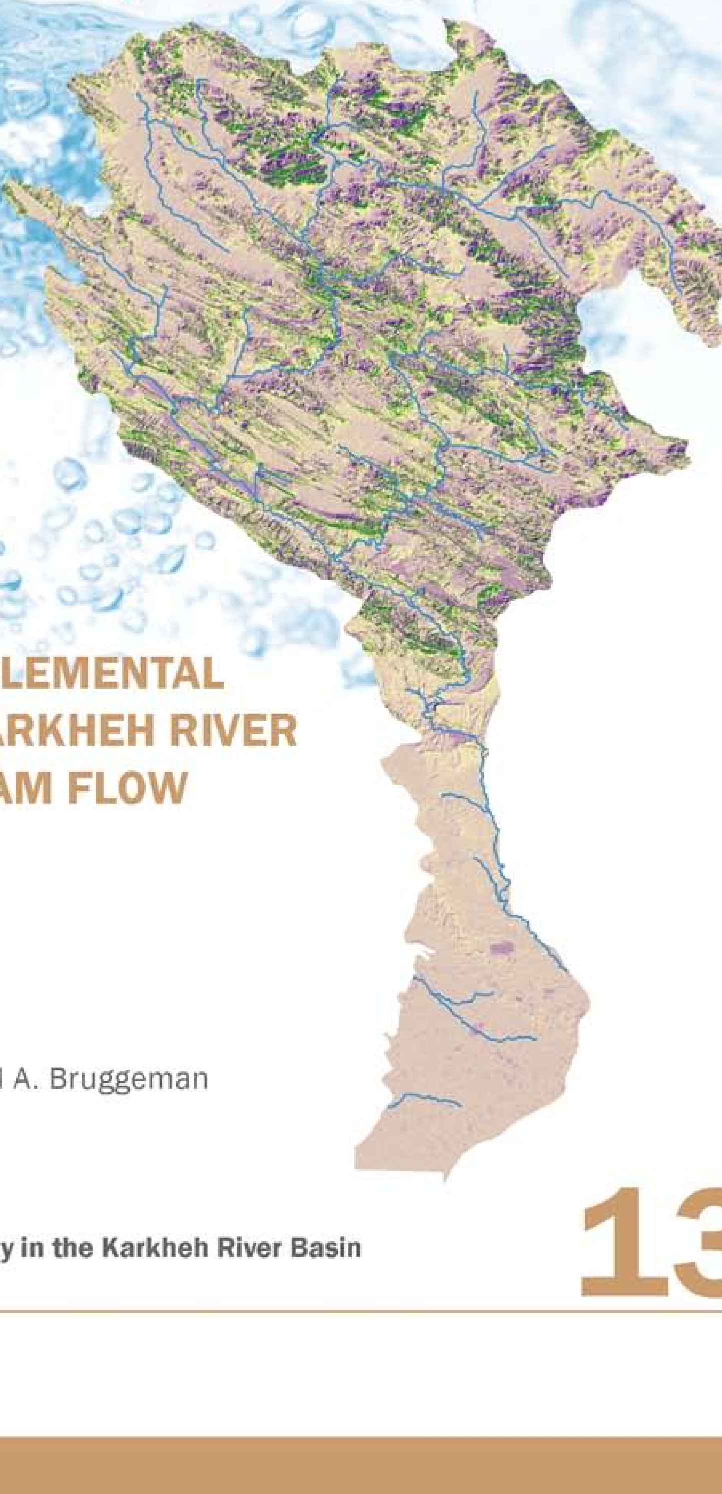

IMPACT OF EXPANDING SUPPLEMENTAL IRRIGATION IN THE UPPER KARKHEH RIVER BASIN (IRAN) ON DOWNSTREAM FLOW

B. Hessari, M. Akbari, F. Abbasi, T. Oweis and A. Bruggeman

Improving On-farm Agricultural Water Productivity in the Karkheh River Basin Project (CPWF PN 8)

13

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International Center for
Agricultural Research
in the Dry Areas

AREEO
Agricultural Research,
Education and Extension
Organization

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Research Report no. 13

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Abbreviations

AERI	Agricultural Engineering Research Institute
AREEO	Agricultural Research, Education, and Extension Organization
BBM	Building Block Methodology
CCC	Criterion continuous concentration
CGIAR	Consultative Group on International Agricultural Research
CMC	Criterion maximum concentration
CPWF	Challenge Program on Water and Food
CV	Coefficient of variation
CWANA	Central and West Asia and North Africa
DEM	Digital elevation model
EF	Ecological flow
EFR	Environmental flow requirements
EPA	Environmental Protection Agency
FDC	Flow duration curve
ICARDA	International Center for Agricultural Research in the Dry Areas
IFAD	International Fund for Agricultural Development
IFIM	In-stream flow incremental methodology
IFR	In-streak flow requirement
INRM	Integrated natural resource management
IRNCID	Iranian National Committee on Irrigation and Drainage
IUCN	International Union for the Conservation of Nature
IWLMP	Integrated Water and Land Management Program
IWMI	International Water Management Institute
IWRM	Integrated water resource management
KRB	Karkheh River Basin
LULC	Land use/land cover
MAE	Mean absolute error
MAR	Mean annual runoff
ME	Mean error
PHABSIM	Physical habitat simulation
RMSS	Root mean sum of squares
RVA	Range of variability approach
RWP	Rain water productivity
SD	Standard deviation
SI	Supplemental irrigation
SMD	Soil management domains
SOTER	Soil Terrain
SWIM	System-wide initiative on water management
UNDP	United Nations Development Programme
WANA	West Asia and North Africa
WP	Water productivity
WSBM	Water and Salinity Basin Model
WUE	Water use efficiency

Contents

Executive summary

The Karkheh River Basin (KRB) of Iran has a semi-arid to arid climate and suffers from low rainfed agricultural productivity. Supplemental irrigation (SI) is recommended in the upper KRB to increase crops yields and water productivity (WP). However, development activities upstream will certainly affect the water quality and quantity flowing to the Karkheh Dam downstream. In this study, suitable areas for SI are basically rainfed and characterized by the presence of arable soils, non-constraining slopes, agricultural land use, and within a distance from, or an elevation difference with, existing irrigation schemes that does not impose uneconomical costs for water conveyance or pumping.

Two methods are examined for targeting suitable lands for SI development. The irrigated areas buffer method and the rivers buffer method. The potential future situation with SI is evaluated by assuming various scenarios at the upstream sub-basins. Current runoff in the upstream KRB is assessed using a surface water balance in a GIS framework. Water demand and new runoff maps were then simulated. A map of potential areas for SI at the upstream sub-basins was prepared using the intersecting layers method within the GIS framework. The results show that 31.4% of the rainfed areas suitable for SI development are located approximately within a 1000 m buffer distance of the irrigated fields, while the rivers buffer areas cover 46.5% of the suitable rainfed areas. The latter value is assumed to be more realistic for the potential expansion of SI.

Four slope priorities in 53 sub-basins and four precipitation scenarios – normal precipitation conditions, normal conditions with an environmental flow consideration, drought conditions, and drought conditions with an environmental flow consideration – are considered in investigating the upstream-downstream interactions. The SI scenarios include full SI (satisfying any deficiency of rainfall), SI for early sowing (100 mm in autumn), and two levels of deficit SI strategies (total 150 mm) involving water that would be conveyed from the rivers considered as buffers.

A FORTRAN program was written to calculate the water allocations for the upstream sub-basins. The results indicate that the amount of water allocated to SI in normal seasons could decrease downstream flow by 15%.Under drought conditions the reduction may amount to 10% of the current flow, if all the potentially suitable areas for SI are developed. Furthermore, for an assessment of the effect of developing SI at the upper Karkheh sub-basins on the water quality of the Karkheh River and the Karkheh Dam, a simplified Water and Salinity Basin Model (WSBM) was developed. The model was calibrated and used to analyze current and past water extractions.

Despite the simplicity of the model, the observed and simulated stream flows and salinity are similar, proving that the model could be used for scenario analyses. The first scenario was setup to analyze the effect of a single SI of 75 mm in the autumn for about 140,000 ha of rainfed areas. This scenario has no significant effect on the water quality of the Karkheh Dam. The results of a second scenario, defined to evaluate the effect of a single SI of 75 mm in the spring for about 200,000 ha of rainfed lands, shows negligible effects compared to the annual flows of the river.

The third scenario, a combination of the first and second scenarios, produced similar results that indicate a 3.9% increase in water salinity. The last scenario consisted of two SI, each of 75mm, in the spring at the heading and milky stages. In this scenario the water salinity of the river increased from 0.8 to 1.2d S/m, but the Karkheh Dam water salinity increases by 4.1%.

Chapter 1.

Potential development of supplemental irrigation in the upper KRB

Chapter 1: Potential development of supplemental irrigation in the upper KRB

1.1. Introduction

The world is currently facing the challenge of producing more food with less water. The understanding of how water is acquired, managed, and used is the key to the solution of this dilemma. Irrigated agriculture is viewed as a highly inefficient use of water. With rapid industrialization, urbanization, and high population growth agriculture is increasingly giving up part of its water to other, competing sectors. Thus, more food must be produced with less water. The most logical solution to this problem is to increase the production or return per unit of water used, usually termed as water use efficiency (WUE) or WP. It is a solution that stretches across disciplines and levels and certainly requires the concerted action of all stakeholders (Ashrafi, 2005).

Water productivity indicates how beneficial water is used in producing goods and services. In simple terms, WP is defined as the return or benefit derived or produced per unit of water supplied or consumed. At the basin/ regional level, national food security, health, and environmental protection are also important issues to stakeholders and policy makers (Ashrafi, 2005).

In the past, the focus had been primarily at the plant and field scale. Now, however, WP at higher levels, such as project, basin, and regional scales, is used more prominently. Looking at water from a basin perspective means that not only water supply and demand are looked at for all users, but also institutional issues are being considered in the allocation. At the basin scale, the interaction between the upstream and downstream uses and users of water becomes more evident and raise acute equity issues. Deterioration of water quality, either from agricultural or urban-industrial complexes, which reduce the value and utility of water to downstream users, is another basin-wide water issue.

The basin perspective allows us to look with greater clarity at the importance of the institutional interventions governing how planning, policies, rights, regulations, monitoring, and water users' organizations need to be designed and implemented to enhance the effective functioning of organizations at the basin and system levels as well as at the levels of individual uses or users. Additionally, environmental and ecological water related issues can also be more properly looked at from a basin perspective (Ashrafi, 2005).

To improve the livelihoods of the large agricultural population in the region, the development and adoption of technologies and strategies that facilitate the maximization of agricultural production per unit of water is becoming increasingly more important.

There is a great scope for improving WP and WUE. Research findings have shown that substantial and sustainable improvements in WP are attainable, but can best be achieved through community-based, integrated natural resource management approaches at the basin level. The KRB, with its semi-arid to arid climate, is suffering from low rainfed agriculture productivity problems.

The SI of rainfed crops is recommended as a measure to increase WP at the upstream of the KRB. The objective of this report is to set a methodology and framework for mapping the iso-potential and actual SI at the basin/sub-basin level under existing conditions bearing in mind the hydrologic data of the gauged stations.

The upper KRB encompasses an area of about 43,000 km^2. The Karkheh River is 900 km long and is located in the southwestern part of Iran where the climate is a semi-arid to arid one. Most of the agricultural area of the upper KRB is rainfed and a large part of the agricultural livelihoods of the regional population is based on dryland farming systems. Water scarcity is a well-known and alarming problem. However, Iran's agricultural strategy identifies improvement of WP as a top priority.

One of the CGIAR Challenge Program on Water and Food (CPWF) projects in Iran is entitled 'Improving on-farm WP in the Karkheh River Basin'. This project concentrated its activities on assessing and improving agricultural WP. The project recommends SI for rainfed crops to increase WP at selected areas in the upstream of the KRB. The upper catchments are the most suitable rainfed zones of the country, with long-term annual precipitation of between 350 and 500 mm.

Geographic information systems-based methods have been developed that point the way to a better geographical targeting of the suitable domains for individual WP enhancing practices. If the practice is SI of rainfed crops, the recommended domain will be determined by the amount of water to be applied to increase WP significantly, the economic feasibility of carrying water over a particular distance, and the presence of biophysical limitations, particularly those related to soils and/or land. This procedure is called iso-potential mapping of SI.

Supplemental irrigation is the addition of water to essentially rainfed crops during times of serious rainfall deficits. The conjunctive use of rainfall and irrigation water is a potentially valuable management principle under conditions of water scarcity. The aim is to reduce the risk of crop failure, where rainfall is normally sufficient, but vulnerability to drought is high, and thus to stabilize yields.

As demonstrated by Oweis *et al*. (2000), the WUE of SI in the Mediterranean dryland environments can be much higher than that of full irrigation, especially if the latter occurs during the summer months, when precipitation is minimal and water requirements are high due to elevated temperatures.

Potential areas for SI in the upper KRB can be identified from maps of the region. This identification needed to estimate the potential effect of SI on productivity and economics. Such maps are also needed to develop SI strategies. The target areas for SI can be identified using GIS-based methodologies. The GIS-based land use, precipitation, available water resources, soils, and climatic maps will be used to complement other local and provincial data to develop maps of suitable areas for SI. This activity will collect and/or estimate the following useful and necessary information/data for the target areas:

- Spatial and temporal variability of precipitation
- Spatial and temporal variability of climatic variables (on a daily or, at a minimum, monthly basis), including: minimum, maximum, and average air temperature, humidity, wind speed, soil temperature, radiation, and pan evaporation and/or reference ETo

- Spatial land and soil variability including slope, and present land cover and land use, texture class and type, soil depth and root impeding layer if any, water holding capacity, general fertility level, and effective rainfall
- Information on plant species, cropping calendar and rotation, long-term crop yields, and common tillage practices and inputs (including seeding rates, fertilizer, and pesticide amounts and timing)
- Hydrometric network, sub-basins, streams and any available water works, and the different types of irrigation works and irrigation infrastructure of the basin
- Spatial and temporal variability of stream flow variables (daily or monthly basis), including normal conditions and drought conditions suitable for water allocation throughout the whole basin.

Given specific irrigation schemes, of which the areas under summer irrigation are known, it is possible to estimate the potential water savings by changing the irrigation systems or cropping patterns to make more frugal use of irrigation water. De Pauw *et al*. (2006) indicate the magnitude of the water savings that could be achieved by simply switching cropping patterns that depend mainly on summer irrigation, with little or no additional precipitation, to systems in which precipitation is complemented by additional irrigation water.

However, if such changes were indeed implemented, it is not so evident where the potential savings could eventually be applied. Apart from social and economic considerations, there are constraints related to land quality (particularly the need for suitable soils and slopes), distance from the irrigated areas, regulated land use conversions (forest to arable land), differences in elevation, etc.

The objective of this study is to apply GIS tools to identify potential areas that would be prime candidates for government programs to introduce SI. In their most simple form, such areas would be characterized by the presence of arable soils, non-constraining slopes, agricultural land use, and within a distance from, or having an elevation difference with, existing irrigation schemes that does not impose uneconomical costs for water transfer or pumping.

How much additional land, and where is it located within the neighborhood of the existing irrigation schemes, would be needed if the available water discharge is to be used to provide SI in winter? This is another typical question that agricultural planners might ask.

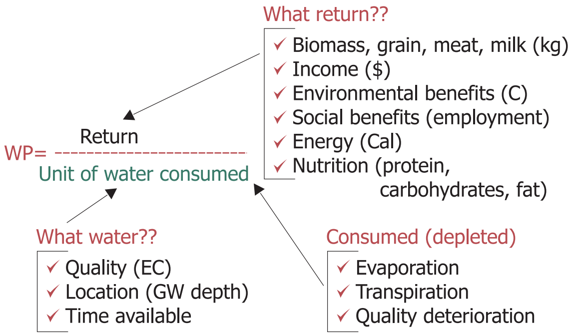
The answer that this study provides would be to identify the suitable areas by integrating existing information, derived from either thematic maps or satellite imagery, in a GIS. In the next sections a method developed for this purpose will be outlined.

1.2. Literature review

Supplemental irrigation (single or multiple irrigations) is the major method used in low rainfall areas to ensure enough water to produce an economic yield. While water harvesting is generally used in areas that receive between 100 and 300 mm of rainfall annually, SI is used in areas with a slightly greater annual rainfall of approximately 300 to 600mm (Oweis *et al*., 1999).

Supplemental irrigation applies a limited quantity of water during times of low rainfall to ensure that enough water is received to support crop growth and stabilize yields (Oweis *et al*., 1999; Tavakoli and Oweis, 2004).The goal of

SI is not to maximize the yield per unit area, but to optimize WP (benefit per unit of water).Equation 1.1 shows a WP definition. Examples of high WP options are SI and deficit irrigation.



Equation 1.1: From presentation by T. Oweis, 2010.

Agricultural WP refers to the measured output per unit of water consumed in evapotranspiration or in quality deterioration. The value derived from a unit of water used is extremely complex because

- Basins include a host of activities that can modify the water pathways of any sub-system
- Land presents a system of activities which interact in ways other than water, including, food, energy, income, or other social exchange
- The valuation systems for different benefits and costs can be difficult to compare.

Each of these factors requires simplification through assumptions. For agricultural water use, the primary focus is placed on food production, therefore WP is defined as food output per unit of water consumed. Outputs resulting from water use include

- The biomass in agriculture and natural vegetation
- The nutritional content of various forms of food produced with water
- Economic and societal value created by water use in different sectors (agriculture, fisheries, livestock, and non-agricultural uses of water).

In all cases, water is quantified as the amount crossing the boundary of the scale considered, or as changes in the amount stored entirely within these bounds during the time period of the analysis. Field water management is the lowest scale at which water management interventions may be used to increase productivity. (Molden *et al*., 2007).

The irrigation system is usually not expected to supply all of the moisture required for maximum crop production. The fraction of the water supplied which is beneficially used should be maximized.

A modeling methodology is available for using GIS tools to identify potential areas where SI can be introduced. The method is based on the assumption that the irrigation water discharge (from either surface or groundwater) available in existing irrigated schemes, which is used to fully irrigate summer crops, could, instead, be used in the winter for the SI of winter crops.

Since water requirements for SI are a fraction of that for full irrigation, the areas that could be irrigated in winter are much larger than the areas currently used under full irrigation in the summer. The method uses a combination of a simple model to calculate the additional rainfed area that can be partially irrigated by the possible water savings –achieved by a shift from spring/summer fully irrigated crops to winter/spring crops under SI – with a water allocation procedure for the surrounding rainfed areas based on suitability criteria. In this research, the same method proposed by De Pauw *et al*. (2006) with some changes in the criteria was applied to the KRB.

The water used for SI can be obtained from different sources. Groundwater, surface water, agriculture wastewater, and water obtained through water harvesting methods are all used for SI. The water harvesting methods are often used in conjunction with SI since SI is often undertaken in low rainfall areas. Important factors to be considered when designing a water harvesting system for SI include the storage capacity, the type of storage, and its location. The specific methods of irrigation used depend upon the resources available to the farmers in the area as well as any economic or labor costs that may be involved in setting up the SI system. Rivers are the main sources of fresh water in Iran, in addition to hundreds of perennial and ephemeral streams.

A literature review of past research efforts indicates that the relation between rainfall amount and crop yield in the dry-farmed zones of Iran has been a subject of interest for decades.

Tavakoli *et al*. (2008) entitled 'Improving RWP by supplemental irrigation and agronomic management practices in the rainfed areas of the upper Karkheh River Basin (KRB), Iran, the authors reviewed previous outstanding work on SI in Iran. According to that review, and considering the limited availability of water resources in the dry areas, applying a small amount of water as deficit SI could provide the opportunity for crops to survive and maintain modest growth until they receives rainfall or irrigation.

In order to investigate the effects of various SI scenarios on rainfed bread wheat (*Triticum aestivum* L.), on-farm experiments were conducted during the 2005-2008 cropping seasons at multiple farms across the benchmark watershed of Honam (Lorestan Province) in the upper KRB.

The treatments included two main management systems (traditional and advanced management) and four levels of limited irrigation (rainfed, a single irrigation of 50 mm in the spring, a single irrigation of 75 mm at planting time, and 125 mm irrigations at planting in the spring).

The results of this study showed that under rainfed conditions, the wheat grain yield (2269 kg/ha) showed a 31.5% increase over that achieved under traditional management (1726/kg/ha). The optimal program was a combination of the advanced agronomic management with limited irrigation options (a single irrigation at planting time/or in the spring).

With this preferred program, the maximum WP and net benefits were obtained. Under rainfed conditions, the RWP of the traditional management system (0.35 kg/m^3) was increased by 28.6% using the advanced management system (0.45 kg/m^3).

The results showed that a single irrigation applied at sowing time or in the spring (during the heading to flowering stage) increased the total WP of the wheat by an average range of from 0.57 to 0.63 kg/m^3 over the three growing seasons. The average irrigation WP of the wheat ranged from 2.15 to 3.26 kg/m^3 by using a single irrigation at the sowing time or in the spring. The SI at the critical stages – planting time/or in the spring, deep root expansion, and incrassating the green canopy cover – and its influence on evaporation control were the main reasons for the effectiveness of the limited irrigation.

Low RWP and yield under the farmers' practices were mainly to the results of sub-optimal agronomic management practices. These preliminary results confirm the potential of a single irrigation and early/normal planting as an effective scheme to enhance productivity (Tavakoli *et al*., 2008).

It can be concluded that SI at the farm scale increases yields, WP indices, WUE, and the stability of crop production under different climatic conditions. However, these increases depend on such factors as seasonal precipitation, rainfall distribution (especially at the two critical stages of the sowing date and heading-flowering stage), the crop cultivar, type of soil, the agronomic practices (including seed rate), the amount, source, and timing of fertilizer use, machinery, weed, pest, and disease control, and the environmental conditions of the specific area.

The objective of this report is to find suitable areas for SI on the basin scale. The potential areas for a single SI in Iran include the western parts (central Zagros Valleys), the northwestern provinces (west and east Azerbaijan Provinces), the north east provinces (Golestan and Khorasan), and the Caspian coast in the north. In addition to these areas, which constitute the main zones of rainfed agriculture, some other, relatively smaller areas and sub-zones, such as the rainfed areas in Fars and Khorasan provinces that have similar agro-climatic conditions, are also suitable for SI.

In addition to wheat and barley as the main rainfed crops, pulses, oilseed, tea, citrus, vegetables, grapes, and figs are also grown under rainfed conditions in various parts of the country. In Iran, SI can be beneficial in raising a diverse set of crops of high market value.

The quantity, quality, and temporal distribution characteristics of the sources of irrigation water have a significant bearing on irrigation practices. Rivers waters are used for various purposes–for domestic water supply, irrigation, and in a variety of industrial processes. Some of these uses are non-consumptive, i.e. they do not involve an appreciable reduction in the flow of water. Water has now become one of the most important raw materials of the world and many nations, particularly those in the arid and semi-arid areas, have become conscious of the importance of water to their economies. Interactions may be between different uses for river waters and/or between different users. The nature of the interactions between the different uses varies widely in different parts of the world depending on climate, economic, and social conditions.

The upper KRB encompasses an area of about 43,000 km^2. It is located in the southwestern part of Iran and experiences a semi-arid to arid climate. Most of the agricultural area in the upper KRB is rainfed and a large proportion of the region’s agricultural livelihood is based on dryland farming. Water scarcity is increasing with diversions to agriculture declining.

Rainfall in the KRB rainfed areas is characterized by low annual amounts, unfavorable distribution over the growing season, and large year-to-year fluctuations. In the upper KRB, a major dryland farming area in southwestern Iran, the annual rainfall ranges from 300 to 607 mm with an overall average of 452 mm and standard deviation (SD) of 58.7 mm. This size of the SD shows that the variation in the amount of precipitation from the upper parts of the basin to the site of the Karkheh Dam is large.

Rainfall occurs mainly during the winter and spring months (January to April) so that crops must often rely on stored soil moisture when they are growing most rapidly during April and May. In the wet months, the amount of stored water is ample and plants sown at the beginning of the season (October) are in their early

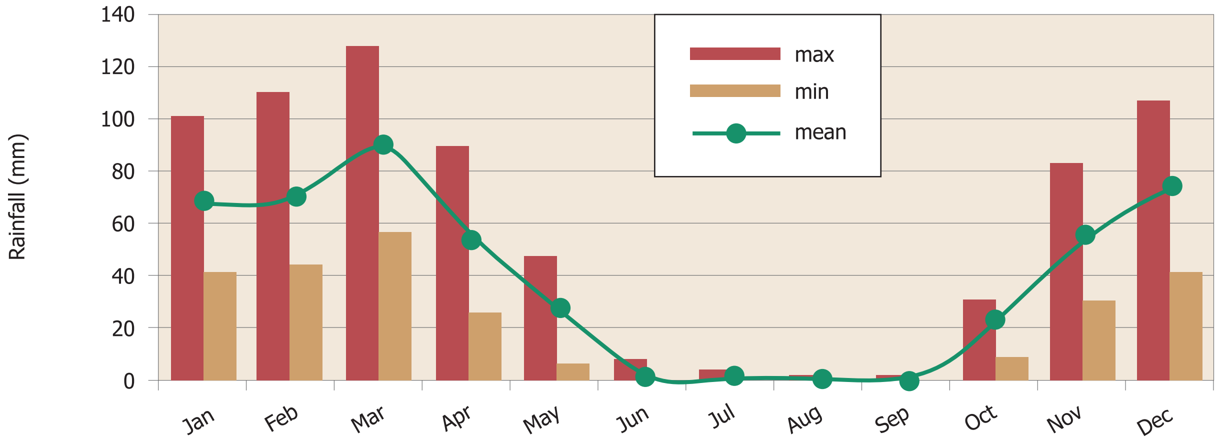


Figure 1.1. Variation in precipitation in the upper KRB.

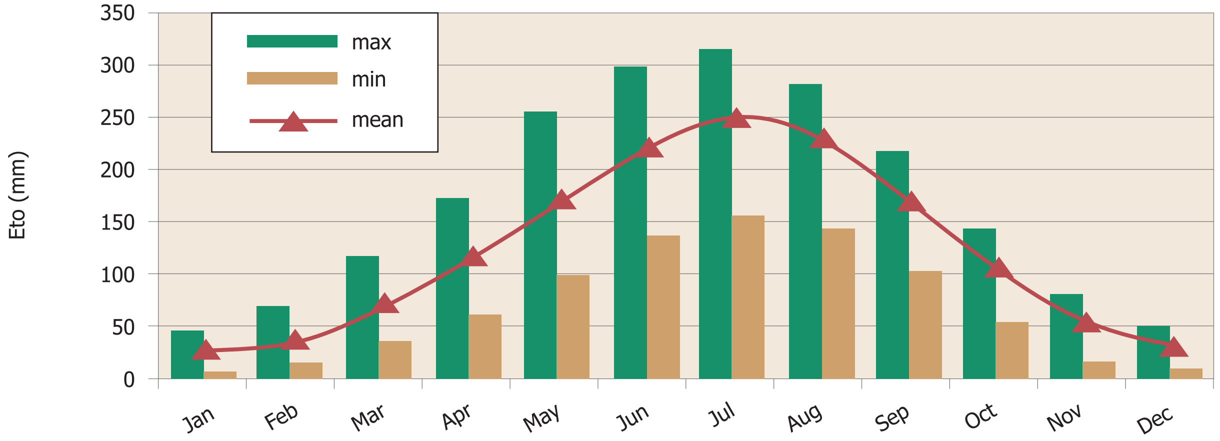


Figure 1.2. Average, maximum, and minimum ETo in the upper KRB.

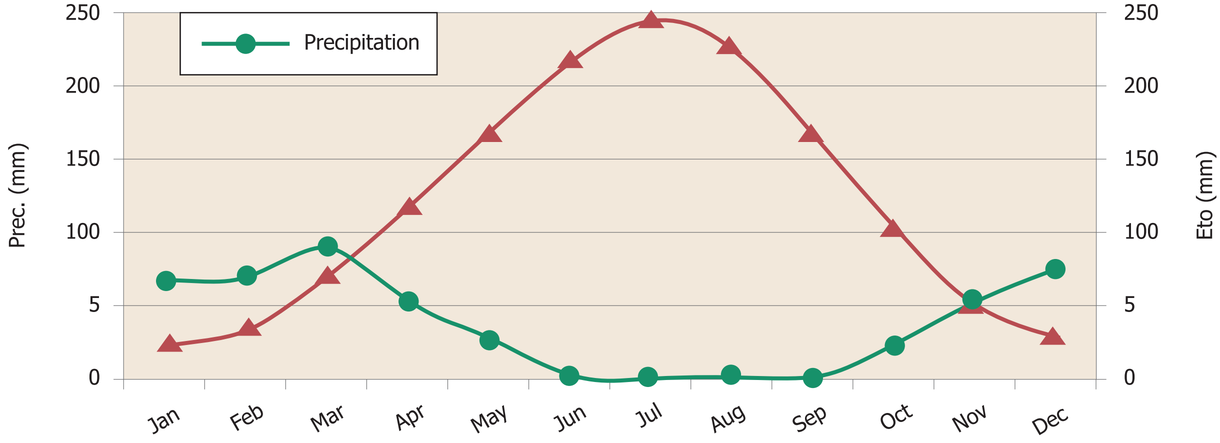


Figure 1.3. Average precipitation and ETo in the upper KRB.

growth stages. The water extraction rate from the root zone is limited. Figure 1.1 shows the average rainfall amounts as taken from precipitation maps of the upper KRB (De Pauw *et al*., 2008).

During spring, plants grow faster with a high evapotranspiration rate and rapid soil moisture depletion as a consequence of the higher evaporative demand conditions. Thus, a stage of increasing moisture stress starts in the spring and continues until the end of the season. Figure 1.2 shows the average values derived from evapotranspiration (ETo) maps of the upper KRB and Figure 1.3 provides a comparison of precipitation and ETo. This Figure also shows the dry and wet periods of the region.

In the last decade, the KRB region has received less rainfall than the long-term average, resulting in a corresponding reduction in stream flow. Some streams have more stable periods or are indicating periods of increasing flow despite declining rainfall, suggesting that groundwater interactions, stream flow regulation (such as dam releases), and land use change. To incorporate this climate variability, long-term data covering the wet and dry periods over a period of about 30 year are used in the analysis.

Iran's agricultural strategy identifies WP improvement as a top priority response to water shortage. Improving WP means growing more food or gaining more benefits with less water. To feed a growing and wealthier population with a more diversified diet will require more water for agriculture on an average annual basis. There is considerable scope for improving physical WP, but not everywhere. Increasing WP, especially the value produced per unit of water, can be an important pathway for poverty reduction. The productivity of the water used in agriculture increased by at least 100% between 1961 and 2001, mainly as a result of increases in crop yields as a consequence of improved agronomic practices (FAO, 2003). Irrigated rice yields doubled and rainfed wheat yields rose by 160% during that period, with little variation in water consumption per kilogram of output. Globally, the FAO estimates that water needs for food per capita were halved between 1961 and 2001, a significant saving and an equally significant gain for other water users.
By one calculation, a 1% increase in WP in food production makes available – in theory, at least – an extra 24 L/day per head of population, while a 10% increase would equal current domestic water consumption. Investing in agriculture and in agricultural water management, therefore, is an attractive strategy for freeing water for other purposes. Improving WP – whether under rainfed or irrigated conditions – requires, first, an increase in crop yields or values, i.e. the marketable yield of the crop for each unit of water transpired. Also necessary, are a reduction of all outflows or 'losses' (e.g., drainage, seepage, and percolation) except crop transpiration, and more effective use of rainfall, stored water, and water of marginal quality. Loss reduction and water control are considered parts of a basin wide integrated water resource management (IWRM), which gives an essential role to institutions and policies in ensuring that upstream interventions are not made at the expense of downstream water users. These three principles apply at all scales, from plant to field and agro-ecological levels, but options and practices associated with them require different approaches and technologies of different spatial scales.

Supplemental irrigation (SI), the addition of small amounts of water at the right time to supplement rain, is an excellent way to increase the productivity of water supplies and evapotranspiration.

Supplemental irrigation is the addition of a small amount of water during times when the rainfall to essentially rainfed crops fails. This addition should provide sufficient moisture for normal plant growth in order to improve and stabilize yields. Research results from ICARDA show that substantial increases in crop yields can occur in response to the application of relatively small amounts of SI (Oweis, 1997). When SI is recommended, the amount of water to be applied to increase WP significantly, the economic feasibility of carrying water over a particular distance, and the presence of biophysical limitations, particularly related to soils or land, are the domains for investigation.

In the dry areas, water, not land, is the most limiting resource for improved agricultural production. Maximizing WP, and not yield per unit of land, is therefore a better strategy for dry farming systems. Under such conditions, more efficient water management techniques must be adopted. Supplemental irrigation is a highly efficient practice with a great potential for increasing agricultural production and improving livelihoods in the dry rainfed areas. In the drier environments, most of the rainwater is lost by evaporation; therefore the RWP is extremely low. In West Asia and North Africa (WANA), a shortage of soil moisture in the dry rainfed areas occurs during the most sensitive growth stages (flowering and grain filling) of the cereal and legume crops. As a result, rainfed crop growth is poor and the yield is consequently low. The mean grain yield of rainfed wheat in WANA is about 1 t/ha, but it ranges from 0.5 to 2.0 t/ha depending on the precipitation amount and its distribution, and on agronomic factors, such as soil fertility and crop variety. These yield levels are far below the yield potential of wheat (more than 4 to 5 t/ha). Supplemental irrigation with a limited amount of water can, if applied during critical crop growth stages, result in substantial improvements in yield and WP.

Research results from ICARDA and others, as well as harvests from farmers' fields, showed substantial increases in crop yield in response to the application of relatively small amounts of irrigation water. This increase is achieved in areas with low as well as high annual rainfall. The results show that increases in wheat grain yields are achievable in the low, average, and high rainfall areas of northern Syria, when limited amounts of SI are applied. Applying 212 mm of additional water to rainfed crops receiving an annual rainfall of 234 mm resulted in a yield increase of 350%.Similarly, applying 150 mm of SI to crops receiving 140 mm annual rainfall produced a 140% increase and applying 75 mm of SI to crops receiving 504 mm annual rainfall increased the yield 30%. By definition, rainfall is the major source of water for crop growth and production, thus the amount of water added by SI cannot by itself support economic crop production (Oweis and Hachum, 2006). In addition to yield increases, SI also stabilized wheat production from one year to the next. The coefficient of variation was reduced from 100 to 20% in rainfed fields that adopted SI (Oweis and Hachum, 2006).

The effect of SI goes beyond yield increases to substantially improve WP. Both the productivity of the irrigation water and that of the rainwater are improved when they are used conjunctively. The average RWP of wheat grains in WANA is about 0.35 kg/m^3. However, it may increase to as high as 1.0 kg/m^3 with improved management and favorable rainfall distribution. It was found that one cubic meter of water applied as SI at the proper time might produce more than 2.0 kg of wheat grain over that of a rainfed crop. Furthermore, using irrigation water in conjunction with rain was found to produce more wheat per unit of water than if it is used alone in fully irrigated areas where rainfall is negligible. In fully irrigated areas, the WP for wheat ranges from 0.5 to about 0.75kg/m^3, one-third of that achieved with SI. This difference suggests that the allocation of limited water resources should be shifted to more efficient practices (Oweis and Hachum, 2006).

Northern Iraq is typical of WANA's rainfed areas and is where most of the grains of the country are produced. In a rainfall zone (having from 300 to 500 mm with non-uniform temporal and spatial distribution), huge investments in SI systems were made to overcome rainfall shortages. The results of studies conducted by ICARDA and Iraq showed that substantial improvement can be made in yield and WP by using SI in conjunction with proper production inputs and system management. In the growing season of 1997/98 (annual rainfall 236 mm), rainfed wheat yield increased from 2.16 to 4.61 t/ha by applying just 68 mm of irrigation water at the critical time. Applying between 100 and 150 mm of SI in April and May achieved the maximum results. Early sowing (November) is the optimal sowing date for wheat in northern Iraq. Every week's delay in sowing may result in a grain yield loss of up to 0.5 t/ha of wheat. The yield, especially the biological, significantly increased with an increase in nitrogen fertilizer and farmers were strongly advised to continuously monitor the nitrogen level in the soil for economic and environmental reasons (Oweis and Hachum, 2006).

In the highlands of the WANA region, frost conditions occur between December and March and put field crops in a dormant mode during this period. In most years, the first rainfall sufficient to germinate seeds comes later than October resulting in the crop stand being small when frost occurs in December and stops their growth. As a result, rainfed yields are much lower than when the crop stand is good and the crop takes off in early spring.

Ensuring a good crop stand in December can be achieved by early sowing and applying a small amount of SI in October. The SI given at early sowing dramatically increases the wheat yield because the plants which emerge earlier in the autumn grow more vigorously and yield much more in the following spring than plants which germinate late.

A four-year trial, conducted in the central Anatolia plateau of Turkey, showed that applying 50 mm of SI to wheat sown early increased grain yields by more than 60%, adding more than 2 t/ha to the average rainfed yield of 3.2 t/ha (ICARDA, 2003). Water productivity reached 5.25 kg grain/m^3 of water consumed, with an average of 4.4 kg/m^3.

These are extraordinary values for WP with regard to the irrigation of wheat. The study also revealed that SI given later in the spring and early summer further increased yields, but resulted in lower WP. Similar results were obtained in the highlands of Iran at Maragheh (Oweis and Hachum, 2006).

A four-year field study (1998/99 to 2001/02) was carried out at the Ankara Research Institute of Rural Services to assess the effect of early sowing with SI and management options during other dry spells on the productivity of a bread wheat cultivar, 'Bezostia'(Ilbeyi *et al*., 2006).

Treatments included early sowing with 50 mm of irrigation water; normal sowing with no irrigation constituted the main plots. Four spring SI levels occupied the sub-plots. These were rainfed (no irrigation), full irrigation to meet crop water requirements, and two deficit irrigation levels –one-third and two-thirds of the full irrigation treatments.

The results showed that early establishment of the crop, using 50 mm of irrigation water at sowing, increased grain yield by over 65% and added about 2.0 t/ha to the average rainfed yield of 3.2 t/ha. Early sowing with SI allowed early crop emergence and development of a good stand before being subjected to the winter frost. As a result, the crop used rainwater more efficiently. Additional SI in the spring also increased yield significantly.

Applying one-third SI resulted in a grain yield of 5120 kg/ha while two-thirds SI achieved 5170 kg/ha and full SI, 5350 kg/ha. The mean productivity of irrigation water given at sowing was 3.70 kg/m^3 with a maximum value of 4.5 kg/m^3. Water productivity at one-third SI was 2.39 kg/m^3, at two-thirds SI was 1.46 kg/m^3, and at full SI was 1.27 kg/m^3 as compared to the RWP of 0.96 kg/m^3 (Ilbeyi *et al*., 2006).

The on-farm experiment involved five replications of two levels of nutrient application (unfertilized and fertilized) and two levels of SI (not irrigated and irrigated). It also included farmers' traditional practices, SI, fertilizer application, and SI combined with fertilizer application.

Supplemental irrigation ranging from 60 to 90 mm per season was applied based on the actual occurrence of dry spell induced crop water stress. The SI had a significant effect on grain yield over the three crop seasons ($p < 0.001$). Supplemental irrigation alone resulted in an average grain yield of 712 kg/ha, while fertilizer application alone gave an average grain yield of 975 kg/ha. Supplemental irrigation combined with fertilizer application resulted in an average grain yield of 1403 kg/ha, which is higher than the farmer's normal practice by a factor of three. In each year, the total above ground biomass yields followed the same pattern as the grain yields.

All three seasons provided data systematically supporting SI as a dry spell mitigating and yield gap reducing technology (Fox *et al*., 2003).

Supplemental irrigation and single irrigation are the major methods used in low rainfall areas to ensure that crops receive enough water to produce an economic yield. While water harvesting is generally used in areas that receive between 100 and 300 mm of rainfall annually, SI is used in areas with a slightly greater annual rainfall of approximately 300 to 600 mm (Oweis *et al*., 1999).

Supplemental irrigation and single irrigation have been described as techniques used on crops that can be grown using rainfall alone, in which a limited quantity of water is applied during times of low rainfall to ensure that enough water is received to support crop growth and stabilize yields (Oweis *et al*., 1999; Perrier and Salkini, 1987; Tavakoli and Oweis, 2004).

Supplemental irrigation is recommended to increase the crop and water productivities in the rainfed systems of the upper KRB. In this region the catchments are among the suitable rainfed zones of Iran, with a long-term average annual precipitation of between 350 and 500 mm. The objective of the present study is to examine the potential areas for expansion of SI in the rainfed areas of the upper KRB and assess the consequences on the downstream flow to the Karkheh Dam. The report provides an overview of the hydrology of the upper KRB, from the point of view of the quantity and quality of the water inflows into the Karkheh reservoir as affected by the use of the river water for SI upstream of the dam.

1.3. Project location and methodology

The KRB is located in the west of Iran, from 30º 58' to 34º 56' N latitude and from 46º 06' to 49º 10' E longitude. The area is about 50,700 km^2, with considerable variations in elevation – from a minimum of 3 m above sea level in the south (Dasht Azadeghan) to a maximum of 3645 m in the Karin Mountains in the north.

The population of the area is around four million and is concentrated in the main cities and towns of Kermanshah, Khoramabad, Malayer, Songor, Kamyaran, Nahavand, and Sosangerd. Outside these cities and towns the KRB is rural. The Karkheh Dam basin – the upper KRB – has an area of about 43,000 km^2 and the main Karkheh River is about 900 km long.

The climate of the basin is semi-arid to arid. Most of the agricultural area in the upper KRB is rainfed and a large part of the region's agricultural livelihood is based on dryland farming systems.

An iso-potential map for the KRB was made by overlaying the single vector themes related to terrain and land use. A minimum of three layers was considered adequate in order to generate the iso-potential map:

- Land use/land cover
- Slope map (+ terrain map)
- River segment layer

A good, detailed soil map will help to determine priority areas for allocation.

1.3.1. Work units

Monthly flow data for the KRB is limited. Some monthly flow time series for the KRB (primarily for the last 10 years) have been provided by the Iran Water Resource Research Company (Iran Tamab).

Stream flow data for the KRB is available for the period 1954 to 2004, although there are long periods for which data are missing data. From the list of 106 stations, only the 53 stations operating during the entire 1975-2004 period were selected. Stations with data covering at least 10 years were selected for analysis.

All monthly flow records for the period 1975-2004 were extracted from the Iran Tamab database. The Iran Tamab data was considered as the base data for the country.

The work units for water allocation were 53 sub-basins. In the study, gauged watersheds were delineated and a drainage analysis of a terrain model was performed automatically. The following information was extracted from the Iran Tamab database for each station

- Latitude
- Longitude
- Start year
- End year.

Figures 1.4, 1.5 and 1.6 show all of the 53 delineated watersheds selected as the work units of the study. All the monthly flow records for the period 1975-2004 were derived from the Iran Tamab database.

Benchmark sites are an essential component of an integrated natural resource management (INRM) approach to agricultural research. In the ICARDA vision of INRM implementation, they are relatively small areas, used to develop, test, adapt, and evaluate improved genetic and natural resources management practices and technologies under real-life conditions and not in research stations (Oweis *et al*., 2006).

If extrapolation of the research conducted in these benchmark sites to a wider area is to be meaningful, the sites have to

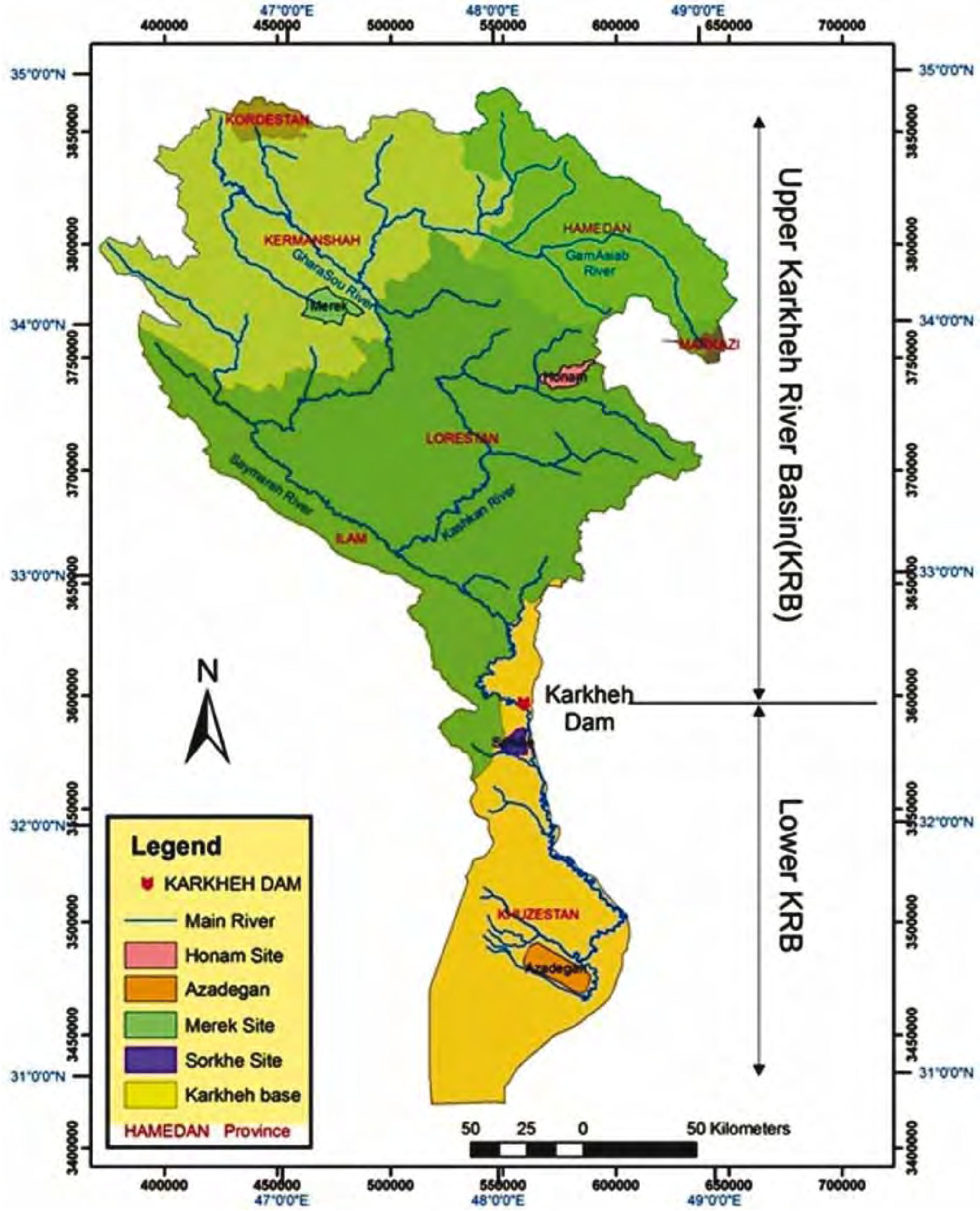


Figure 1.4. The general location of the KRB.

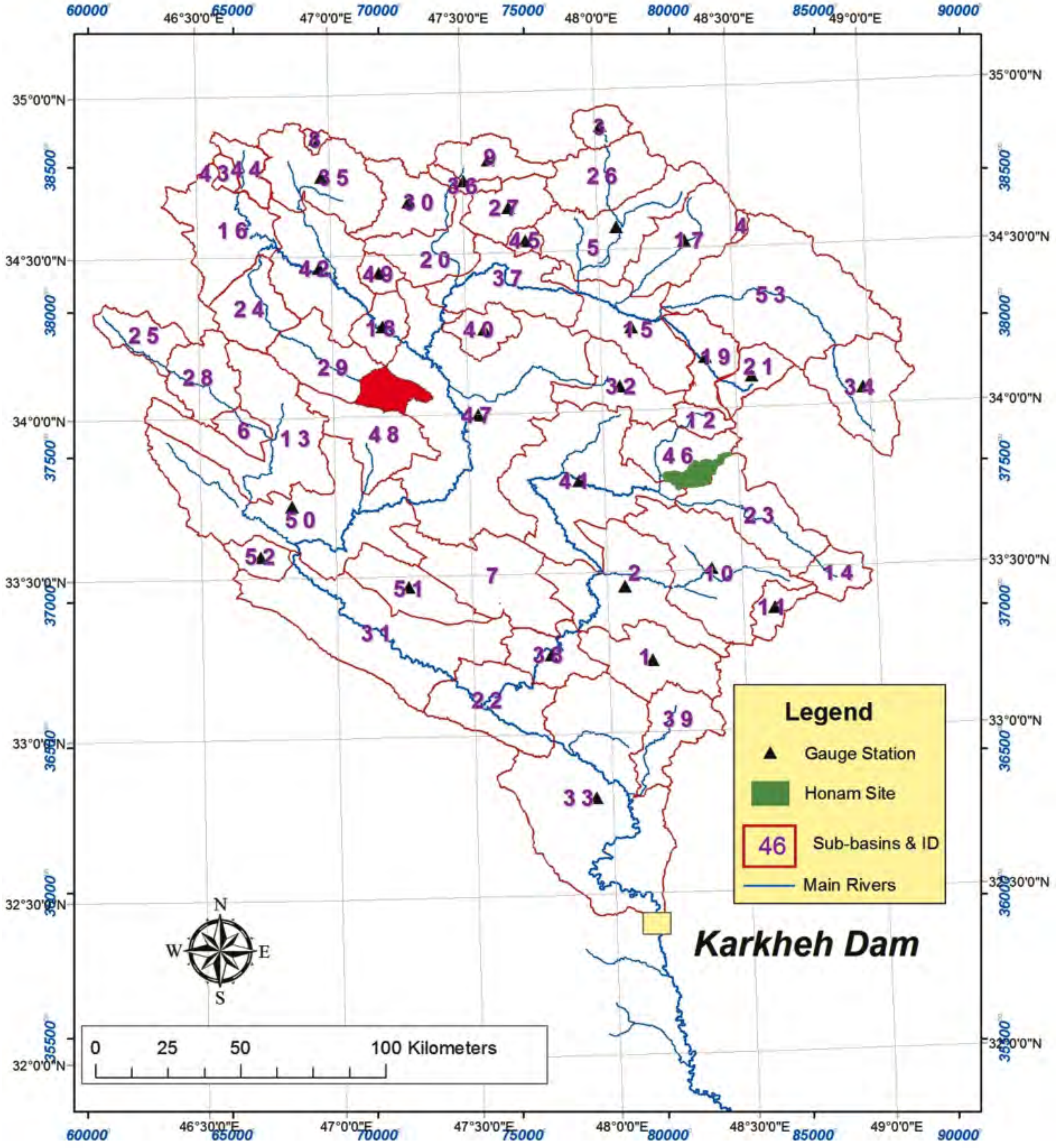


Figure 1.5. Main rivers and sub-basins in the KRB.

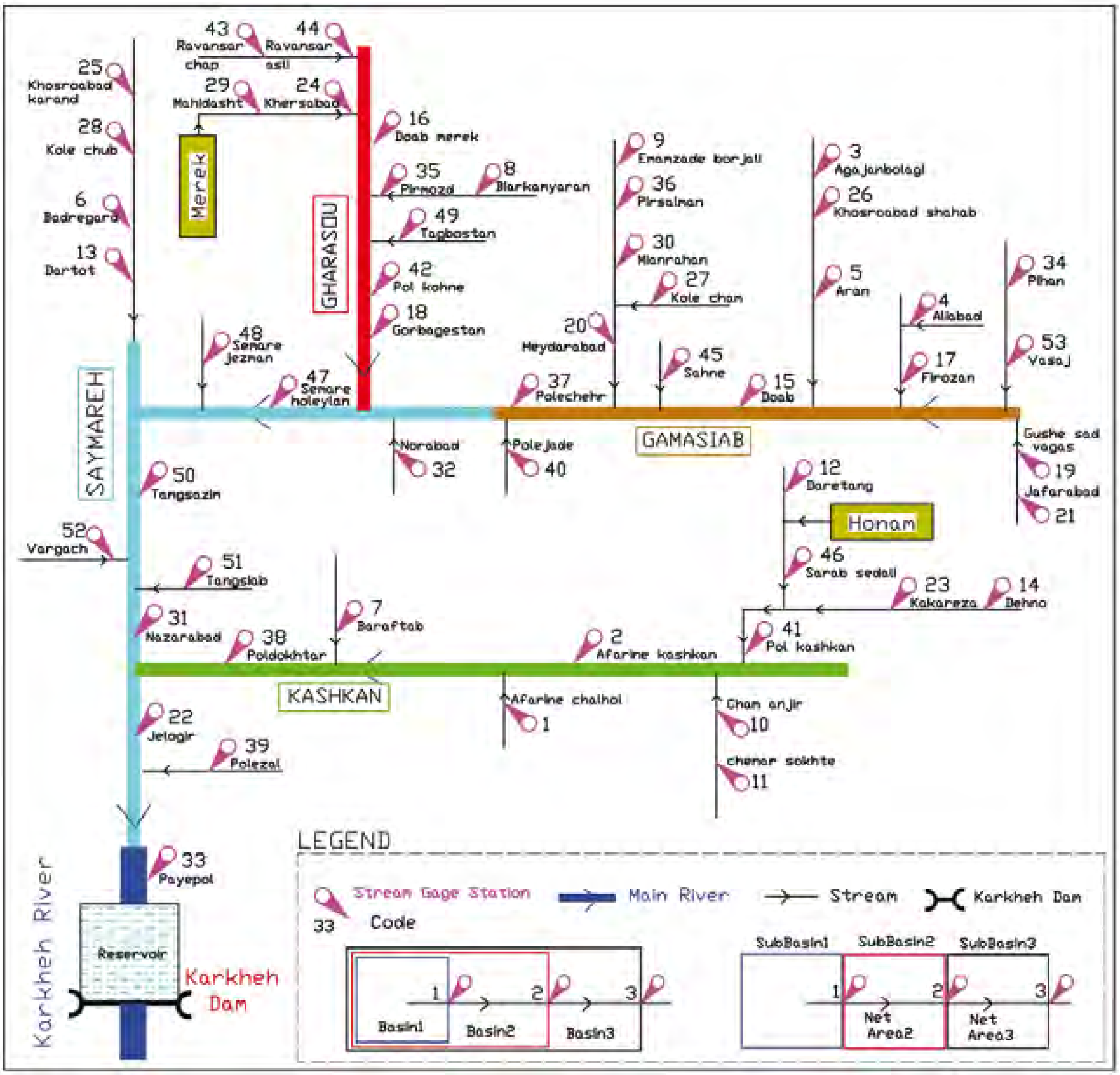


Figure 1.6. Schematic of the stream gauge flow network of the upper KRB.

be representative of the larger target areas of the research. This means that they should resemble the broader agro-ecological zone(s) of interest in terms of the major agricultural, environmental, and human elements.

Four benchmark sites were established in the KRB, two for the upper and two for the lower part of the basin. The locations of these sites are shown in Figure 1.4. The sites in the upper KRB, Honam and Merek, were delineated as hydrological catchments.

1.3.2. Precipitation map

A database of point climatic data covering the monthly averages of the precipitation totals for the main stations in Iran for the period 1973-1998 was obtained from the Iranian Meteorological Organization. The ‘thin-plate smooths spline’ method of Hutchinson, as implemented in the ANUSPLIN software, was used to convert this point database into ‘climate surfaces’.

The Hutchinson method is a smoothing interpolation technique, using the elevation obtained from a digital elevation model as a co-variable, in which the degree of smoothness of the fitted function is determined automatically from the data by minimizing a measure of the predictive error of the fitted surface, as given by the generalized cross-validation (De Pauw *et al*., 2008).

The first criterion for developing and finding suitable lands for SI is identifying areas with an annual rainfall of more than 300 mm. Figure 1.7 shows an annual precipitation (rainfall + snow equivalent water) map of the KRB. In the southern agricultural region of the KRB (the lower KRB) precipitation is considerably less than in the northern and central agricultural regions.

A strong gradient of declining precipitation, from between 300 and 350 mm to between 140 and 200 mm in the lower KRB ensures that rainfed agriculture is limited to the northern region. Further south, only irrigated agriculture is possible. According to the annual precipitation map of the KRB, the upper KRB region above the Karkheh Dam is suitable for the development of SI.

1.3.3. SRTM digital elevation model and Slope

The Shuttle Radar Topographic Mission (SRTM[1]) is a high resolution, global, digital elevation model (DEM) released in 2000. Its resolution is 3 arc-seconds (90 m), suitable for use at a scale 1:100,000. From this data set, available from the internet, the sub-set covering the KRB was created and the slopes were derived using the slope function in the spatial analyst module of ArcGIS (ESRI, Inc.).

Slope, a basic element of landform, plays an important role where mechanization is concerned. Sys *et al*. (1991) believe that on slopes steeper than 20% mechanization becomes impossible and that for slopes less than 20% there are still important variations in productivity according to the variations in slope. Navas and Machin (1997) state that in order to avoid soil erosion and other problems derived from the use of machinery, only land with slopes less than8% should be used.

The slope of the land is very important. Some types of sprinklers can operate on slopes up to 20% or more, but furrow or graded border irrigation is usually limited to a maximum slope of from 2 to 6%. Trickle irrigation can be used on slopes up to 60% (Walker, 1987).

Suitable slopes for surface irrigation should be of less than 5%, for sprinkler irrigation between 0 and 16%, and for

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[1] http://srtm.csi.cgiar.org/SRTM_FAQ.asp

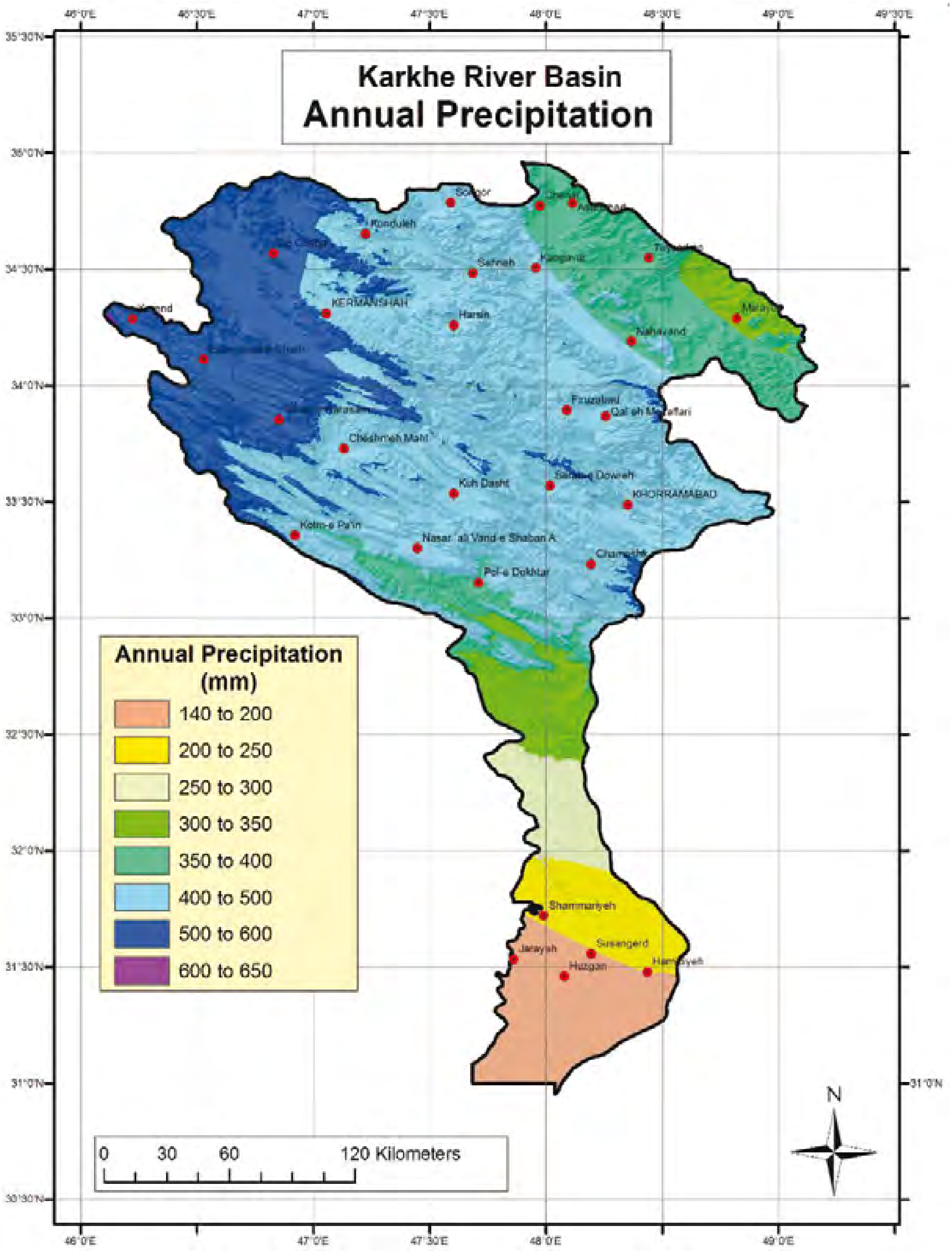

Figure 1.7. Mean annual precipitation (mm) of the KRB.
Source: De Pauw *et al*., 2008.

trickle irrigation between 8 and 12%. Steep slopes (between 16 and 20 %) are suitable for tree planting if there is extra water that can be allocated (according to field work on the Marageh research stations). Steep slopes are not accessible for agriculture or even grazing. Therefore, the proposed classes of slopes are from 0 to 5%, from 5 to 8%, from 8 to 12%, and from 12 to 20%.

Slope classes determine the priorities of rainfed cultivation for SI. Irrigated areas according to the simplified land use map of upstream KRB are considered as accessible water resources for potential SI areas buffering the irrigated areas.

1.3.4. Land use/land cover map of KRB

The land use/land cover (LULC) map of the KRB is based on the country vector map produced by the Forest, Rangeland, and Watershed Organization (FRWO 1998), which was developed from visual interpretation of hardcopy Landsat images and field checking. The LULC map was prepared by clipping from the latter map to the KRB boundary and converting to raster using a cell size of 0.000833 decimal degrees, which is equal to the resolution of the high resolution SRTM DEM. For the KRB area it contains 12 classes.

The 12 classes were reduced to six. These six classes are, with the exception of the 'rainfed cultivation' class (in which two LULC classes were merged), the same as their counterparts in the original map. Four of the original LULC classes (saline areas, sand dunes, urban areas, lakes/reservoirs) were taken out of the simplified LULC theme and regrouped as 'General themes'. The class 'Rock outcrops' was added to the corresponding class 'Rock outcrops and very shallow soils' in the soil management domains map. The areas with classes that were taken out of the new LULC classification were reclassified as 'na' (not applicable) (De Pauw *et al*., 2008).

The map has six homogeneous classes differentiated according to the following major categories

- Bare areas with or without sparse cover
- Cultivated areas
- Forests and other wooded areas
- Rangelands
- Irrigated areas
- Water bodies.

Also this vector map was converted into raster format, for compatibility with the river and SRTM DEM. Figure 1.8 shows the simplified land use map of the KRB.

Landsat imagery is very suitable for obtaining the necessary LULC classes that are used in the evaluation. From the satellite imagery the necessary LULC layers are derived for extracting the irrigated perimeters, determining the distances from the irrigated perimeters, and identifying prohibited or potential areas for expansion of SI.

From the DEM, the permitted slope range is determined. Strictly speaking, satellite imagery is not necessary if recent LULC maps exist at a good resolution. Table Apx-1.1 shows land use information of the sub-basins.

1.3.5. Soil map of the KRB

The original 1:1,000,000 digitized soil map of Iran (1996 edition) was clipped to the KRB outline. The soil map of Iran is a soil association map, in which the soil components are classified according to soil taxonomy. The association contains listings of dominant, associated, and included soils, but no percentages. Each mapping unit is also classified as a soil and terrain (SOTER) database land form.

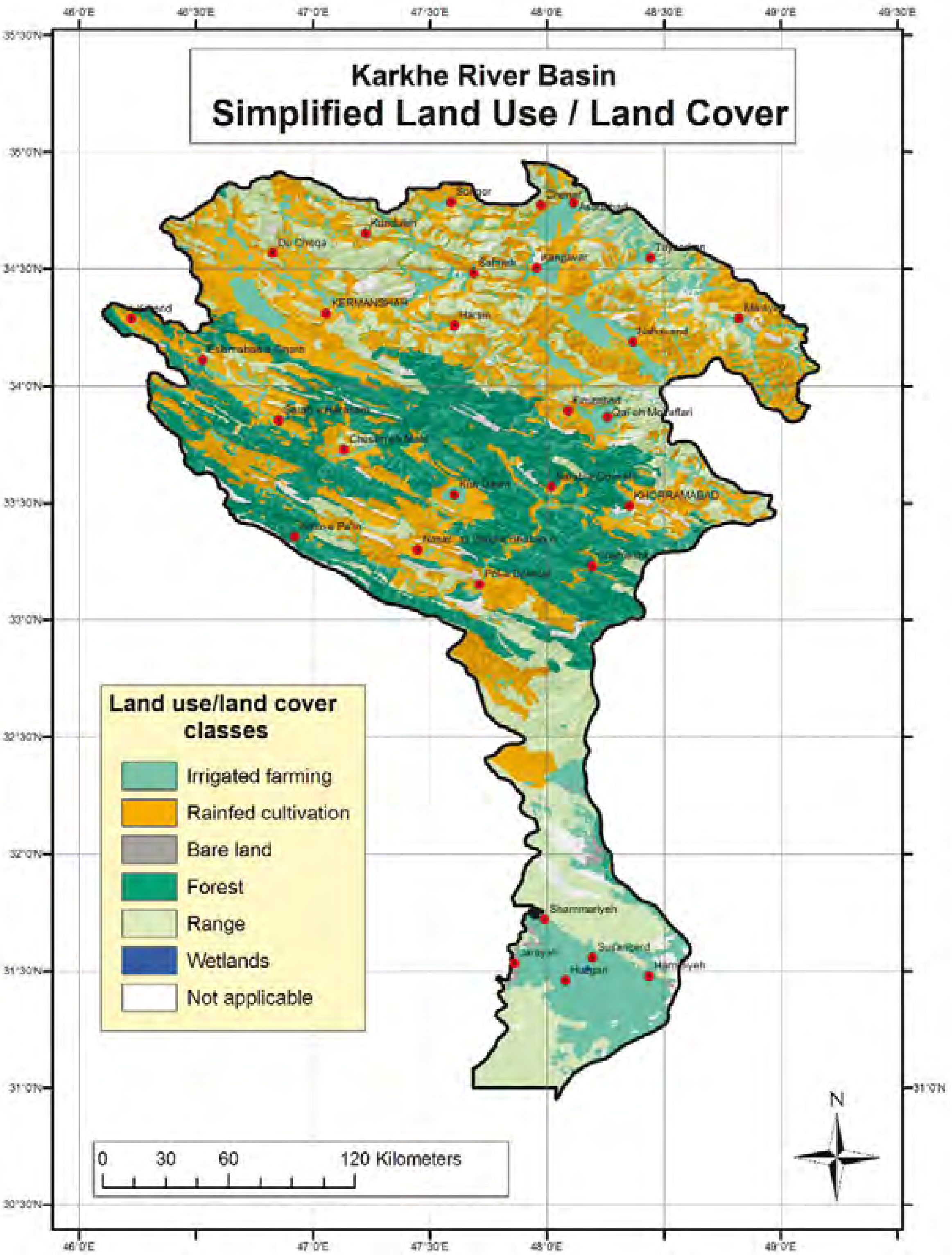

Figure 1.8. Simplified LULC map of the KRB (Source: De Pauw *et al*., 2008).

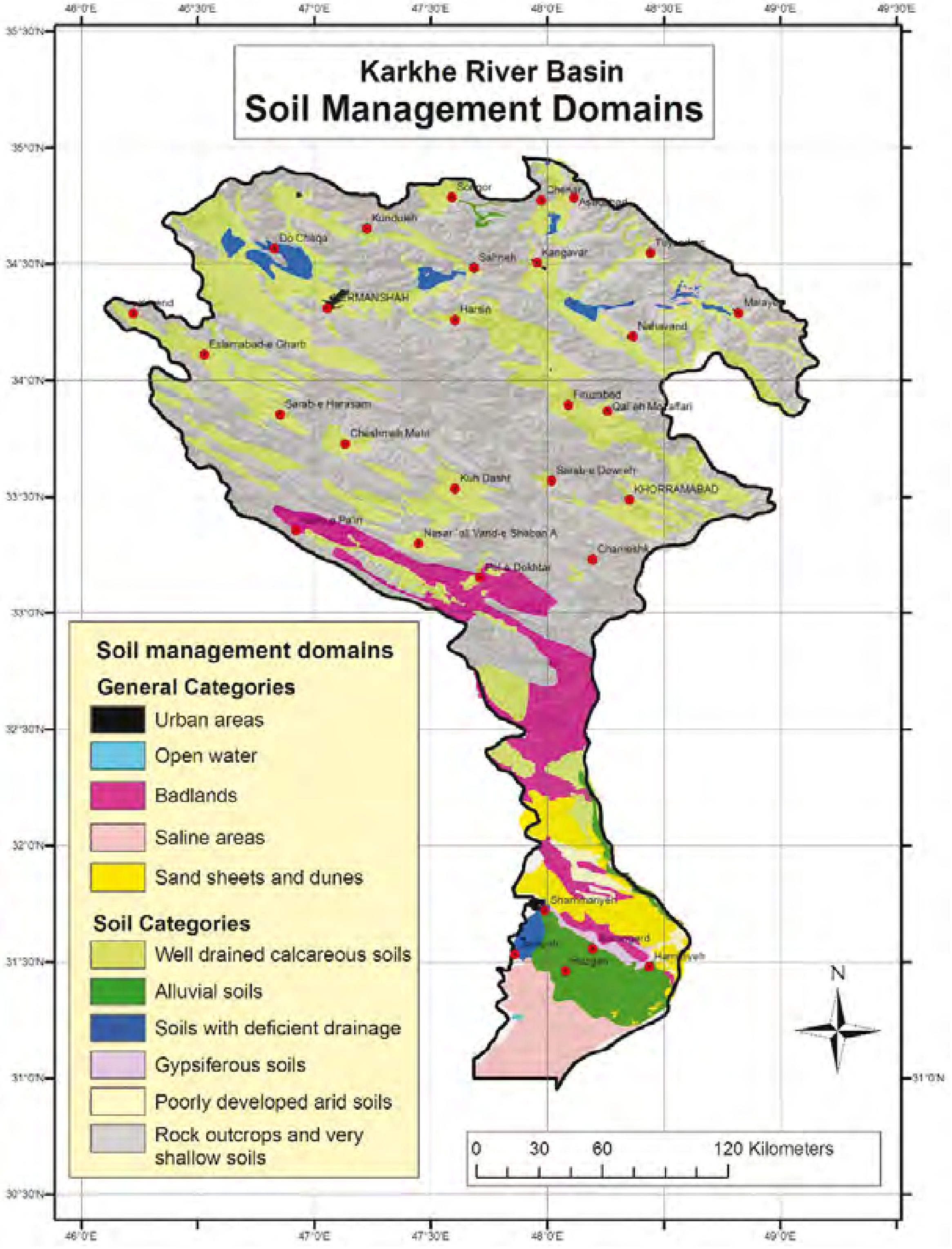

Figure 1.9. Soils of the KRB (Source: De Pauw *et al*., 2008).

The numeric labels of the original soil map refer to the soil association codes. The soil classes of the soil map of Iran were then regrouped in accordance with their major properties with respect to ‘usability’ into ‘soil management domains’ (SMD).

The regrouping of the soils capes into SMDs was based on the dominant soil taxonomic unit. The classes ‘dune land’, ‘sandy soils’, ‘saline soils’, ‘badlands’, and ‘urban’ were removed from the new soil map and added to the corresponding General Theme layers in the Agro-Ecological Zoning(AEZ) map. The class ‘marsh’ was removed from the new soil map and added to the land use category ‘wetlands’. The areas with classes that were removed from the new SMD classification were reclassified as ‘na’ (De Pauw *et al*., 2008)

The vector soil map of the KRB basin was converted into raster format, for compatibility with the climate surfaces and SRTM DEM. Figure 1.9 shows the simplified soil map of KRB. This map, particularly at the upper parts, is very rough and does not show the limitations of the soils and, therefore, in this research the soils are accepted as uniform (De Pauw *et al*., 2008).

1.4. Suitability for SI

According to the simplified LULC map, the upstream KRB includes 15,840 km^2 of dryland areas with potential for rainfed cultivation. Since steep slopes are not suitable or agriculture, the slope classes were used to determine the priorities of rainfed cultivation for SI. Of the 42,908 km^2 of the upper KRB in the 53 selected sub-basins, 13.5% of the rainfed areas with slopes between 0 and 5% has the first priority and areas with slopes between 5 and 8% has the second priority for SI development.

The water resources of a region are in its rivers, springs, and groundwater. Different types of irrigation works have been developed in the upper KRB. These include percolation wells (shallow or deep), springs, qanats (subterranean canals or infiltration galleries), ponds or small reservoirs, storage reservoirs, pumping or lifting from rivers and lakes, and different combinations of the above. In this stage, the source from which the water is to be allocated should be decided. Irrigated areas according to the simplified land use map of the upstream KRB are assumed to have accessible water resources for potential SI areas buffering the irrigated areas. River and surface stream flows are major accessible sources throughout the upper KRB.

Figures 1.10 and 1.11 show the distribution of the land use classes and slope classes of the rainfed areas of the upper KRB. For resolution consideration, The Sarab Sedali sub-basin, stream flow gauge station number 46, with the Honam site located inside it is selected to show the results.

1.5. Buffering methods

1.5.1. Irrigated areas buffer method

In this method, the current irrigated areas are considered as water sources for the irrigated areas regardless of the source of water (well or channel). The assumption is that the excess irrigation water is potentially available for additional irrigation schemes.

The method uses a combination of a simple model to calculate the additional rainfed area that can be partially irrigated by the potentially available water, with a water allocation procedure for the surrounding rainfed areas based on suitability criteria.

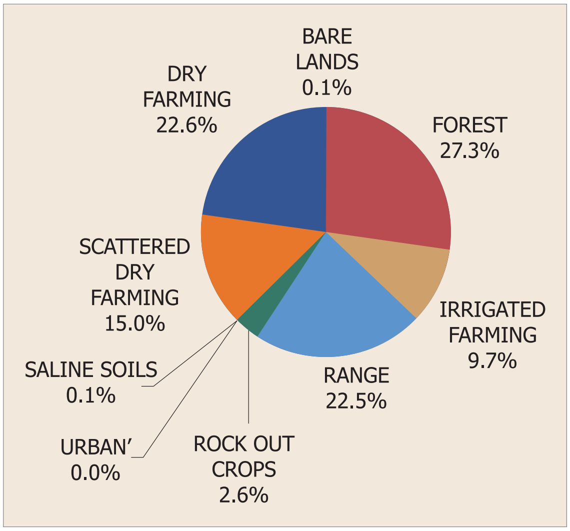

Figure 1.10. Percentage distribution of land use classes in the upper KRB.

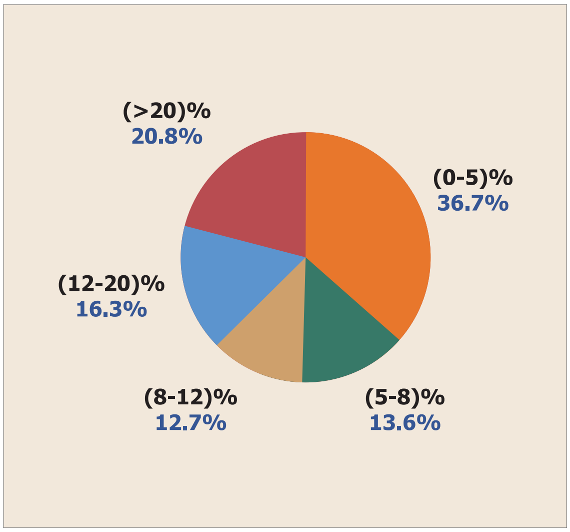

Figure 1.11. Percentage distribution of slope classes of the rainfed areas in the upper KRB.

This potential water from the irrigated areas is then allocated to the neighboring rainfed areas, using an allocation procedure that reflects the potential suitability of the areas surrounding an irrigation perimeter to benefit from a possible water allocation.

Small scattered irrigated areas have little water and thus are ignored as sources of water for potential SI development. Because of the different types of irrigation works, analysis of the whole basin is impossible. But, from the land use map the location of the irrigated areas is known and these areas can be assumed to have sufficient water resources to provide water for SI in the nearby areas. Approximately 10% of the total land in the upper KRB is presently irrigated.

Topographic restrictions on potential irrigation development in the rainfed areas include the location and relative elevation of the water source. Irrigation development is an economic decision that may involve fairly high operational costs. Some systems have limitations with respect to the type of soil or the topography on which they can be used. A small, readily available water supply is best utilized in a small capacity irrigation system that incorporates frequent application. A 100 m buffer for areas smaller than 1 ha, a 500 m buffer for areas up to 10 ha, a and 1000+ m buffer for the rest were created around irrigated land polygons and used to determine the economic feasibility of carrying water over a particular resource distance (Figures 1.12 to 1.15). This buffered layer is overlaid on the rainfed areas in the different slope classes and 53 sub-basins. This map called an iso-potential map of SI (Figure 1.15).

1.5.2. Rivers buffer method

In this method, rivers are considered as accessible water sources. Large quantities of water are abstracted from river flows for domestic water supplies and irrigation; the leftover flow is recorded at the gauges.

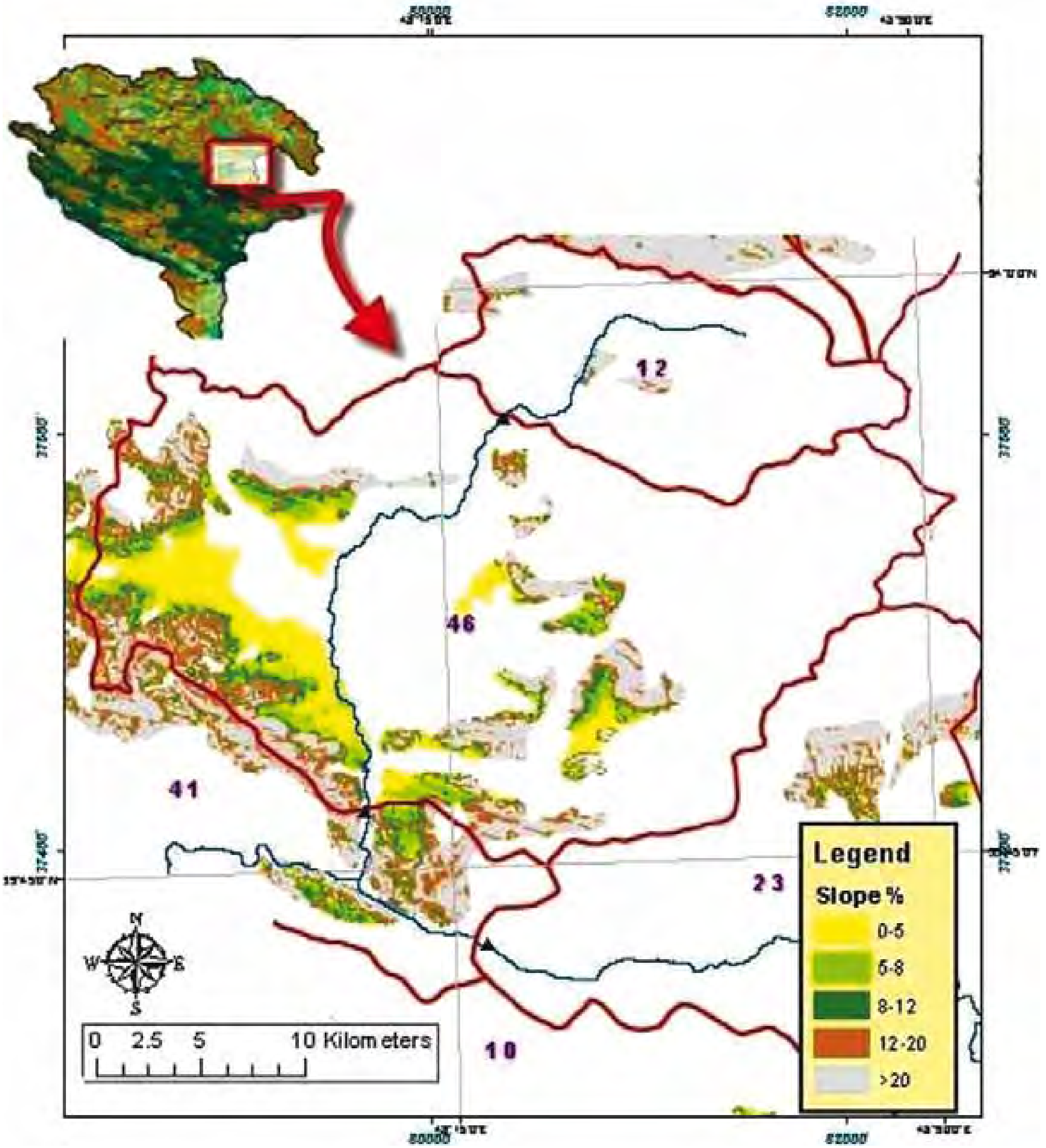

Figure 1.12. Sample rainfed areas in the different slope classes of some of the sub-basins of the upper KRB.

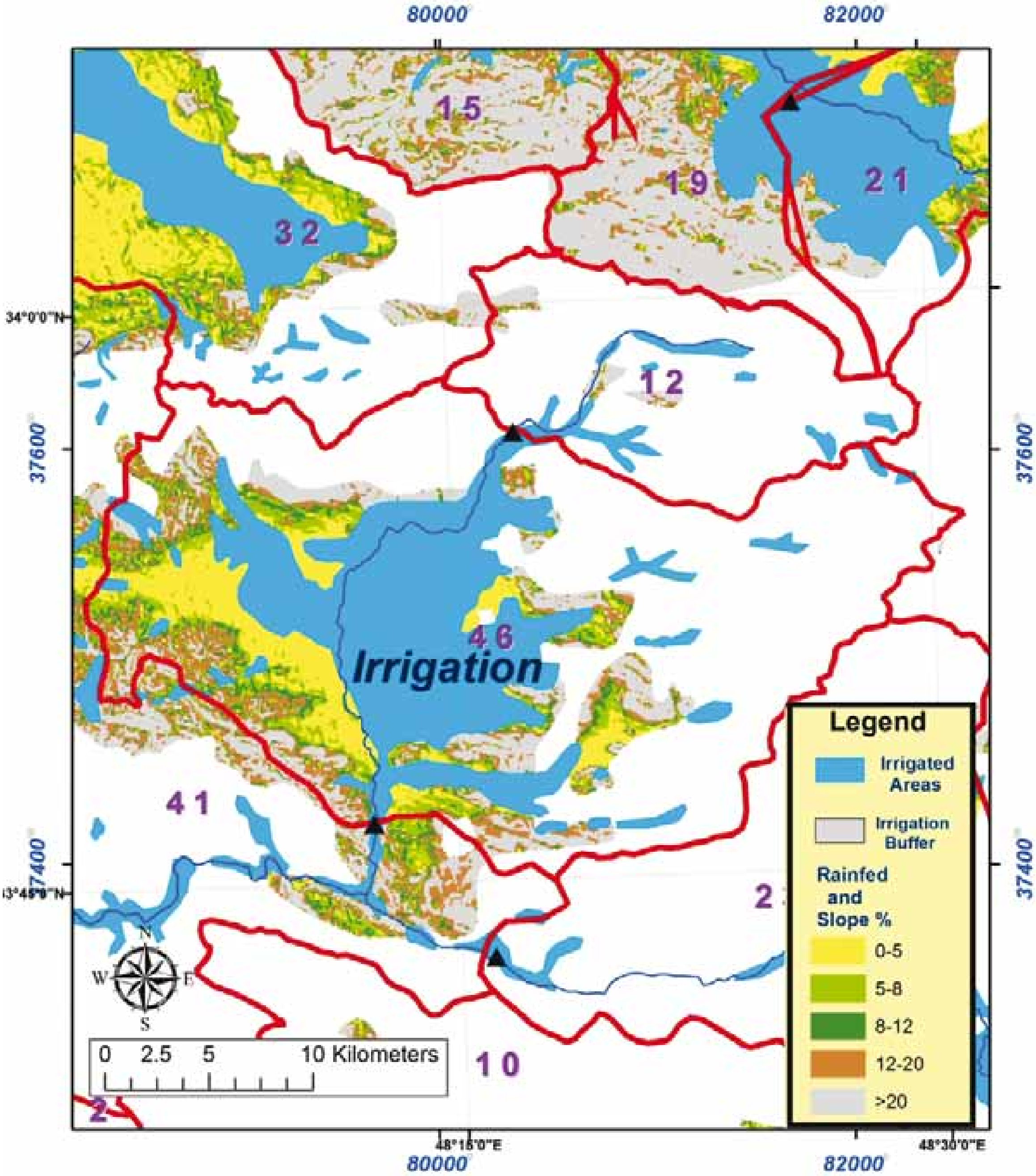

Figure 1.13. Rainfed areas and irrigated areas of some of the sub-basins in the upper KRB.

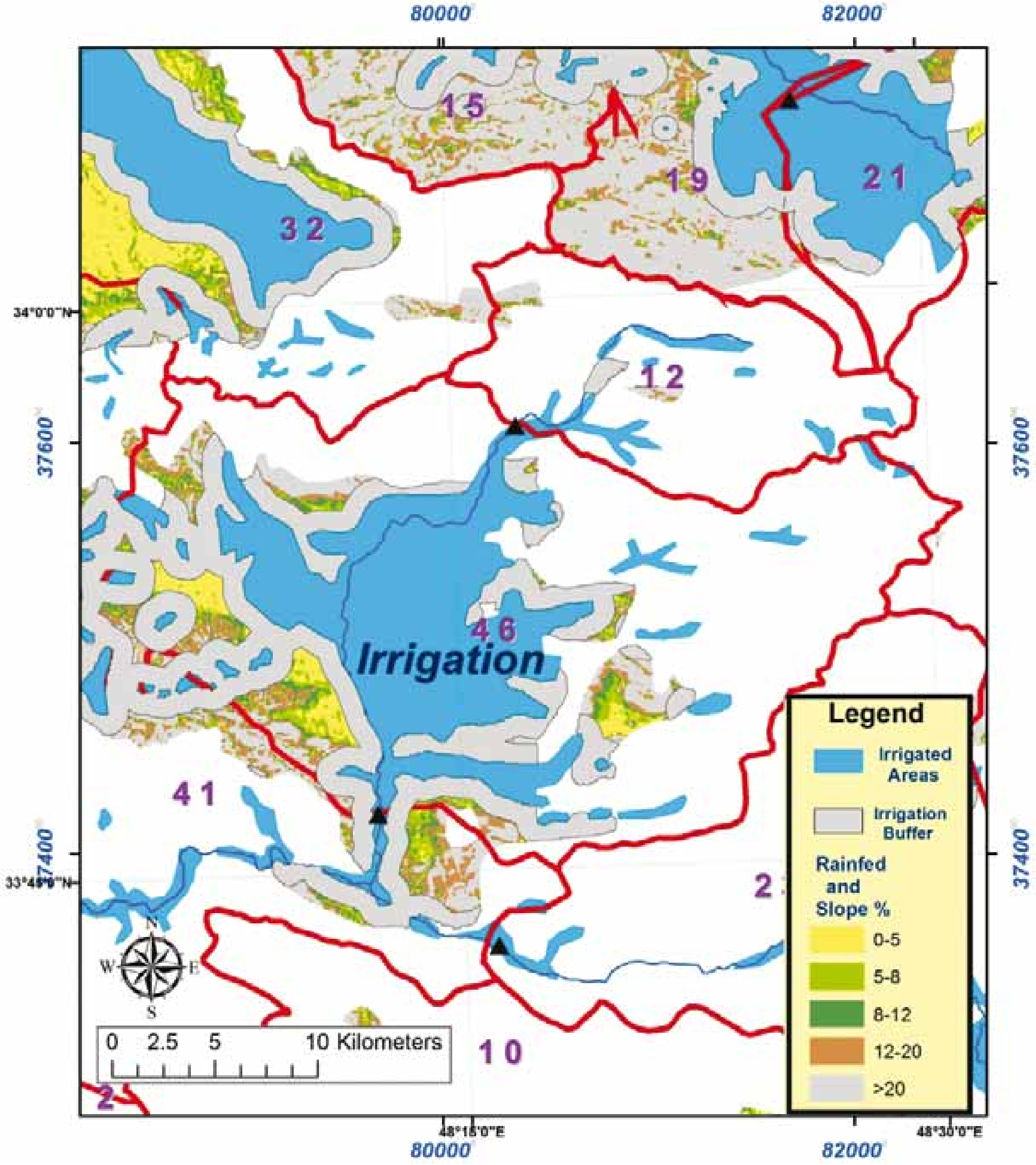

Figure 1.14. Irrigated areas and irrigation buffer areas of some of the rainfed areas in the upper KRB.

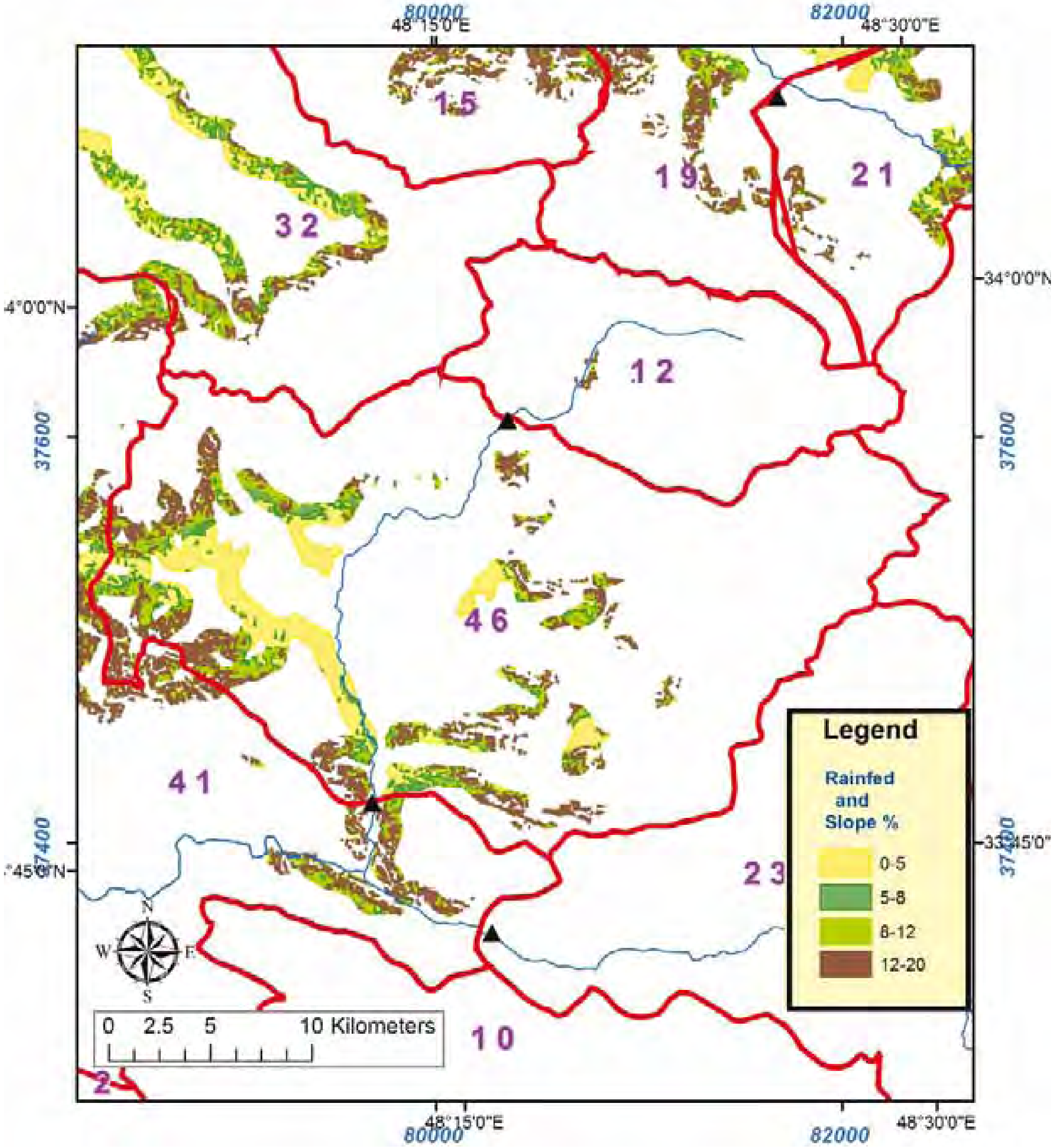

Figure 1.15. Rainfed areas suitable for SI in some of the sub-basins of the upper KRB.

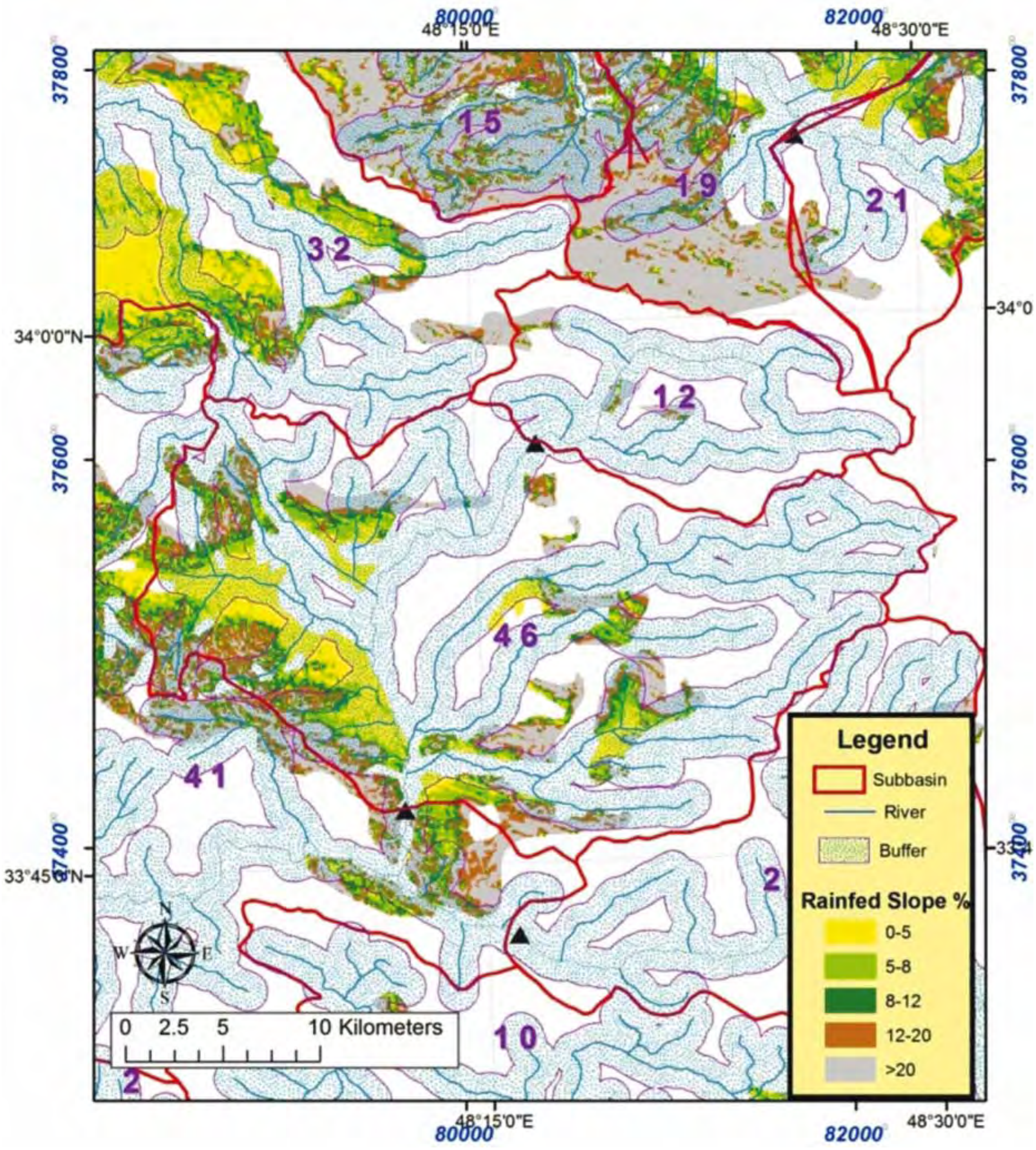

Figure 1.16. River buffers overlaid on some rainfed areas in the upper KRB.

A 1000m buffer area around the rivers was considered as having an economic feasibility for conveying water over a particular distance. Figure 1.16 shows the buffer areas around the rivers of the KRB. This buffer layer was overlaid on the rainfed areas of the 53 sub-basin with different slope classes. This map is called the iso-potential map of SI.

1.6. Results and discussions

The rainfed areas cover 15,840 km^2 of the total 42,908.3 km^2 of the upper KRB. The results of this study show that about 36.7% of the rainfed areas have slopes in the range 0 to 5%, 50.2% in the range have 0 to 8%, 62.9% in the range 0 to12%, 79.20% in the range 0 to 20% slope, and 20.8 % are not suitable for cultivation. Of the 53 selected sub-basins in the 42,908 km^2 of the upper KRB, 13.5% of the rainfed areas have a first priority for SI development (a slope in the range 0 to 5%) and 5% has a second priority (a slope in the range 5 to 8%). Almost 31.4% of the rainfed areas suitable for SI are located within a 1000 m buffer distance of the irrigated areas. Areas with a slope in the range 0 to 5% occur with a frequency of 17.4%, those with a slope in the range 5 to 8% occur with a frequency of 4.8%, those with a slope in the range 8 to 12% occur with a frequency of 4.4%, and those with a slope in the range 12 to 20% occur with a frequency of 5.3%. Nearly 46.5% of the same suitable rainfed areas are located within a 1000 m buffer distance of surface streams. Inside the river buffer zones the areas with a slope in the range 0 to 5% occur with a frequency of 22.4%, those with a slope in the range 5 to 8% occur with a frequency of 7.9%, those with a slope in the range 8 to 12% occur with a frequency of 7.2%, and those with a slope in the range 12 to 20% occur with a frequency of 9%.

This methodology has been developed for an assessment of the suitability for SI mapping. The approach can be applied, subject to the availability of similar data, without modifications to other dryland countries. In addition, it is a relatively straightforward exercise to modify the methodology to develop a regional or global map.

As results of the river buffer method show, there is more SI potential near the rivers than there is near the ground water resources(irrigated areas buffer method).A comparison of results between the two methods is presented in Figures 1.17 - 1.21. For this analysis and comparison the second method is more promising and closer to the real situation.

When a reliable and suitable supply of water becomes available for SI it can result in vast improvements in agricultural production and assure economic returns to the grower. As the total irrigated areas of the upper KRB are just 9.7%, then buffering around this area does not show the real high potential for SI development. The most common and easily accessible means of water supply are the rivers in the KRB, where flow data is recorded. Therefore, the second method, the rivers buffer method, was selected in this research. Figure 1.18 shows the selected iso-potential map for SI.

In this study it was assumed that the rainfed areas have suitable soils for cultivation. However, a high resolution soil map would be very useful in differentiating between high potential areas and soils with limitations for SI. All the rainfed areas have a potential for SI development, but the buffering methods target accessible areas that are economically suitable.

These methods do not consider the elevation and pump head; therefore,

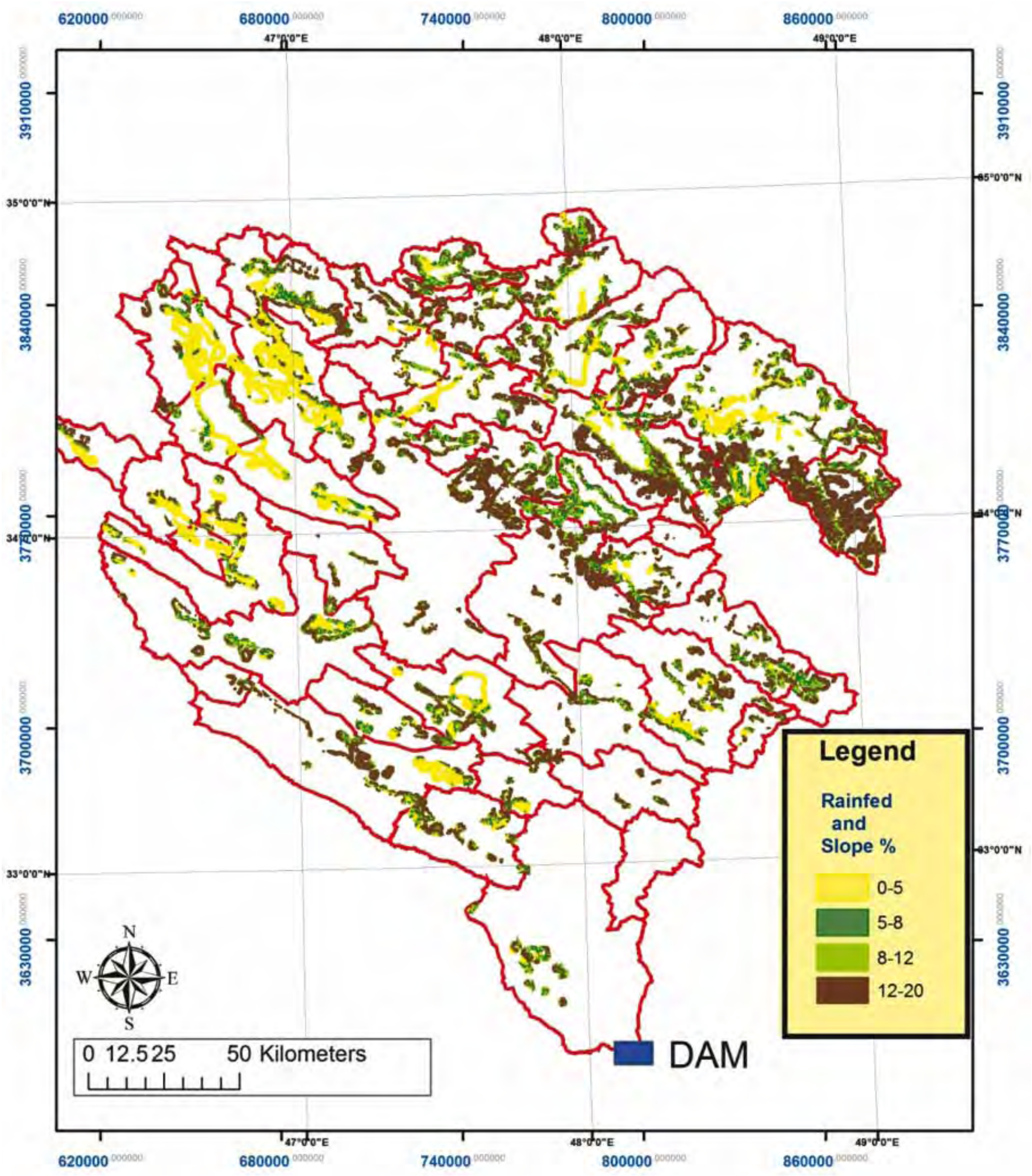

Figure 1.17. Iso-potential map for SI based on buffer areas of irrigated lands in the upper KRB.

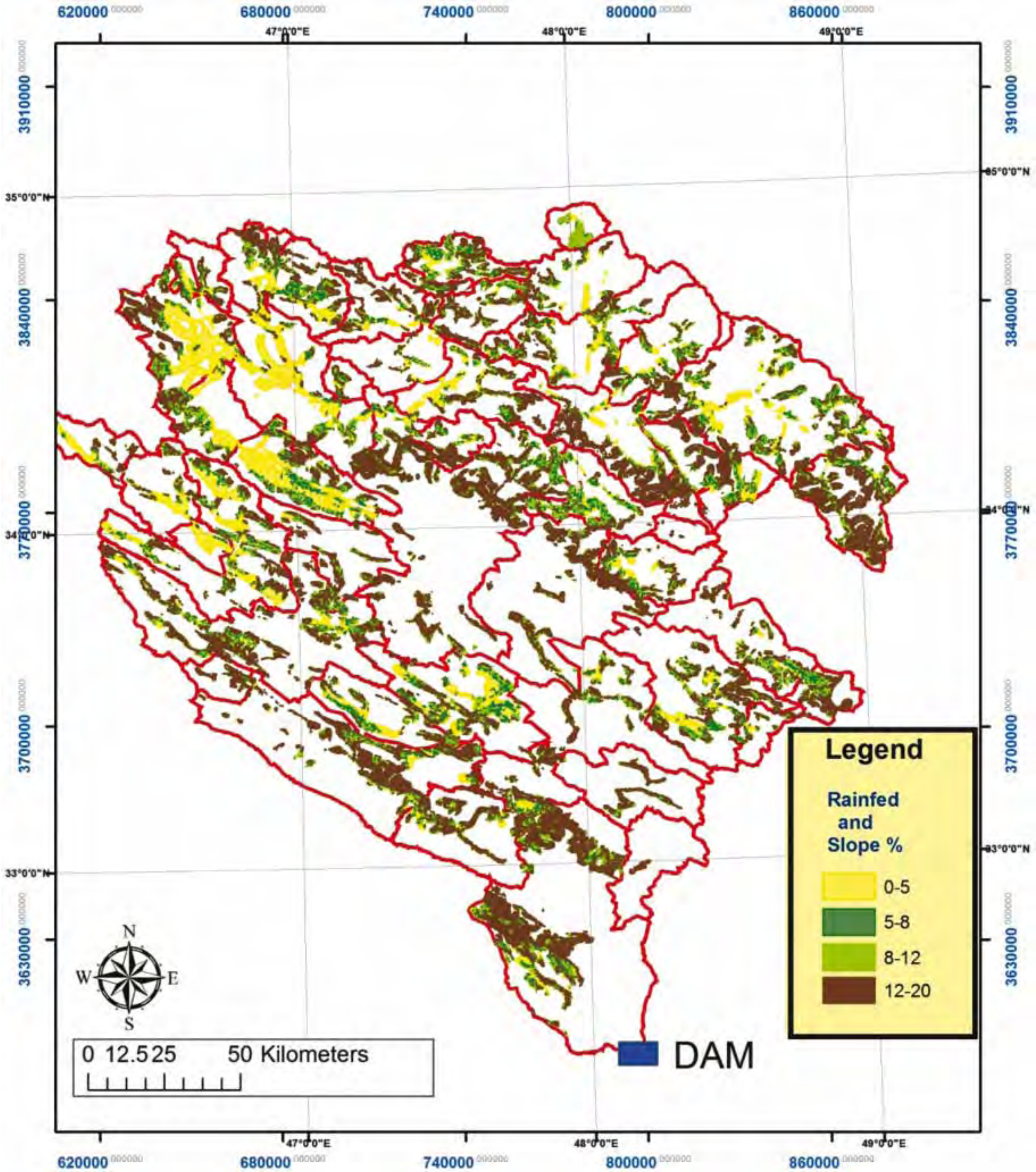

Figure 1.18. Suitable rainfed areas for SI in the upper KRB, based on the buffer areas around the rivers.

it is recommended that site selection techniques and a map inquiry function be used to target more detailed rainfed areas which are close to rivers, irrigated areas, and the pumping head. In this research, a constant distance for buffering was applied. It is suggested that a fuzzy logic procedure be used to develop better criteria for buffering. Infrastructure and irrigation systems should be studied and developed to identify areas suitable for SI areas in the upper KRB.

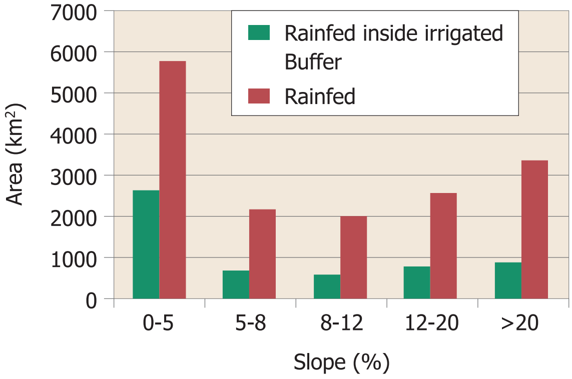

Figure 1.19. Comparison of rainfed areas and rainfed areas suitable for SI in the upper KRB using the irrigated areas buffer method (first method).

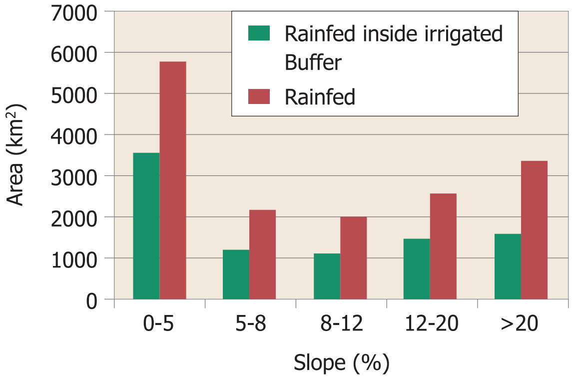

Figure 1.20. Comparison of rainfed areas and rainfed areas suitable for SI in the upper KRB using the rivers buffer method (second method).

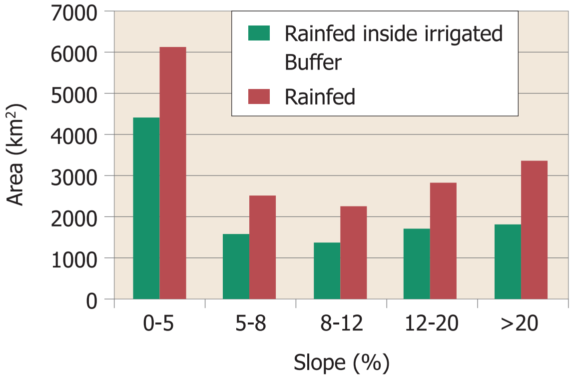

Figure 1.21. Comparison of rainfed areas suitable for SI in the upper KRB using the first and second methods.

Chapter 2.

Effect of supplemental irrigation on the flow downstream to Karkheh reservoir

Chapter 2: Effect of supplemental irrigation on the flow downstream to Karkheh reservoir

2.1. Introduction

To better geographically target areas suitable for various WP enhancing practices, such as SI, GIS-based methods have been developed.

The objective of the present study is to examine potential areas for SI in the rainfed areas of the upper KRB and the consequences on the downstream flow. This procedure; have four stages of assessment:

- SI iso-potential mapping or the targeting of lands suitable for SI development in the upper KRB
- Water resource requirements(system, SI, and environmental flow)
- Flow allocation
- Assessment of different SI scenarios.

2.2. Methodology

This research was undertaken to provide a summary of the surface hydrology in the KRB region. The summary focused on the surface water management of sub-areas in the region for the purpose of making allocations for SI to improve WP. The report includes an overview of the region, and then provides sections on the surface water management sub-areas for which stream flow data is available.

A priority of the this research is to determine potential water allocations for the region so that excess surface water can be managed to improve the WP of the wheat growing, rainfed areas of the upper KRB, Iran. Mean monthly flows in this report will be used to determine allocation limits for surface water use in the region. Mean monthly flows have been calculated using stream flow data, where available. Accomplishing the tasks described above involved a large amount of data processing using ArcGIS, and FORTRAN program. Major steps in the analysis included:

- DEM processing
- Selecting a set of flow gauges spanning the appropriate period of record
- Delineating watersheds from selected gauges
- Preparing an iso-potential map of SI
- Determining the irrigation water requirements of SI
- Determining the environmental flow requirement to each sub-basin
- Determining the net measured inflow to each sub-basin
- Allocation water for potential SI under different flow scenarios and targeting feasible SI areas according to available water of each sub-basin
- Assessing flow reduction to Karkheh Dam of each scenario.

2.2.1. Selecting gauging stations for analysis

Flow data for the KRB is limited. Some monthly flow time series for the KRB (primarily for the last 10 years) have been provided by Iran Tamab. Stream flow data for the KRB is available for the period 1954 to 2004, but there are with long periods where data is missing. From the list of 106 stations, stations which had been operating for the entire period 1975 to 2004 were selected. This selection yielded a set of 53 stations. Stations with at least 10 years of data were selected for analysis. All monthly flow records for the years 1975 to 2004 were extracted from the Iran Tamab database. The Iran Tamab data was considered as the base data for all cases in Iran. The key elements available in each station record including latitude, longitude, start year, and end year.

For covering wet and drought periods, 30 year periods were selected for data processing and then the data of some of the newly established stations or missing data were synthesized.

Quality of the data

Regional water authorities have the responsibility for collecting and preparing a database of flow data in Iran. Accurate information about the rate of flow of water in open channels (discharge) is a prerequisite for most hydrologic analysis. Discharge data are used for a number of purposes including operational decision making, input for hydraulic and hydrologic models, records for litigation about water rights or damages, calculation of 'loads' and transport of sediment and other water quality constituents, and for the design of water control and conveyance structures.

Because of the dynamic nature of hydrologic systems, the information typically needed for most hydrologic analyses is a record of the discharge. However, direct measurement of discharge in open channels is time consuming and costly (and sometimes impractical during high floods). Therefore, most discharge records are developed by converting the measured water stages to discharge by using a calibrated stage discharge rating, which permits a fast and relatively inexpensive means of determining the discharge (Herschy, 1999).

Most stream flow gauge stations in Iran use a stage discharge rating to estimate the discharge from the observed water elevations. Most rating curves are established annually through velocity measurements and are graphically or statistically fitted to the data. Theoretically and practically uncertainties happen in the discharge estimates from rating curve method. Then the discharge estimated from the rating may differ significantly from the true discharge (Herschy, 1999). Figure 2.1 shows the hydrometric station in Doab Alashtar in upper the KRB.

The accuracy of the gauged stream flow data is unknown and if the missing data is determined statistically then the accuracy of the results presented in this section on stream flow would not be as good as the results obtained from an analysis of the long-term and well gauged stream flow data.

Figure 2.1. Doab Alashtar gauge station.

Missing data analysis

Extension and completion of the data is needed to fill data gaps. Although these gauge stations have incomplete records for the index period 1975 to 2004, the missing data for the 30year flows were estimated. Monthly and annual flows for the hydrometric stations were extended and completed for the index period by using the following two methods:

- Liner regression
- Making adjustments based on a nearby gauge with a complete record for this period.

The statistical package SPSS (IBM) was used to calculate a correlation matrix of the monthly data series of the 53 stations. A maximum R^2, a significant error less than 5 % or a p value less than 0.005, and availability of the corresponding data were the criteria for selecting suitable stations from which to obtain the missing data.

In order to evaluate the statistical reliability of the data completion and extension, the concept of effective length of record or equivalent length of record was used. Langbein's equation was used as follows:

In making a correlation between two sets of data, the error of regression from extending the data should be less than the existing error in short samples. Then, the length of extending can be calculated from the following formula (Mahdavi, 2007):

Ne= N1+ N-nn-2 1- r^2

$$Ne = \frac{N}{1+\frac{N-n}{n-2}(1-r^2)} \qquad (2\text{-}1)$$

Where Ne is the effective length of the record year (dependent station) or a suitable length of data set for an incomplete station after extension
n is the number of years of the short data set
N is the number of years of the complete data set of the station with complete data
ris the regression coefficient of the two sets before extending in common years

The use of the effective length of the record index is better than the correlation coefficient index only, because the effective length of the record index includes data in the common period for two stations – the dependent station and the base station. It includes also the data period of the base station in addition to the correlation coefficient. 'Ne' shows the statistical value of the extended period for the dependent station. In fact, from a conceptual point of view, the statistical value of the dependent station data after extension is equal to the number of years of existing data in that station.

The index of the effective length of the record has many applications. One of its most important applications is in determining the most appropriate station for extending the data of a particular station. The station which has the largest Ne is the best one to extend. This does not necessarily mean the maximum correlation coefficient in such a case. Therefore, the data of a dependent station may be extended by using an intermediate base station via the main base station.

For each station and month with incomplete record, a search was made for longer records among the stations used, to find which will contribute most toward increasing the reliability of the statistics computed from the incomplete record. For example, consider the correlation between September Pihan (station 34) and September Kakareza (station 23).With nine common years of data (n=9) for the two stations, 48 years' worth of data for Kakareza (N=48), and with anR^2= 0.918 for the common years, Ne=32.9. Therefore, statistically speaking, Kakareza station is suitable for filling the gaps in the September data of Pihan for 30 years of the selected period.

For all months, the bivariate correlations matrix was calculated using SPSS. The bivariate correlations procedure computes the Pearson's correlation coefficients, with their significance levels. The correlations measure how the flows of the stations are related. Before calculating a correlation coefficient, the data is screened for outliers (such as wrongly transcribed data), which can cause misleading results, and evidence of a linear relationship. Pearson's correlation coefficient is a measure of linear association. As an example, the Vasaj (sub-basin 53) flow in April correlated bivariate with the all April flows of the other 52 stations. Analyzing the data from the period 1975 to 2004 yields a Pearson's correlation coefficient (0.87) which is significant at the 0.0001 level. Table 2.1 presents the correlation matrix of the April flows of Vasaj with the April flow data of other stations to determine which can be used statistically to fill gaps. As the Jelogir station data shows a high relationship then this station is selected for filling gaps.

Table 2.2 shows the regression parameters of the Vasaj and Jelogir stations in April. This procedure indirectly targets stations with homogenous hydrologic behavior.

If there are situations where the regression method is not applicable then another simple method – the normal rations method –can be used to fill the gaps. The following equation was used for making flow adjustments:

$$Q_{b,i} = Q_{a,i} * \frac{\bar{Q}_{b,c}}{\bar{Q}_{a,c}} \qquad (2\text{-}2)$$

In equation (2-2), station b is a station with incomplete records covering c years of the corresponding period data, and station a is a nearby station with complete records for the corresponding period (Reed *et al*., 1997) .The precipitation can be added to the formula, but by using a nearby downstream station it is assumed that the precipitation ratio is the same for the two stations. To apply this method

Table 2.1. Correlation matrix of the April flows of Vasaj with statistically suitable stations.

Station	**AFARINEK**	**FIROZAN**	**CHAMANJ**	**NAZARAB**	**ARAN**	**DOABM**	**PIRSALMA**	**POLCHE**
Pearson correlation	0.855	0.818	0.804	0.795	0.663	0.714	0.687	0.807
Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.001	0.000	0.001	0.000
N	20	21	20	19	21	20	20	21
Station	**SEMAREH**	**DARTOT**	**TANGSAZ**	**BARAFTA**	**TANGSI**	**DEHNO**	**KAKAREZ**	**SARABSE**
Pearson correlation	0.811	0.870	0.775	0.614	0.567	0.820	0.837	0.861
Sig. (2-tailed)	0.000	0.000	0.000	0.005	0.011	0.000	0.000	0.000
N	21	15	21	19	19	16	20	20
Station	**KHERSAB**	**JELOGIR**	**GORBAGE**	**HEYDARA**	**BIARKA**	**POLDOKH**	**NORABAD**	**GAZAND**
Pearson correlation	0.725	0.870	0.705	0.698	0.742	0.771	0.800	0.497
Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.042
N	21	21	21	21	18	20	20	17

Table 2.2. Liner regression parameters of Vasaj and Jelogir in April.

Independent: JELOGIR

Dependent	**Math. model**	**Rsq**	**d.f.**	**F**	**Sig. or p value**	**b0**	**b1**
VASAJ	Linear	0.757	19	59.07	0.000	-5.3104	0.0335

a downstream station with full data is selected and used to fill the gaps in the incomplete data of the other.

For the accuracy of the discharge data to be acceptable, about 27.5% of the data should be complete. As the flow accumulates at the downstream stations the importance of having completed data sets can be seen by weighting the flow by the area of each station. The error will decrease to 12% and this is considered statistically acceptable at the 5% level of significance. It should be noted that monthly and annual data are averaged for their 30 year periods. Mean annual flows have been calculated for the sub-basins using stream flow data, where available (Table Apx-2.1). The analyses show that stream flow is highly variable between catchments. Therefore, it is difficult to translate flow statistics from gauged catchments to un-gauged catchments, as the catchments have different hydrologic regimes because of the different geological, land use, and rainfall characteristics. Table Apx-2.1 shows summaries of the 30year averages of the available stream flow data from the gauging stations of the upper KRB. The number of available stream flow data presented in the same table, shows where records are available and where there are gaps. The locations of the stations in Table Apx-2.1 are based on the stream gauge flow network maps of the upper KRB in Figures 1.1 to 1.3.

2.2.2. DEM processing and watershed delineation

The Arc Hydro extension in ArcGis9 (ESRI, 2007) was used to derive several data sets that collectively describe the drainage patterns of the Karkheh catchment. The raster analysis is undertaken to generate data on flow direction, flow accumulation, stream definition, stream segmentation, and watershed delineation. These data are then used to develop a vector representation of the catchments and drainage lines from selected points. The utility of the Arc Hydro tools is demonstrated by applying it to develop attributes that can be useful in hydrologic modeling.

Terrain pre-processing uses DEM to identify the surface drainage pattern. Once pre-processed, the DEM and its derivatives can be used for efficient watershed delineation and stream network generation. This function creates a grid in which each cell carries a value (grid code) indicating to which catchment the cell belongs. The value corresponds to the value carried by the stream segment that drains that area, as defined in the stream segment link grid. The catchment polygon processing function converts a catchment grid into a catchment polygon feature. Figure 1.3 shows all 53 delineated and corrected watersheds.

2.2.3. Hydrologic variability

Hydrologic variability has a great influence on the reliability of the water supplies from rivers and, to a lesser extent, on groundwater. As the level of water use in a basin increases, variations in hydrology have an increasing impact on the reliability and risk of supply to any individual or bulk user. As allocations increase the supply security of any user decreases unless the user has preferential access, in which case reliability for the remaining users is even further compromised.

Hydrologic variability can be assessed using time series data at annual, monthly and even 10day scales.

a) Annual analysis (spatial)

The first step in the annual analysis is modeling the present situation of water distribution i.e. preparing a grid map of runoff or runoff mapping, for the KRB.

The discharge of the gauged watersheds will be distributed in grid cells on the surface of the basin and calibrated with the observed data. By using the eight direction pour point model (D8) an amount of distributed runoff will be accumulated along the river. The surface water balance and soil water balance methods are two GIS- based methods for making runoff mapping.

Two independent water balance models exist to describe the different components of the hydrologic cycle. These are a soil water balance, and a surface water balance. These models are constructed using a GIS that provides a framework for storing and manipulating spatial data and facilitates modeling control volumes of various sizes and shapes. The surface water balance model is a steady-state one and uses an empirical relationship to estimate the mean annual runoff and evaporation in un-gauged areas. Accomplishing the tasks above involved a large amount of data processing. Major steps in the analysis included

- DEM processing
- Selecting a set of flow gauges spanning the appropriate period of record
- Delineating watersheds from selected gauges
- Determining the average annual precipitation in each watershed
- Determining the net measured inflow to each watershed
- Compiling a set of watershed attributes, including percentage urbanization, reservoir evaporation, recharge, and spring flow
- Plotting runoff per unit area versus rainfall per unit area and deriving an ‘expected’ runoff function
- Creating grids of expected runoff, actual runoff, and evaporation (Reed *et al*., 1997).

For this study the available data are:

- A previously prepared precipitation grid map
- A previously prepared DEM
- Gauged stream flow data, and other data sets will be used to generate spatially distributed maps of mean annual runoff and evaporation.

In the process of creating these maps, the gauged watersheds are delineated, then, drainage analysis of a terrain model is performed automatically on the watersheds delineation.

Determining mean precipitation and net inflow

Given a grid of precipitation values and a grid of watersheds, a table of the mean precipitation in each watershed can be determined provided the two grids are defined with the same cell size. The grid of the mean annual values is shown in Figure 2.2.

Based on the computed 30 year mean flows for each station, the net measured inflow (outflow minus the sum of inflows) for each of the 53 watersheds was computed. To make a comparison of the runoff characteristics between different size watersheds, the net measured inflow [m^3/sec] was normalized by the watershed area and expressed in mm/ year.

Expected runoff

A plot of the average runoff (mm) versus average rainfall (mm) for all delineated watersheds is shown in Figure 2.2. A trend of increasing runoff with rainfall is clear, but there are a number of outliers from the general trend. These are the points that merit further investigation. Most of the outlying points are from watersheds with significant anthropogenic influences in the form of urbanization, reservoirs, agriculture, or diversions for municipal use. A few of these outliers result from unusual hydrogeology. This results in lower than expected runoff in the watershed where recharge is occurring and higher than expected runoff in the spring fed stream of an adjacent watershed. Heavy recharge and re-emergence of this same water as spring flow within a watershed may also limit evaporative losses and result in higher than expected runoff values. These observations regarding outlying points led to the hypothesis that a set of criteria could be used to define the runoff expected under conditions of minimal human influence and in the absence of large groundwater transmissions.

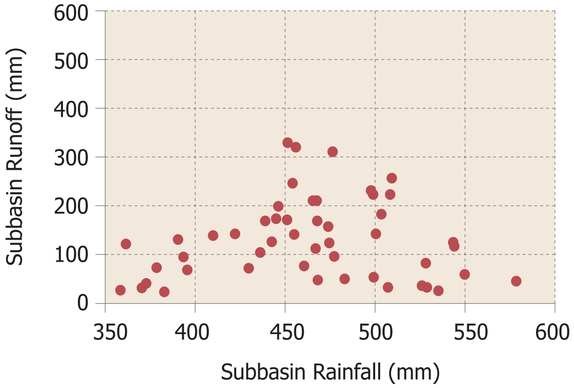

Figure 2.2. Runoff vs. rainfall for all watersheds.

Many sets of criteria have been used and selected as reasonable ones that produce a sub-set of watersheds with a more definitive relationship between rainfall and runoff (Reed *et al*., 1997). Some of the criteria that have been selected include:

- Net measured inflow is greater than zero
- The fraction of the drainage area that is urbanized is less than 0.1
- Annual recharge is less than 51 mm/year
- Reservoir evaporation [mm/watershed area] from reservoirs impounded before 1990 divided by the rainfall [mm] is less than 0.1.

In this research, a lack of data did not allow consideration of the last two above mentioned criteria. Some basins behave abnormally. For example, if the rainfall value is less than the runoff value then these points are omitted .When these criteria have been satisfied, some distinctive outliers from the general trend remain. Some of these points represent data for a spring fed river and may result from canalization of this river, but this is only speculation. This point was not considered when deriving the expected runoff function.

A function that minimizes the sum of squares errors was fitted to the remaining data points. Figure 2.3 shows this selected set of 30 watersheds and Figure 2.4 is a plot of the data points for these watersheds with the fitted function. In theory, with increasing rainfall one might expect the slope of the rainfall-runoff curve to keep increasing until a value of one is reached, indicating that the maximum amount of evaporation possible has been reached. At this point, the only difference between the precipitation and observed runoff would be the potential evaporation. The amount of annual rainfall needed to reach this theoretical slope of one is certainly beyond the range of rainfall values in this data set. By choosing appropriate selection criteria, the notion is that the expected runoff function can be used to estimate natural runoff in all areas except major groundwater recharge and discharge zones.

Criticisms of the expected runoff curve are easy to come by. The concept of expected runoff is artificial and the precise form of the curve is subjective. The criteria used in developing this curve were specifically chosen to eliminate

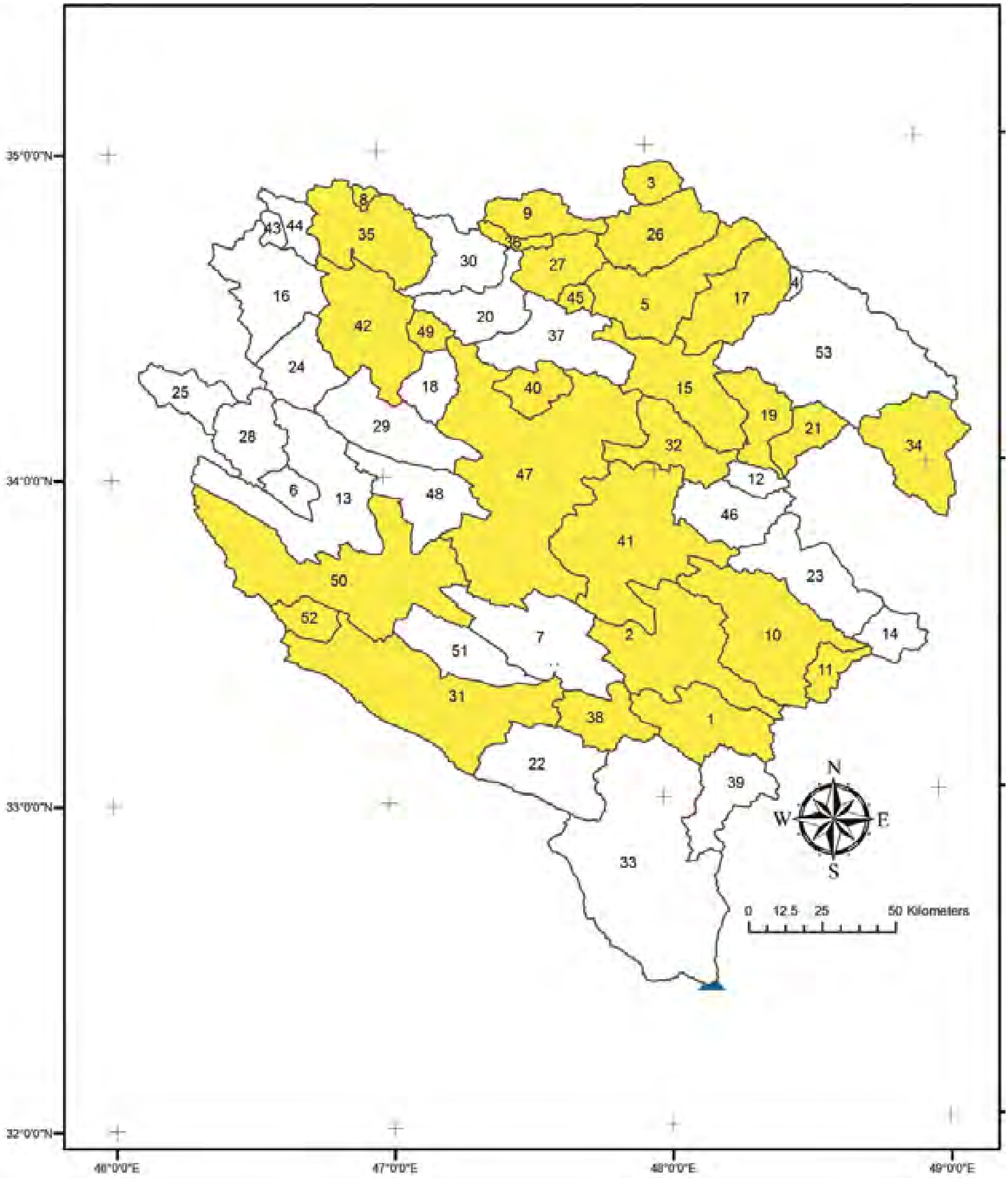

Figure 2.3. Distribution of the 30 watersheds selected.

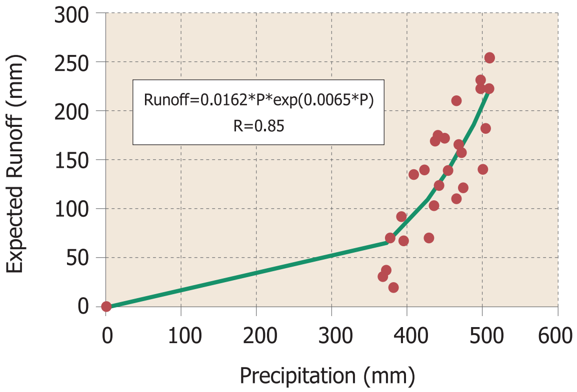

Figure 2.4. Runoff vs. rainfall for selected watersheds.

data points that do not fit the trend, an approach that certainly will not please statisticians. In its defense, the criteria used to derive the expected runoff curve are based upon real physical data that define the concept itself. In addition, information from the outlying points was not discarded; this information was used to create a map of actual runoff. The fact that data from watersheds ranging in size from 40 to 40,000 km^2 follow the same trend implies that the behavior represented by the expected runoff curve is scale-independent, which is an interesting result. Using the inference of scale-independence, the expected runoff function was applied to the precipitation grid to create a spatially distributed map of expected runoff. This runoff function is not suitable for application in urban areas because data from watersheds with considerable urbanization were not used in its development.

Mapping actual runoff and evaporation

A grid of actual runoff was created by combining the net runoff information at the watershed scale. To create the actual runoff grid, an adjustment grid was created in which all cells in a given watershed were assigned the value of the measured runoff per unit area less the watershed mean expected runoff, and this adjustment grid was added to the expected runoff grid. The expected runoff grid is shown in Figure 2.5, the adjustment grid in Figure 2.6, and the actual runoff grid in Figure 2.7. The expected runoff map reflects the variations in precipitation across the state. The expected runoff values range from less than 50 mm/year in south KRB to about 360 mm/year in the wettest part of northwest KRB.

The adjustment map shown in Figure 2.6 highlights areas with unusually large (dark blue) or small measured runoff (dark red). Logical explanations exist for many of these ‘extreme’ adjustment areas. For example, the dark red areas are likely to be caused by large agricultural diversions in these areas. The dark red areas are likely also to indicate locations where extensive recharge occurs. The large dark blue spots are caused by the emergence of springs. One drawback of using this type of runoff map is that the effect of springs is averaged over the entire watershed in which it emerges. Consequently, it appears that a large area is generating excess runoff when the excess runoff is primarily due to a point discharge from groundwater. The accumulated runoff maps that will be described later may provide a more realistic representation for this type of flow phenomenon. Several dark blue or dark red areas are likely caused by the inter-watershed transfer of water for municipal and industrial use. Another possible explanation for the dark blue areas, but not for the dark red ones, is that extensive urbanization has increased the runoff coefficient.

A map of the losses was created by subtracting the actual runoff map from the precipitation map. Creation of this map assumes that the annual change in water storage is zero. This map of losses, shown in Figure 2.8, is equivalent to a map of the actual evaporation in locations

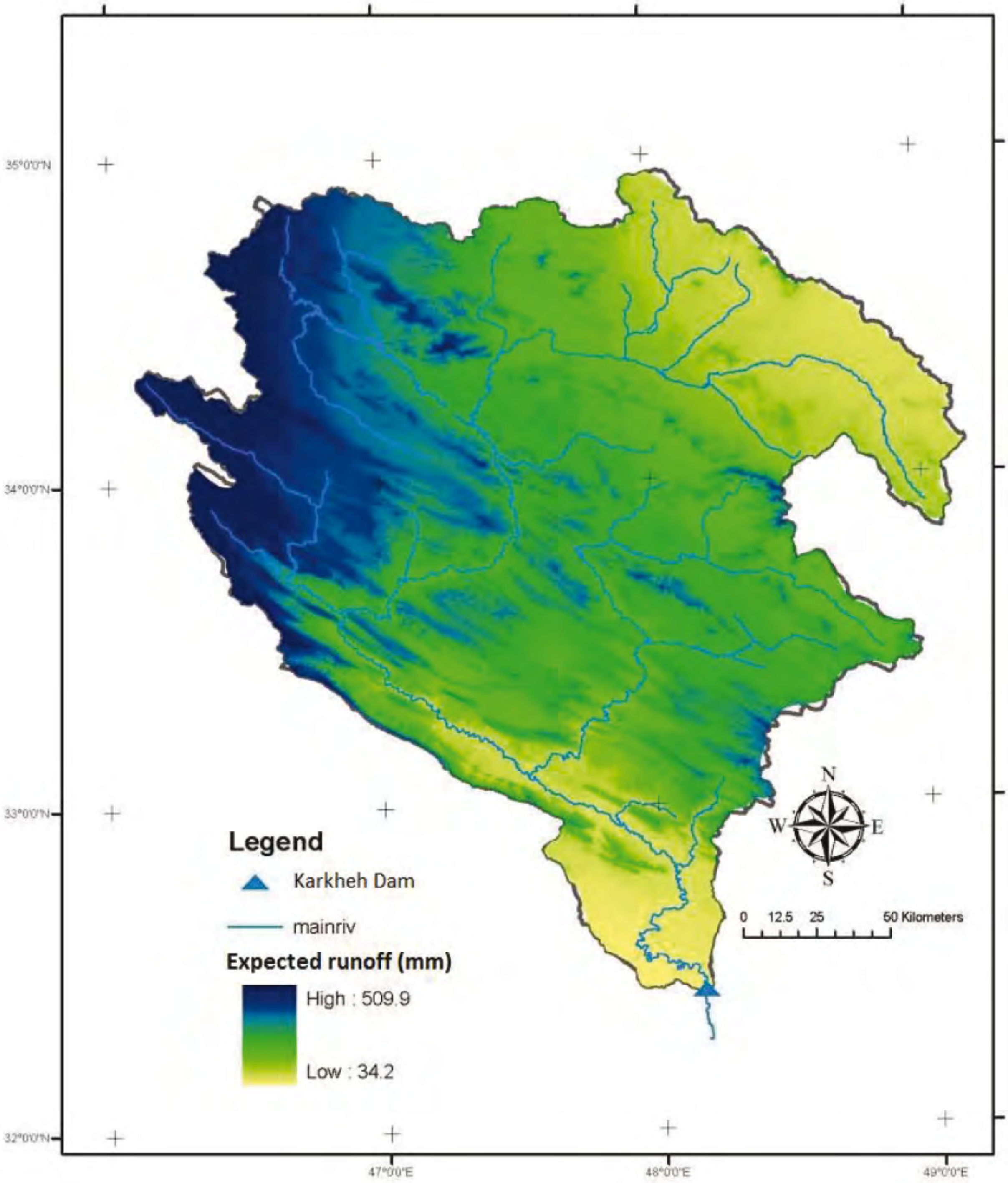

Figure 2.5. 'Expected' mean annual runoff.

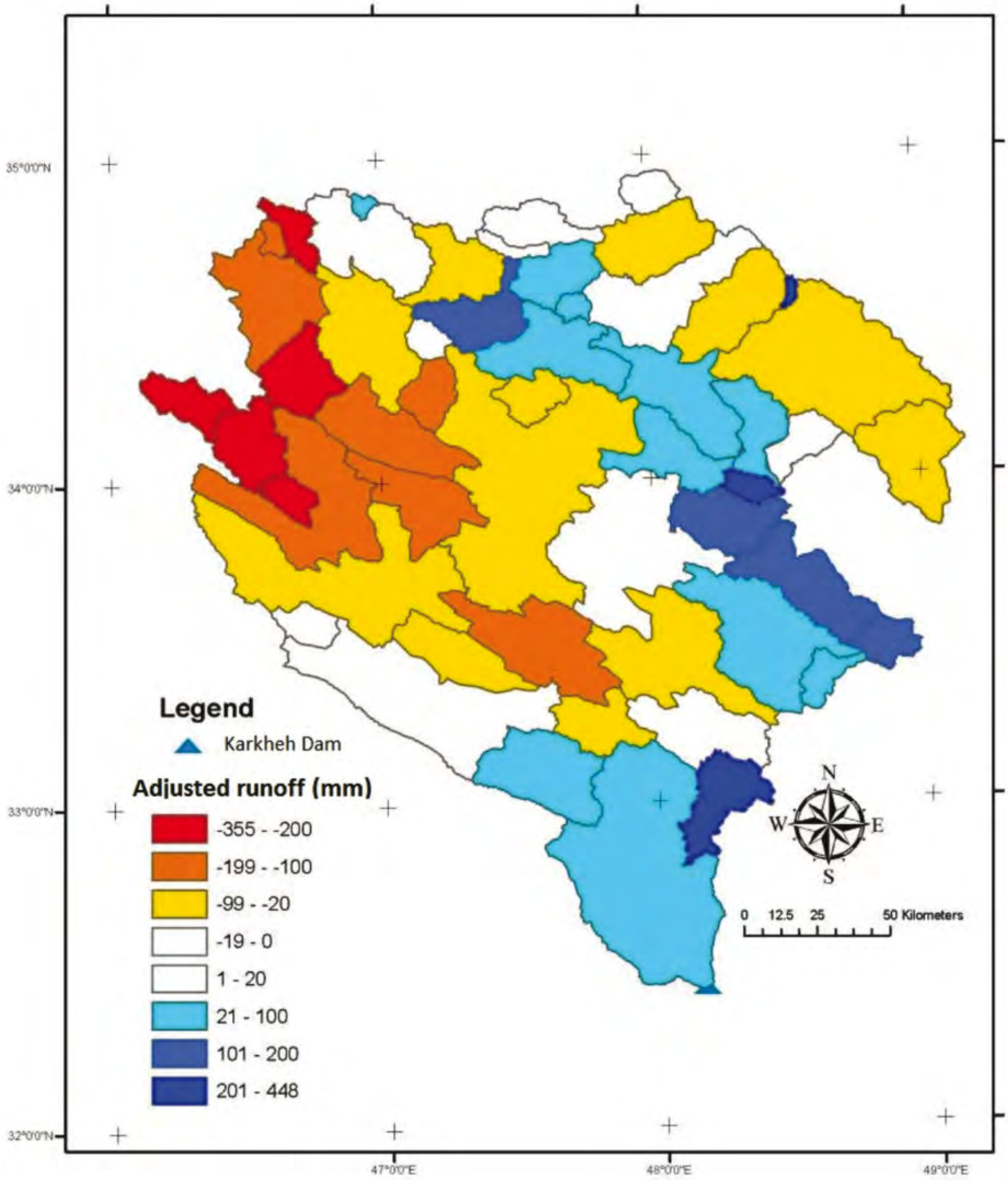

Figure 2.6. Observed runoff – mean 'Expected' runoff.

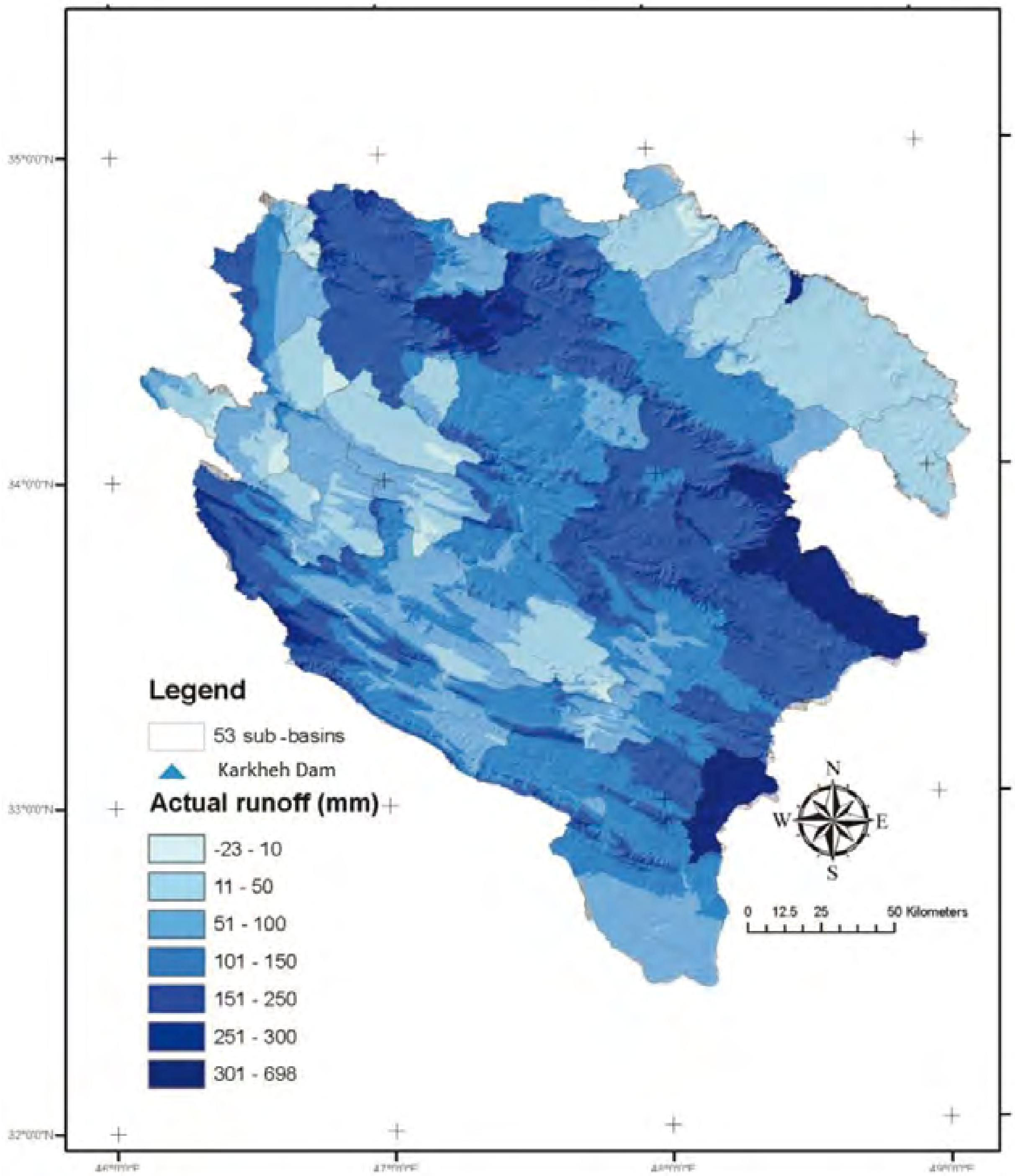

Figure 2.7. Actual mean annual runoff.

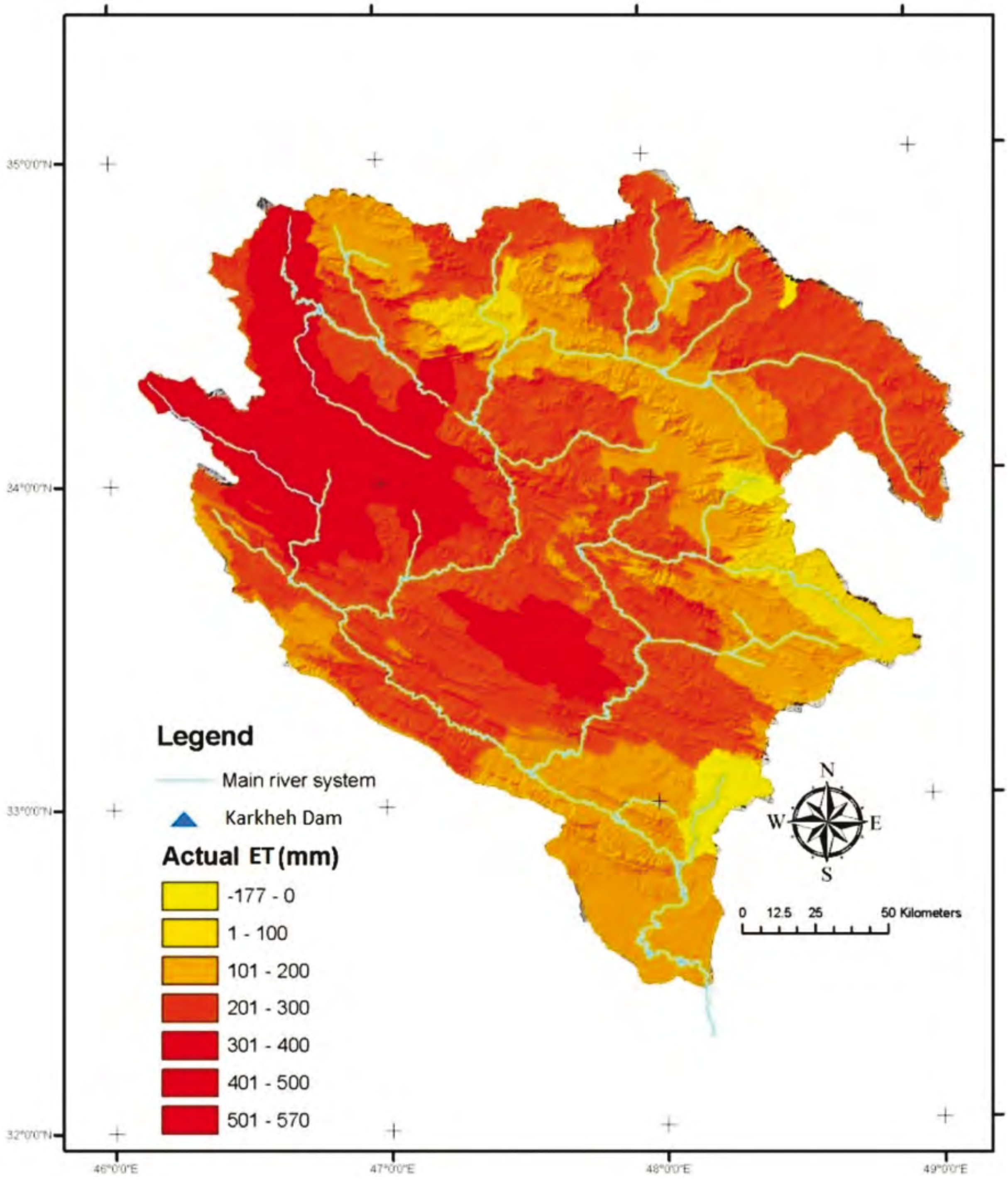

Figure 2.8. Annual losses: rainfall – runoff.

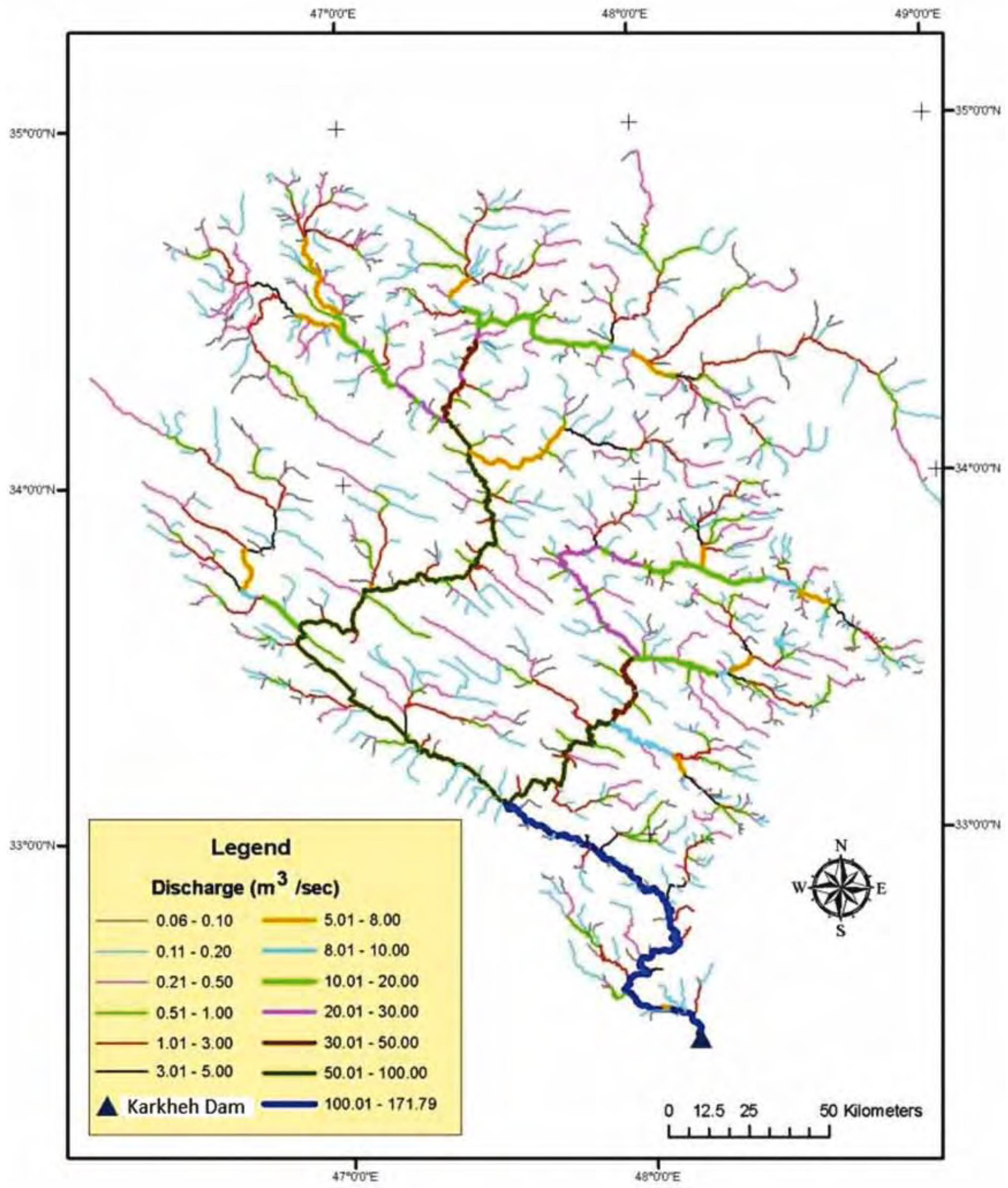

Figure 2.9. Actual accumulated runoff.

where inter-watershed transfers are negligible.

After creating a hydrologic DEM with the DEM re-conditioning function and other DEM processing functions of Arc Hydro tool (ESRI, 2007) – such as the fill sinks function, flow direction, and flow accumulation functions –and by applying a weighted flow accumulation function to the runoff map, the actual flows were calculated for each of the 100 x 100 m DEM cells in the KRB. Using this information, a flow map was created using line thickness and color to distinguish between minor creeks and major rivers. Figure 2.9 shows the actual accumulated runoff of the KRB.

A comparison was made between the drainage areas defined by the DEM flow accumulation results and those reported by Iran Tamab for each gauge. This comparison is shown in Figure 2.10. The reasons for some of the worst discrepancies are obvious, and some of the discrepancies are clearly problems with using the DEM while others point to errors in the Iran Tamab values. Despite these problems, the accuracy achieved using the SRTM DEM is satisfactory in most of the watersheds. The total runoff predicted for each watershed (sum of the runoffs in all the cells) was compared with that measured by the gauging stations. Figure 2.11 illustrates the observed versus the accumulated total discharge at gauge stations.

b) Annual stream flow analysis (temporal)

The annual variation at the Payepol station, code 33,which discharges into the Karkheh Dam is presented in Figure 2.12. This figure shows a sharp reduction in the discharge in the recent decade. Drought and increasing water consumption because of population growth are the reasons for the reduction in the runoff.

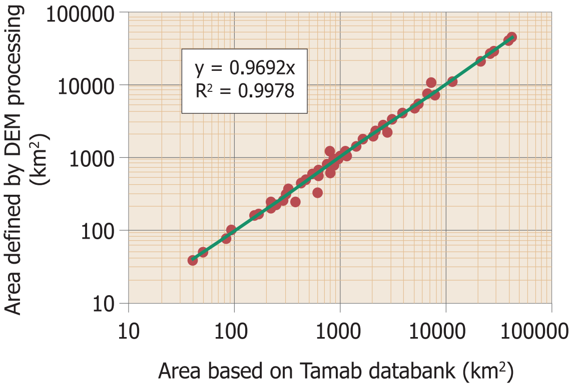

Figure 2.10.Watershed areas reported by Iran Tamab versus areas defined by DEM processing.

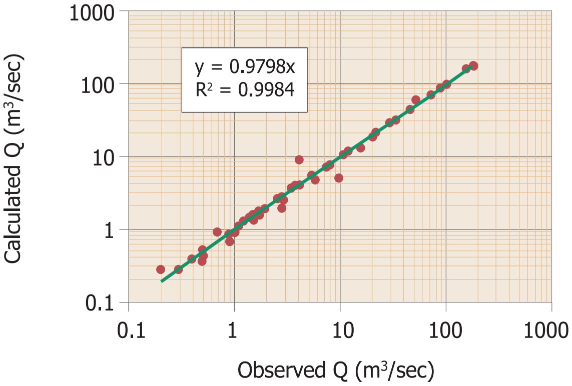

Figure 2.11. Observed versus accumulated total discharge at the gauge stations.

Years with a discharge above the Mean + SD line (the cyan line in the Figure), are wet years. The Mean + SD line indicate the wet threshold and the Mean - SD line indicates the drought threshold (Smakhtin and Shilpakar, 2005). Wetness and drought intensity can be seen by the distance from the Mean line (the brown line in the Figure). The years below the red line are drought years. A seven year moving average has been applied and shows the wet and drought periods. Using the seven year moving average line, the main wet and dry periods can be

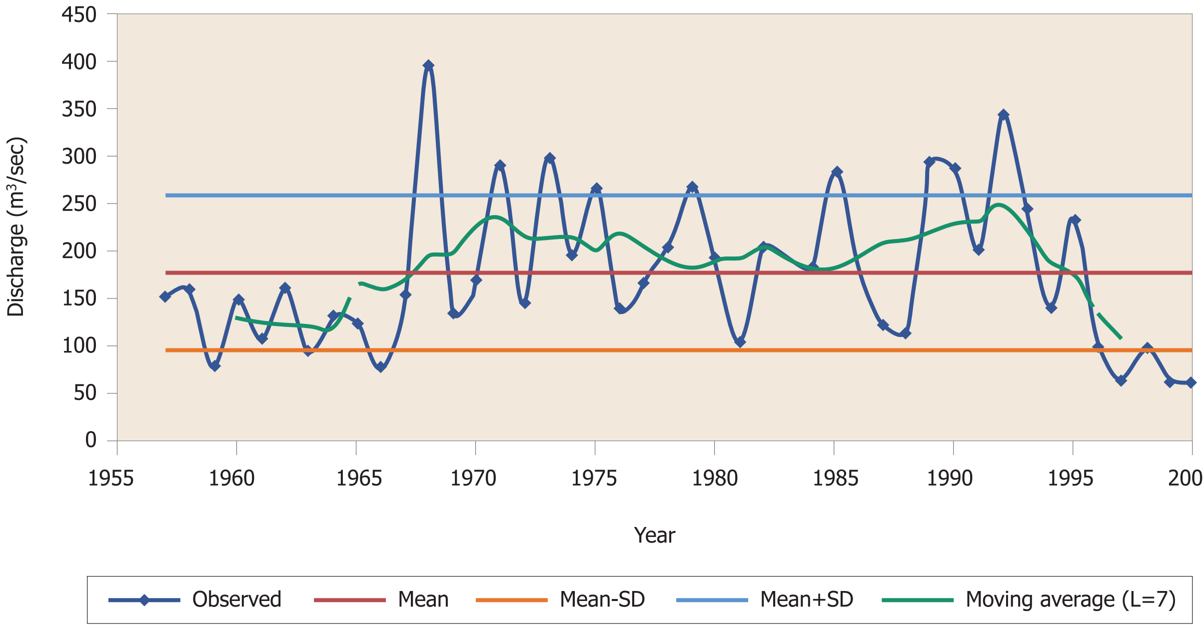

Figure. 2.12. Discharge variations of the upper KRB outlet (Mean=175.4 m³/sec, SD=80.44 m³/sec).

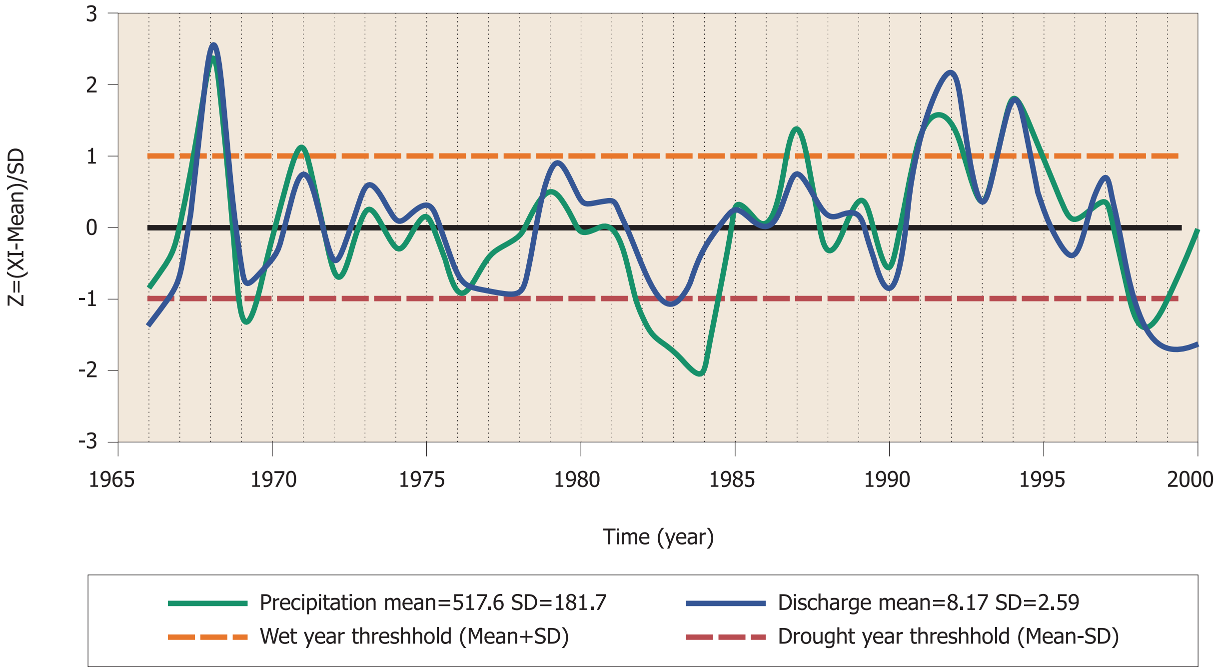

Figure 2.13. Normalized, dimensionless, annual variations in discharge and rainfall of the Sarab Sedali sub-basin.

observed as follows:

A. Dry periods based on the moving average line being below the mean:

- From 1956 to 1967 (11 years)
- From 1996 to 2000 (5 years)
- The total of the two periods is 16 years.

B. Wet periods based on the moving average line being above the mean:

- From 1968 to 1995 (27 years)

A long period of wetness was experienced between 1968 and 1995.

Four benchmark sites have been established in the KRB, two for the upper basin and two for the lower one. The sites in the upper KRB, Honam and Merek, were delineated as hydrological catchments. For resolution considerations, the Sarab Sedali sub-basin, code (46), in which the Honam site is located, has been selected to show the results.

To show the effect of variations in precipitation and discharge a graph, standardized using the normal frequency formula, was prepared .The dimensionless, normalized, annual variations in precipitation and discharge of the Sarab Sedali sub-basin, code (46), are presented in Figure 2.13. This basin is small and the only rainfall station of the basin has been selected as representative of the basin to show the variations in rainfall. This Figure shows, approximately, a smooth reduction in the discharge in the recent decade. The wet and drought thresholds have been added to the graph. The coefficient of variation (CV) in the rainfall is 35% and the discharge CV is 32%.These figures show a close agreement between rainfall and discharge. The reason for the lower CV in the upper parts of the KRB region where springs provide sufficient flow is that there are continuous discharges to meet consumption requirements.
The year where the discharge and rainfall lines meet the mean line, 1986, is taken as the normal one.

c) Monthly stream flow analysis

Based on the information given above, the monthly flow data for Payepol and Sarab Sedali hydrometric stations are presented in Figures 2.14 and 2.15 for the period 1975/2004.

The maximum, wet threshold, mean, drought threshold, and minimum of the monthly flow variations were calculated and added to the graphs. It can be seen from the Figures that there was a remarkable variation in flow for the Payepol hydrometric station during the period under consideration.

As can be seen at the bottom of these Figures, the coefficients of variation for some of the months are too high. Such months belong to the beginning of the wet season of the water year. The flow is increasing, but not so much that it significantly increases the monthly long-term mean flow. The occurrence of one or several relatively high floods will increase the SD and consequently the CV. This occurred in December. In the wet months, the occurrence of floods will not increase the CV because the flow is high in these months.

In order to study water resources planning and allocation, the annual and monthly flows of the river should be specified at the hydrometric stations and intermediate basins of the whole basin.

Projects are planned for the future and the planners cannot be certain as to the precise conditions to which the works will be subjected. The water resource engineer is less certain of the flows. Hydrologic uncertainties and future water requirement uncertainties can have devastating effects on the entire project.

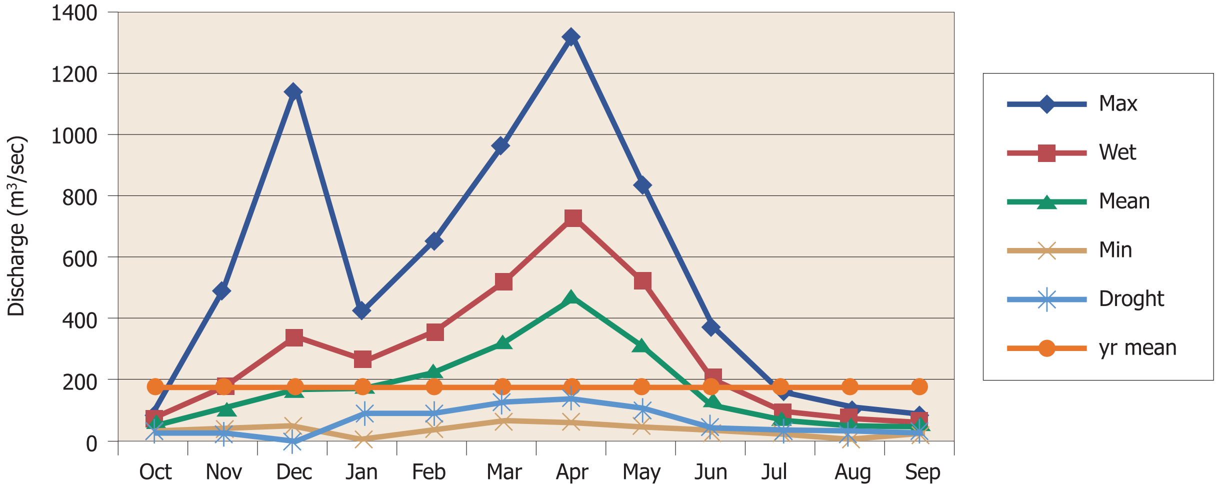

Figure 2.14. Monthly variations in discharge at the upper KRB outlet (Payepol station) for1975/2004. (Average monthly inflows into the Karkheh reservoir).

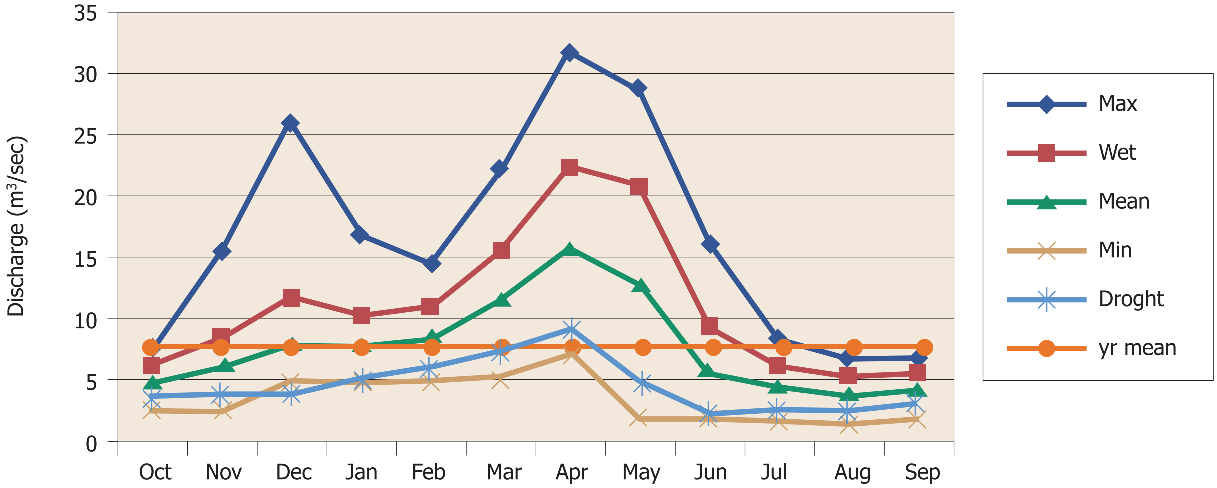

Figure 2.15. Long-term monthly variations in discharge at the Sarab Sedali sub-station for 1975/2004.

Since the exact sequence of stream flow for future years cannot be predicted, then the probabilities of hydrologic events should be estimated. As hydrologic analyses become more sophisticated, the proper design and interpretation of these analyses require a greater knowledge of statistical methods. In fact, two long-used hydrologic tools, the flood frequency curve and the duration curve, require an understanding of the theory of statistics for proper evaluation. The basin is a random occurrence that is generally described by probability laws.

Stream flow analysis is a random occurrence that is generally described by probability laws. Probability plots are used to determine how well data fit a theoretical distribution, such as the normal, lognormal, or gamma distributions. This could be attempted by visually comparing histograms of sample data to density curves of the theoretical distributions.

However, research into human perception has shown that departures from straight lines are discerned more easily than departures from curvilinear patterns. By expressing the theoretical distribution as straight line plots, departures from the distribution are more easily perceived. This is what occurs with a probability plot. To construct a probability plot, quintiles of sample data are plotted against quintiles of the standardized theoretical distribution (Helsel and Hirsch, 2002).

Hydrological frequency analysis is a method for determining the magnitude of hydrological variables which correspond to a given frequency or recurrence interval. Frequency analysis can be conducted for many hydrological variables, including stream flows, floods, rainfalls, and droughts.

Flow duration curve (FDC) analysis looks at the cumulative frequency of historical flow data over a specified period. A FDC relates flow values to the percentage of time those values have been met or exceeded. The use of ‘percentage of time’ provides a uniform scale ranging between 0 and 100. Thus, the full range of stream flows is considered. Low flows are exceeded a majority of the time, while floods are exceeded infrequently. Figure 2.16 and 2.17 displays FDCs for Payepol and Sarab Sedali.

A QuickBasic program for fitting normal, log normal, Pearson Type III, log Pearson, and Gumble distributions was prepared. The method of moments is used to mathematically fit the data and the methods of least squares and root mean sum of squares (RMSS) criteria, are used as the goodness-of-fit techniques. Fundamental and basic discussions of frequency analysis can be found in hydrology and statistical text books.

Frequency analysis was applied to the flow data for all 53 stations and sub-basins. The analysis was undertaken on a monthly basis. The observations are fitted to the five distributions using the following equation:

$$Q = X+KS \qquad (2\text{-}3)$$

Where Q is the expected discharge, X is the mean of the observed values, S is the standard deviation of the observed values, and K is a factor that is a function of the skew coefficient of the observed values and the selected non-exceedence probability. For log normal and log Pearson, the logarithms of the data are used.

The procedure of fitting the distribution was performed twice; the first time to determine the best distribution and the second time to find the dominant distribution. The 30 year periods of the monthly discharge recorded for Payeh pol and Sarab Sedali stations were fitted to the different statistical probability distributions, and the Pearson Type III has been recognized as the most suitable and dominant distribution for the region. The results of the fitting has are shown in Tables 2.3 and 2.4. The Tables show the stream flow at different return periods in wet and dry periods under different probabilities.

2.2.4. Supplemental irrigation iso-potential mapping

The result of SI iso-potential mapping, or targeting suitable lands for SI development in the upper KRB, was obtained from another ongoing project, the ‘Preparation of an iso-potential map for SI in the KRB, Iran’.

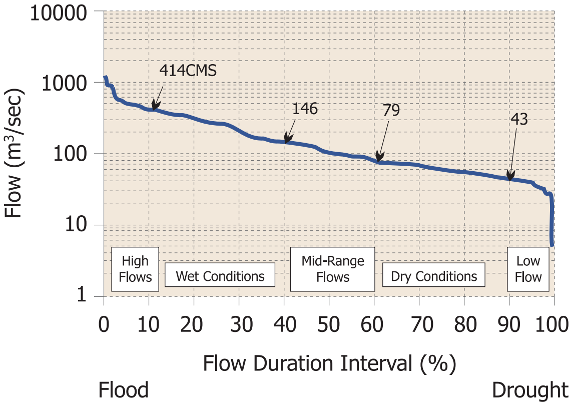

Figure 2.16. Long-term monthly FDC for Payehpol station.

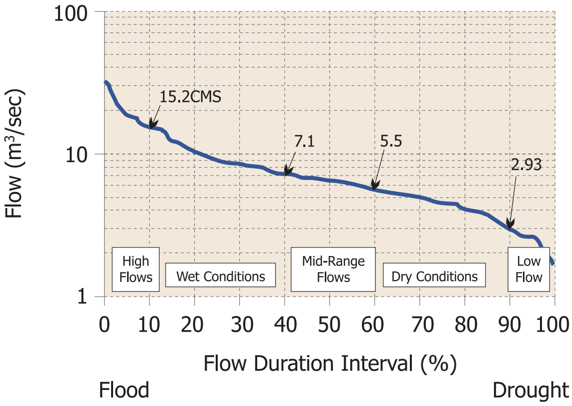

Figure 2.17. Long-term monthly FDC for Sarab Sedali station.

In this method, the river is considered as an accessible water resource. A 1000 m buffer was created around the river. Within this buffer it was considered economically feasible to transport water over a particular distance. This buffered strip was overlaid onto the rainfed areas for the different slope classes of the 53 sub-basins.

Figure 1.15 of Chapter One shows suitable rainfed areas for SI in the upper KRB. Low slope areas have a high priority for water allocation. Tables Apx-1.2 and Apx-1.3 of Chapter One shows the rainfed areas inside the river buffer for the different slopes of the 53 sub-basins.

2.2.5. Demands for water resources

Water resources demands include domestic, food production, recreational and industrial needs as well as the natural requirements of animal and plant life. The use of the resource depends on social, political, economic, institutional, and environmental considerations. The legal and political machinery to implement the new policies needs to be modified and reorganized continuously.

The aim is to improve the efficiency of resource allocation and use while at the same time attempting to improve the quality of life. Economic considerations play a dominant role in political policies. One of the most significant aspects influencing water resource requirements is the environment. The problem of including environmental issues in the definitions of water resources requirements has many intangibles. The problem of quantifying some of the intangible environmental factors, however, requires value judgments that are rather difficult to make even in the best of circumstances. The changes in climate, government policies, non-scientific exploitation of water resources, and over-exploitation of groundwater resources have led to an inefficient management of water resources. Based on experience, understanding how to handle the water resources of large river basins on a regional scale is hard, especially water allocations for environmental needs. In the KRB, the water quantity and quality varies with the rainfall and the hydrologic conditions of the country warrant a more scientific management of the water resources.

The demands on the water resources of the upper KRB include:

- Existing needs (irrigation, industry, municipal, etc.)
- New SI needs
- Environmental flows.

Table 2.3. Stream flow frequency analysis of Payepol station (m³/sec).

Exceedence probability (%)	**99**	**98**	**96**	**95**	**90**	**80**	**50**	**20**	**10**	**5**	**4**	**2**	**1**
Status	**Dry periods**					**Normal**			**Wet periods**				
Return period (year)	**100**	**50**	**25**	**20**	**10**	**5**	**2**	**5**	**10**	**20**	**25**	**50**	**100**
Oct	11.8	16.6	22.9	25.1	32.8	42.0	**57.4**	69.2	74.0	77.4	78.3	80.6	82.4*
Nov	62.3	64.5	66.1	66.4	66.6	67.3	**83.8**	147.2	209.6	280.6	304.9	384.7	470.2
Dec	0.0	0.0	0.0	0.0	0.0	14.9	**183.8**	355.2	444.9	519.0	540.5	602.3	657.8
Jan	47.7	54.6	65.1	69.3	86.0	112.0	**178.5**	268.5	325.7	378.5	394.9	444.5	492.4
Feb	0.0	0.0	18.3	29.3	69.5	122.7	**229.5**	337.9	394.7	441.5	455.1	494.2	529.3
Mar	75.5	89.7	111.2	119.7	153.3	204.7	**334.3**	506.2	614.1	713.3	744.0	836.4	925.5
Apr	38.6	60.5	92.9	105.4	153.7	224.7	**393.2**	603.0	729.6	843.4	878.2	981.9	1080.5
May	3.5	16.5	36.5	44.4	76.2	125.6	**253.0**	426.1	536.4	638.6	670.3	766.2	859.1
Jun	0.0	4.8	13.8	17.3	30.9	51.0	**98.9**	158.8	195.1	227.8	237.8	267.6	296.1
Jul	23.2	26.1	30.2	31.8	37.7	46.2	**65.2**	87.4	100.3	111.6	115.0	125.0	134.5
Aug	5.2	9.6	15.6	17.8	25.5	35.2	**53.4**	70.1	78.1	84.3	86.1	91.0	95.2
Sep	25.5	27.1	29.5	30.4	34.0	39.1	**51.2**	66.1	75.0	83.0	85.4	92.7	99.5
Annual	**60.6**	**65.7**	**73.4**	**76.5**	**88.8**	**108.2**	**160.9**	**240.6**	**297.0**	**353.4**	**371.8**	**429.8**	**489.7**

*:On average, there is one year in every 100 years when the stream flow is equal to or greater than 82.4 m³/sec

Table 2.4. Stream flow frequency analysis of Sarab Sedali station (m³/sec).

Exceedence probability (%)	**99**	**98**	**96**	**95**	**90**	**80**	**50**	**20**	**10**	**5**	**4**	**2**	**1**
Status	**Dry periods**					**Normal**			**Wet periods**				
Return period (year)	**100**	**50**	**25**	**20**	**10**	**5**	**2**	**5**	**10**	**20**	**25**	**50**	**100**
Oct	2.4	2.6	2.8	2.9	3.3	3.8	**4.8**	6.0	6.6	7.1	7.3	7.7	8.2
Nov	4.0	4.0	4.1	4.1	4.2	4.4	**5.4**	7.5	9.2	10.9	11.4	13.2	15.1
Dec	0.2	0.8	1.7	2.0	3.2	4.8	**7.9**	11.1	12.8	14.1	14.5	15.7	16.7
Jan	5.2	5.2	5.3	5.3	5.5	5.8	**6.9**	9.3	11.1	12.9	13.5	15.3	17.2
Feb	3.5	3.9	4.4	4.7	5.4	6.4	**8.5**	10.6	11.6	12.5	12.8	13.5	14.2
Mar	5.3	5.6	6.1	6.2	6.9	8.0	**10.8**	14.5	16.8	19.0	19.7	21.7	23.7
Apr	5.0	5.6	6.5	6.9	8.2	10.2	**15.1**	21.1	24.8	28.1	29.1	32.1	35.0
May	0.0	0.0	0.6	1.2	3.3	6.1	**12.4**	19.5	23.4	26.9	27.9	30.9	33.7
Jun	1.4	1.5	1.7	1.8	2.2	2.9	**5.0**	8.3	10.5	12.7	13.4	15.5	17.6
Jul	1.3	1.5	1.7	1.9	2.3	2.9	**4.2**	5.8	6.7	7.5	7.8	8.5	9.1
Aug	1.2	1.4	1.7	1.8	2.2	2.8	**3.9**	5.1	5.7	6.3	6.4	6.9	7.4
Sep	1.6	1.8	2.1	2.2	2.6	3.2	**4.3**	5.4	6.0	6.5	6.6	7.1	7.4
Annual	**3.8**	**4.1**	**4.4**	**4.5**	**5.0**	**5.7**	**7.4**	**9.8**	**11.3**	**12.7**	**13.1**	**14.5**	**15.8**

For the purpose of the present study, the assumption is that excess water in the upper KRB will be allocated to SI in the autumn and spring. At the gauge stations, the excess water of the sub-basin is recorded after all consumptions and abstractions. Planning the allocation of water to SI is based on the recorded data at the gauge stations and assumes that all existing needs have been considered.

Estimation of water requirements for SI

The amount of irrigation water needed depends not only on the amount of water already available from rainfall, but also on the total amount of water needed by the various crops. The crop water need mainly depends on

- The climate; for example, in a sunny and hot climate crops need more water per day than in a cloudy and cool climate
- The crop type; crops like rice or sugarcane need more water than crops like beans and wheat
- The growth stage; growing crops need more water than crops that have just been planted.

If there is some rainfall, but not enough to cover the water needs of the crops, the irrigation water has to supplement it in such a way that the rainwater and the irrigation water together cover the water needs of the crop. This is often called SI; the irrigation water supplements the rainwater. The influence of climate is given by the reference crop evapotranspiration ETO; the reference crop used for this purpose is grass.

This deals with the influence of the crop type and growth stage on crop water needs. In other words, this section discusses the relationship between the reference grass crop and the crop actually grown in the field. Figure 2.18 presents a flowchart required for estimating the water requirement for SI.

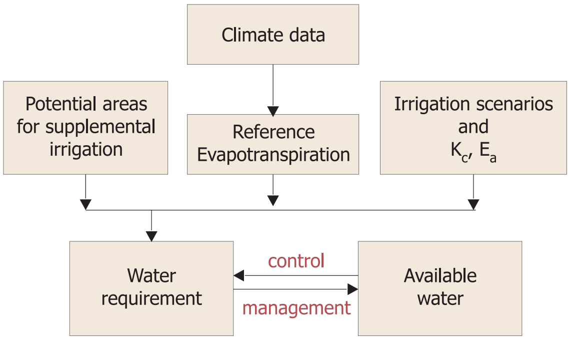

Figure 2.18. Flowchart for estimating the water requirement for SI.

The relationship between the reference grass crop and the crop actually grown is given by the crop factor, Kc, as shown in the following formula:

$$\text{ETcrop} = \text{ETo} \times \text{Kc} \qquad (2\text{-}4)$$

where ETcrop is the crop evapotranspiration or crop water needs (mm/day), Kc is the crop factor, and ETo is the reference evapotranspiration (mm/day).

The crop factor, Kc, mainly depends on the type of crop, the growth stage of the crop, and the climate. The total growing period (in days) is the period from sowing or transplanting to the last day of the harvest. It is mainly dependent on the type of crop and the variety, the climate, and the planting date. As the growing period depends heavily on local circumstances (e.g. local crop varieties) it is always best to obtain these data locally. Once the total growing period is known, the duration (in days) of the various growth stages has to be determined. The total growing period is divided into 4 growth stages:

- The initial stage; this is the period from sowing or transplanting until the crop covers about 10% of the ground
- The crop development stage; this period starts at the end of the initial stage and lasts until full ground cover has been reached (a ground cover of between 70 and 80%).It does not necessarily mean that the crop is at its maximum height
- The mid-season stage; this period starts at the end of the crop development stage and lasts until maturity. It includes flowering and grain-setting
- The late season stage; this period starts at the end of the mid-season stage and lasts until the last day of the harvest. It includes ripening (Allen *et al*., 1998).

Part of the rainwater percolates below the root zone of the plants and part flows away over the soil surface as runoff. This deep percolation water and runoff water cannot be used by the plants. In other words, part of the rainfall is not effective. The remaining part is stored in the root zone and can be used by the plants. This remaining part is the so-called effective rainfall. The factors which influence which part is effective and which part is not include the climate, soil texture, soil structure, and the depth of the root zone. If the rainfall is high, a relatively large part of the water will not be available through deep percolation and runoff.

Deep percolation: If the soil is still wet when the next rain occurs, the soil will simply not be able to store more water, and the rainwater will thus percolate below the root zone and eventually reach the groundwater. Heavy rainfall may cause the groundwater table to rise temporarily.

Runoff: A heavy rainfall will result in a large percentage of the rainwater running across the surface and, especially in sloping areas, flowing to downstream areas.

The irrigation water need of a certain crop is the difference between the crop water need and that part of the rainfall which can be used by the crop (the effective rainfall).

For each of the crops grown in an irrigation scheme the crop water need is determined, usually on a monthly basis. The crop water need is expressed in millimeters of water depth per month (mm/month). The effective precipitation is estimated on a monthly basis, using measured rainfall data. An empirical formula has been developed by FAO/AGLW based on analyses for different arid and sub-humid climates (Brouwer *et al*., 1986). This formula is as follows:

For total rainfall < 70 mm
Effective rainfall = 0.6 * Total rainfall – 10 (2-5)

For total rainfall > 70 mm
Effective rainfall = 0.8 * Total rainfall - 24 (2-6)

For wheat, and for each month of the growing season, the irrigation water need is calculated by subtracting the effective rainfall from the crop water need.

For this research these data were obtained from the AGWAT program. This program is linked to a long-term meteorological database and on selecting the province and plain name shows a list of representative stations. By selecting a station, climate data, and crop type, the program gives the planting date under standard conditions .Soil characteristics can be determined or can be assumed as default values, like field capacity and wilting point, for loam soil. After selecting the irrigation system, the formula for the effective rainfall calculation and the irrigation efficiency the AGWAT program estimates the water requirement of the crop with several evapotranspiration methods, such as the FAO Penman-

Montieth method, in different time scales, such as daily, 10 day, and monthly (Alizadeh *et al*., 2002).

Table 2.5 shows the station location, planting date, and total growing season for wheat. Figure 2.19 shows the K_c variation and Table Apx-2.2 shows the duration of the various growth stages of the wheat crop. For the crop the minimum and maximum lengths of the total growing period have been taken and sub-divided into the various growth stages, effective rainfall and water requirement for full irrigation under a standard situation. Figure 2.20 shows Kc for the selected stations.

The SI scenarios will involve various percentages of the full irrigation amount required under standard situations. According to Tavakoly's ongoing project,

Table 2.5. Characteristics of stations, planting date, and total growing season for a wheat crop.

Row	**Name**	**Location**		**Planting date**	**Growing season**
		X_geo (degree, second)	**Y_geo (degree, second)**		
1	Kermanshah	47° 7'	34° 17'	1Oct	250 days
2	Eslamabad	46° 26'	34° 08'	1Nov	210 days
3	Kangavr	48° 00'	34° 30'	1Oct	250 days
4	Sarpolzahab	45° 52'	34° 27'	1Oct	250 days
5	Ravansar	46° 40'	34° 43'	1Oct	250 days
6	Sarrodkermansh	47° 19'	34° 20'	1Oct	250 days
7	Gilangarb	45° 55'	34° 08'	1Oct	250 days
8	Shahabadgarb	46° 36'	34° 06'	1Nov	210 days
9	Krnd Garb	46° 14'	34° 17'	1Nov	210 days
10	Khoramabad	48° 22'	33° 29'	1Oct	250 days
11	Brojerd	48° 45'	33° 54'	1Oct	250 days
12	Alashtr	48° 22'	33° 29'	1Oct	250 days
13	Drod	49° 09'	33° 29'	1Oct	250 days
14	Shirvanbrojerd	48° 48'	33° 46'	1Oct	250 days
15	Nahavand	48° 24'	34° 09'	1Oct	250 days
16	Ilam	46° 25'	33° 38'	1Oct	250 days
17	Dehloran	47° 16'	32° 41'	1Nov	210 days
18	Safiabad	48° 25'	32° 16'	21Nov	170 days
19	Mazo	48° 31'	32° 47'	21Nov	170 days
20	Hafttape	48° 21'	32° 05'	21Nov	170 days
21	Andimeshk	48° 18'	32° 20'	21Nov	170 days
22	Dezfol	48° 23'	32° 24'	21Nov	170 days
23	Shosh	480 17'	32° 17'	21Nov	170 days
24	Shahabad	48° 30'	32° 18'	21Nov	170 days
25	Bostan	48° 00'	31° 43'	21Nov	170 days
26	Sanandaj	47° 00'	35° 20'	22Sep	270 days

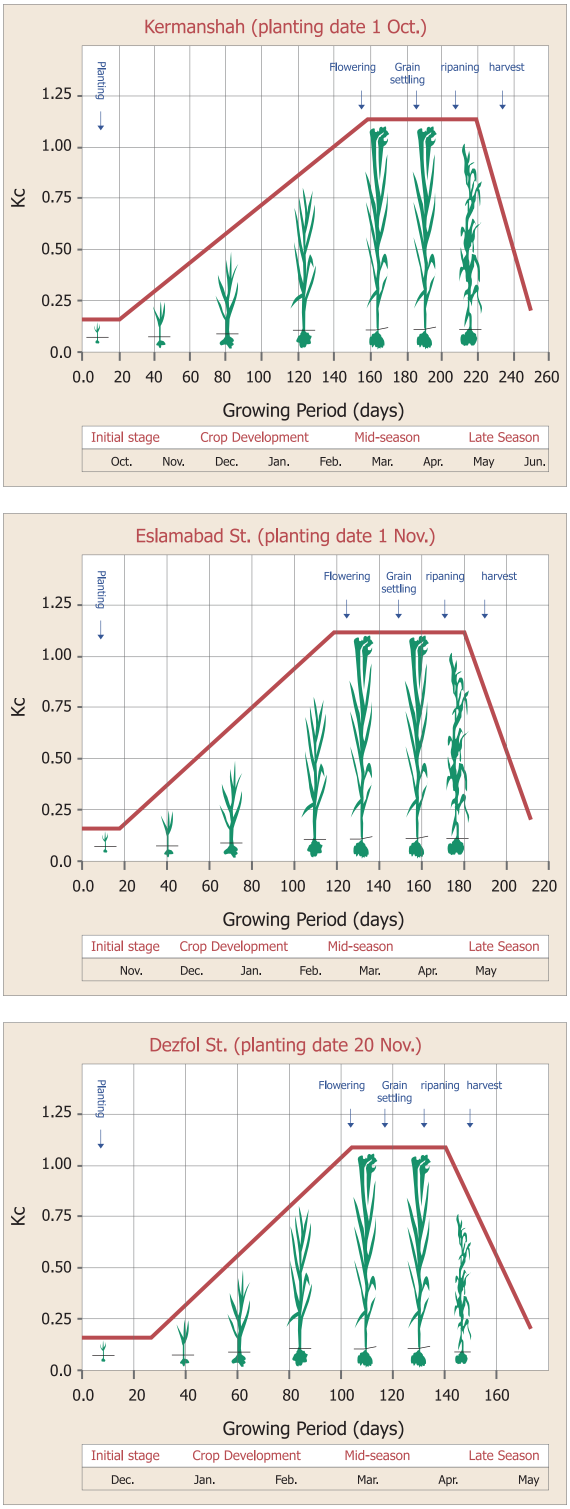

Figure 2.19. Wheat Kc variation and planting calendar in the upper KRB stations.

‘Improving RWP by SI and agronomic management practice in the rainfed areas of the upper KRB, Iran, the current WP values for the dryland crops of the KRB range from 0.3 to 0.5 kg/m^3. Supplemental irrigation is a proven and efficient technology for increasing the yields of main dryland crops (wheat and barley) especially when combined with other improved agronomic management practices. Between 2005 and 2007, on-farm experiments during the winter cropping seasons for wheat and barley were conducted at a number of farms across the two benchmark watersheds of Merek (Kermanshah province) and Honam (Lorestan Province) in the upper KRB. The goal of this strategy was to ensure adequate crop establishment and soil moisture prior to winter to maximize the effectiveness and productivity of the rainfall. Under the farmers’ usual practices in the rainfed areas of the Merek site, grain production for a local barley variety was between 1000 and 2100 kg/ha, for an advanced barley variety (Sararood1) between 2100 and 2900 kg/ha, for a local wheat variety between 800 and 2000 kg/ha, and for an improved wheat variety (Azar2) between 2000 and 2700 kg per ha. Early planting with the help of a single irrigation (between 50 and 75 mm) increased production to between 3500 and 3700 kg/ha for the barley and between 1800 and 3100 kg/ha for the wheat. Similar results were obtained at the Honam site. The present values of the RWP for the major crops of interest were for wheat from 0.3 to 0.5 kg/m^3, for barley from 0.3 to 0.6 kg/m^3, and for chickpea from 0.1 to 0.3 kg/m^3. The results of this study showed that a combination of advanced management with a single irrigation application at the sowing time or in the spring (during the heading to flowering stage) increased the total WP of wheat from 0.4 to 0.48 kg/m^3 and of barley from 0.45 to 0.8 kg/m^3. The irrigation WP of wheat and barley ranged from 1.1 to 3.7 kg/m^3 by using a single irrigation at

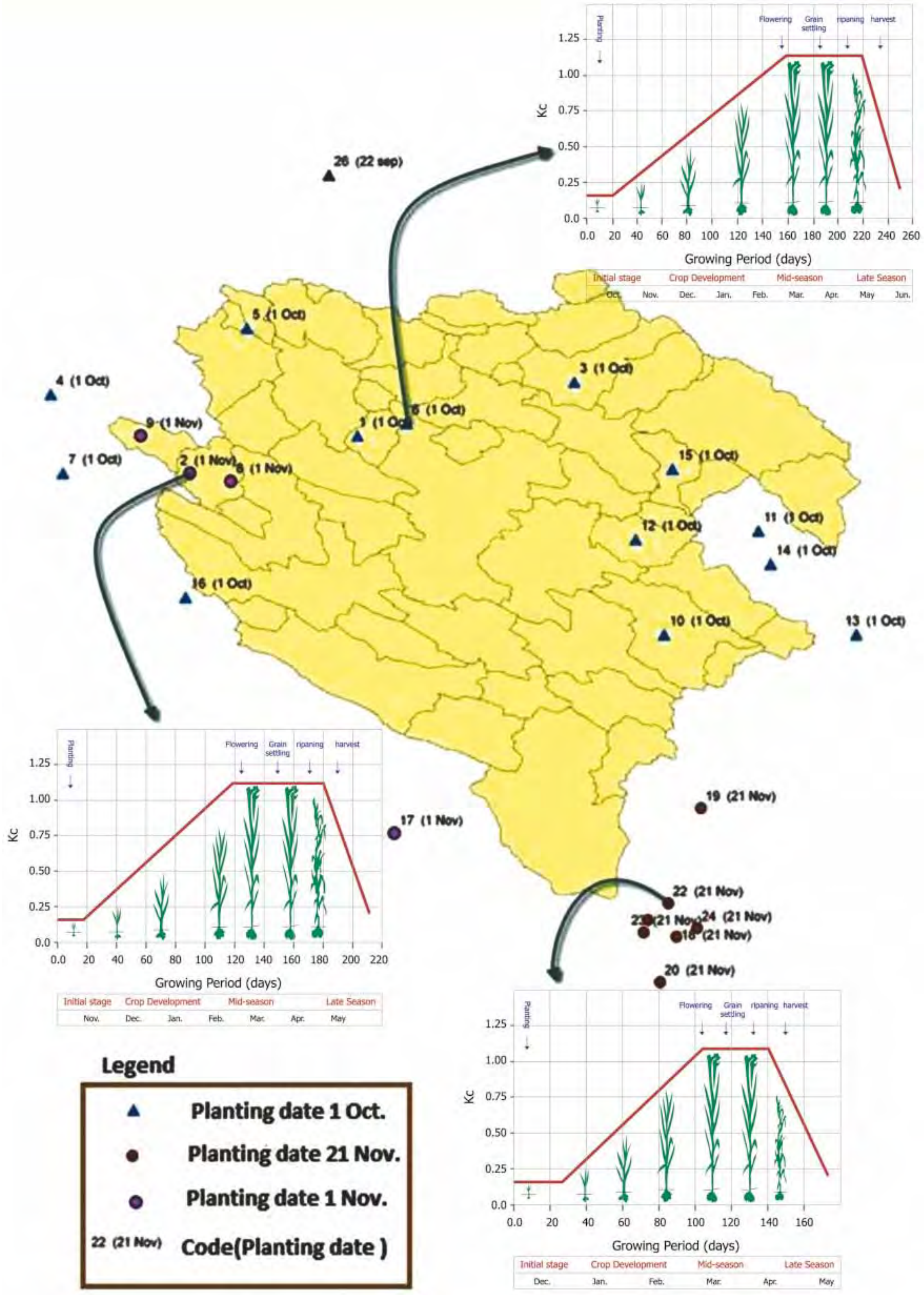

Figure 2.20. The stations and Kc for the selected stations under standard situations.

sowing time or in the spring. The low RWP (and yield) achieved following the farmers' practices were mainly a result of the poor, traditional agronomic management. These preliminary results confirm the potential of a single irrigation and advanced management as an effective way of enhancing productivity.

Supplemental irrigation applications of between 50 and 75 mm in October and 50 mm in May are relatively small in comparison with the values recorded in Table Apx-2.2 showing that deficit irrigations were applied .In this research, these amounts of water are acceptable, but for water allocation from rivers and other water resources, conveyance efficiency needs to be considered. In earth canals, conveyance efficiency is between 65 and 75%.Therefore, assuming a conveyance efficiency of 75%, the amount of water that should be taken from the river and allocated from the hydrometric flow of the stream is 100 mm in October,75 mm in May for a single irrigation, and 150 mm in May for two irrigations.

There are no Kc values for the rainfed situation in the upper KRB and all assumptions are taken from Tavakoly's report. The Kc value at the beginning of the season is less critical because the ETo is very low and SI of 50 mm in the initial stage is a practical amount to be applied as surface irrigation. In the lower parts of the KRB there is no difference between the irrigated and the rainfed areas, but in the upper parts, like Kermanshah and Lorestan Provinces, the flowering stage occurs in May.

The annual rainfall is not sufficient to support the crops during the early and later parts of the season and, therefore, SI is necessary for wheat and barley at the early planting time (at least one month before the first effective precipitation) and during the spring and in early summer, during the heading and flowering stages (Oweis and Hachum, 2006; Tavakoli and Oweis, 2004; Ilbeyi *et al*., 2006; Tavakoli *et al*., 2008).

The application and allocation of water was set according to the cropland situation – whether in the mountain or on the plain – and the planting date. Figure 2.20 shows that planting dates of three sub-basins, Jelogir (No. 22), (Payepol (No. 33), and Polezal (No. 39), start at November and end in May.

Environmental flow

It is challenge to determine the amount of water, and its quality, which should be allocated for the maintenance of the ecosystem through an 'environmental flow allocation' and the amount that should be allocated to agriculture, industry, and domestic services (Ramsar Convention Secretariat, 2007).The 8th Meeting of the Contracting Parties to the Ramsar Convention (November 2002) adopted a resolution that called for the allocation of water to maintain the ecological functions of the wetlands.

A major problem in the management of rivers has been balancing the tradeoffs between the in-stream (e.g. aquatic life, and recreation) and out-of- stream (e.g. reservoir regulation) uses of water. Management problems are normally exacerbated during periods of low flow and with ongoing water resources development resulting in the gradual reduction of the flow available for in-stream uses (Smakhtin, 2001). The amount of water available in each sub-basin was checked and according to the daily and monthly flows of the river an allocation was made for the recharge of available groundwater resources. Variations in the discharge data and the wet and drought thresholds for the sub-basins were assessed and the recorded flows in the sub-basins constituted the available amount of water for allocation.

There is an increasing awareness of the need to reserve some water along a river to ensure the continued functioning of the ecological processes that provide much needed goods and services for human use and for the maintenance of biodiversity (Smakhtin and Shilpakar, 2005). Water which is allocated and made available for maintaining the ecological processes in a desirable state is referred to as the in-stream flow requirement, environmental flows, or environmental flow requirement (Helsel and Hirsch, 2002; Smakhtin and Shilpakar, 2005). The allocation of water to satisfy environmental uses was initially developed out of the need to release minimum flows from dams to ensure the survival of often a single aquatic species with high economic value. However, the provision of environmental flows that attempt to preserve the natural flow characteristics, such as the timing, frequency, duration, and magnitude of the flows, is considered important for sustaining freshwater ecosystems, since the flow regime is one of the major drivers of ecological processes in a river.

The International Water Management Institute (IWMI) noted that insufficient water was being left in rivers in many parts of the world and urged policy makers to consider the making the allocation of environmental flows a top priority.(Smakhtin and Shilpakar, 2005).

The methods for estimating environmental flow requirements (EFRs) fall into the following four categories:

- Hydrological methods
- Hydraulic rating
- Habitat simulation
- Holistic methods (Mazvimavi *et al*., 2007).

Different criteria have been used for the hydrological method of EFRs (Smakhtin and Shilpakar, 2005 and Mazvimavi *et al*., 2007).

Smakhtin (2001) outlined a number of possible methods for low flow analysis and environmental flow determinations. Changes in stream morphology may potentially affect the distribution and abundance of stream biota. Stream flow reduction can also aggravate the effects of water pollution. Winds, bank storage, spring seepage, tributary streams, and the warming effect of the sun usually have a greater effect on stream water temperatures during low flow periods. With an overall reduction in flow, the influence of these factors increases. Lowering the water table and/or reducing overbank flooding may result in changes in the density, productivity, and species composition of wetland and riparian vegetation. Changes in aquatic habitat caused by extended low flow periods may result in long-term changes in species distribution and abundance. Increased siltation and adverse water quality effects associated with unnaturally persistent low flows can alter the distribution and abundance of fish, etc. The well-known techniques of ecological flow (EF) assessment include the Tennant (or Montana) method, which estimates the required seasonal flows for fish and wildlife as percentages of the mean annual flow, and the wetted perimeter technique, which estimates a desired low flow value from a habitat index that incorporates stream channel characteristics (Smakhtin, 2001).

A more widely used method of environmental flow assessment is the in-stream flow incremental methodology (IFIM). A primary component of IFIM is the physical habitat simulation system (PHABSIM). It is used to relate the total habitat area for a particular species to the river discharges. This is then combined with a FDC to produce a habitat duration curve. The IFIM method is best adapted for use in tradeoff analyses, but it is also very complex and requires considerable time, money, and technical expertise. According to Smakhtin (2001) claimed that IFIM applications are limited in many situations because the required input of quantitative biological information is scarce. In traditional IFIM, the emphasis is placed on target species and not on the management of the complete in-stream and riparian components of the river ecosystems. The output of IFIM is not a recommended modified flow regime as would be required for the whole river management plan. Management of rivers for some specific purpose (e.g. to satisfy fish requirements) is no longer viewed as an entirely valid approach. Rivers are now considered as balanced ecosystems and recommendations are often required as to in-stream flows which would ensure fish passage, temperature levels, different habitat maintenance, sedimentation control, recreation, etc. It is suggested that in-stream flows should be evaluated in the context of multiple uses where each use has water requirements that vary over time in a unique way. The largest should determine the overall in-stream requirement at any given time and must be considered in competition with the demand for municipal and agricultural uses (Smakhtin, 2001).

With the increasing pressure on water resources came the recognition that the aquatic environment is not a user of water in competition with other users, but is the base of the resource itself, which needs to be actively cared for if development is to be sustainable. This principle received particular attention in countries with limited water resources, like South Africa and Australia. The Australian ‘Holistic Approach’ and the South African Building Block Methodology (BBM) are both designed to determine the required nature of a river’s modified flow regime. In the BBM, this regime is described in terms of the month-by-month daily flow rates (in-stream flow requirements – IFRs) which should maintain the river in a prescribed ecological condition (and/or satisfactory status for downstream users) after any water resource development has taken place. The process normally involves a multidisciplinary team of specialists, from aquatic ecologists to water engineers, and is implemented in any river system where such water resource developments are planned. The components of a flow regime which are considered important for the estimation of IFR include low flows, small increases in flow, and small and medium floods. Large floods, which cannot be managed, are normally ignored.

More specifically, the in-stream flow assessment process has the objectives:

- To establish low-flow and high-flow discharges for ecological river maintenance for each of the 12 months of the year. Additional information that describes the required duration of high-flow events and the severity of low-flow ones (in terms of their probability of occurrence) is often also included
- To determine minimum flow requirements during drought years. These are also determined as a set of month-by-month daily flow rates and are viewed as the flows which could prevent irreversible damage to the river system during extreme droughts
- To estimate the total water volume (ecological reserve), which will be required to maintain the desired ecological state of the river after the water resource development has been implemented. The process requires the description of (preferably) a natural flow regime and the stream flow time series data with daily time resolution. The IFRs are estimated at several different sites below the proposed impoundment or other water resource development.

The estimation of IFR is an information consuming process where the hydrological information (including low-flow data) is a basic need and, at the same time, a primary component for the final recommendations. The recent development related to the IFR estimation, where the technique to convert tabulated monthly IFR values into continuous daily modified flow time series (e.g. daily reservoir releases) has been suggested. It has further suggested using this technique to estimate the assurance levels, or frequency of exceedence, for different BBM components. This extension of the IFR methodology opened the way to the implementation of the EF recommendations within the context of a water resource plan or management scheme for the river.

The reviews of EF assessment techniques (which also include the role of low flows) are provided by Smakhtin (2001). One direction which has been receiving increasing attention in recent years is the economic aspect of low-flow management. As cited by Smakhtin (2001), investigated the benefits of low-flow alleviation for different purposes, reviewed the techniques which ensure that a balance is achieved between the financial costs of low-flow alleviation and the environmental benefits, and analyzed the techniques based on benefit transfer, whereby the economic values of low-flow alleviation estimated for one project are transferred to another (Smakhtin, 2001).

A threshold value of 10% of the mean annual runoff (MAR) to be reserved for an aquatic ecosystem was considered to be the lowest limit for the EF recommendations – corresponding to severe degradation of a system. One positive aspect of the Tennant method is the awareness that 10% of the MAR may be considered the lowest and highly undesirable threshold for EF allocations and that at least some 30% of the total natural MAR may need to be retained in the river throughout the basin to ensure the fair conditions of riverine ecosystems. (Smakhtin and Anputhas, 2006).

A low flow is defined as the flow exceeded 95% of the time (the 95th percentile on the FDC). (Smakhtin and Anputhas, 2006).

In other research, the monthly non-exceedence probabilities (low flows) for a 1% chance of occurrence (1 time in 100 years), 2% chance (1 time in 50 years), and 4% chance (1 time in 25 years) were established from stream flow data for the years 1951 through 2000. The mean monthly flows for the 1% chance of occurrence are equal to, or slightly below the 7day 10year frequency low flow (43 feet^3/s or 66.5 million gallons per day) for 7 months. The months are January through March, August, and October through December. The remaining months exceed the 7day Q10 flows. The 2% and 4% flows exceed the 7day Q10 for all months. For this report, all statistical determinations were made using the log Pearson Type III method (WHPA, 2003).

One way of maintaining flow variability across the full flow regime is to protect the flow across the entire FDC. Some of the earlier suggested environmental flow assessment (EFA) methods may be interpreted from this perspective. The range of variability approach (RVA) is an excellent example of a technique where the role of hydrological variability in structuring and maintaining a freshwater dependent ecosystem is raised to the highest level. Thirty-two hydrological characteristics (parameters), which jointly reflect different aspects of flow variability (such as magnitude, timing, frequency, duration, and rate of change), were suggested. To estimate these characteristics, the method uses a reference daily and monthly time step, stream flow time series at the site of interest. This time series is representative of the natural (undisturbed) flow conditions in an upstream river catchment. It is further suggested that in a modified flow regime, all 32 parameters should be maintained within the limits of their natural variability. For each parameter, a threshold of one SD from the mean is suggested to be used as a default arbitrary limit for setting environmental flow targets in the absence of other supporting ecological information. Flows on the FDC and, following the RVA default threshold, assume that the annual value achieved by each selected parameter should be:

(mean – 1 SD) < parameter < (mean + 1 SD) (2-7)

Of the originally proposed 32 RVA parameters only 16 were selected. Twelve monthly means are required as they jointly capture one primary aspect of flow variability– seasonal flow distribution – and also reflect to a certain degree both the timing of the flow events and their magnitude. These flows, however, do not reflect the variability of the flows at the top and low ends of the flow range. The report also examines the possibility of using a more advanced hydrology based method, the South African Desktop model. Some of these techniques were modified, following a discussion of their limitations. It was indicated that the hydrology based, desktop methods of environmental flow assessment represent a necessary first step in planning for environmental allocations in developing countries. It is shown that the complementary features of existing techniques can be used to arrive at justified environmental water need estimates even in conditions of limited, basin-specific, eco-hydrological knowledge. Finally it was found in Nepal that an environmental requirement of between 20 and 25% of the natural MAR is suitable (Smakhtin and Shilpakar, 2005).

The hydrology-based design flow method was developed by the US Geological Survey to answer questions relating to water supply and high flows. Most states currently use a hydrology-based design flow method. A hydrology-based design flow is computed using the single lowest flow event from each year on record and then examining these flows for a series of years. This statistical method is based on selecting and identifying an extreme value, such as the lowest 7day average flow in a 10 year period (i.e. 7Q10). The advantage of this method is that it utilizes an extreme value analytical technique (e.g. log Pearson Type III flow estimating technique) supported by past engineering and statistical practice. The disadvantages of this method are that it is independent of biological considerations and it cannot easily use site-specific durations and frequencies that are sometimes specified in aquatic life criteria. The 1Q10 and 7Q10 are both hydrology-based design flows. The 1Q10 is the lowest 1day average flow that occurs (on average) once every 10 years. The 7Q10 is the lowest 7day average flow that occurs (on average) once every 10 years.

The biologically-based design flow method was developed by the US Environmental Protection Agency (EPA) Office of Research and Development. The biological method examines all low flow events within a period of record, even if several occur in one year. The biologically-based design flow is intended to examine the actual frequency of biological exposure. The method directly uses site-specific durations (i.e. averaging periods) and frequencies specified in the aquatic life criteria – e.g.,1 day and 3 years for the criterion maximum concentration (CMC) and 4 days and 3 years for the criterion continuous concentration (CCC).Since biologically-based design flows are based on durations and frequencies specified as water quality criteria for individual pollutants and whole effluents, they can be based on the available biological, ecological, and toxicological information concerning the stresses that aquatic organisms, ecosystems, and their uses can tolerate. The biologically-based calculation method is flexible enough to make full use of special averaging periods and frequencies that might be selected for specific pollutants (e.g., ammonia) or site-specific criteria. This method is empirical, not statistical, because it deals with the actual flow record itself, not with a statistical distribution that is intended to describe the flow record. Hydrology-based design flows are determined by performing an extreme value statistical analysis of the single lowest flow event in each of the X years of the record. Biologically-based design flows are determined by analyzing the absolute lowest flow events in the combined X years of record. The biologically-based flow event calculation may therefore include multiple low flow events in a single year and no events from other years.

The rationales for the two methods are also different. The hydrology-based design flow method was initially developed to answer questions relating to water supply, such as, ‘On average, in how many years out of ten will the flow be below a certain level?’ The biologically-based method was developed to facilitate the use of two averaging periods specified in the two concentrations (i.e. the CCC and CMC) used to express aquatic life criteria in calculating design flows. Biologically-based design flows are intended to measure the actual occurrence of low flow events with respect to both the duration and frequency (i.e. the number of days aquatic life is subject to flows below a certain level within a period of several years). Although the extreme value analytical techniques used to calculate hydrology-based design flows have been used extensively in the field of hydrology and in state water quality standards, these methods do not capture the cumulative nature of the effects of low flow events because they only consider the most extreme low flow in any given year. By considering all low flow events within a year, the biologically-based design flow method accounts for the cumulative nature of the biological effects related to low flow events.

The 4B3 is a biologically-based 4day average flow event which occurs (on average) once every 3 years. The 4B3 is often used as a basis for the US EPA chronic aquatic life criteria. The 4Q3 is a hydrology-based design flow and does not equate to the 4B3 (EPA, 1986).

The simplest method for setting minimum flows is a historic flow method. Historic flow methods use a flow statistic such as the once in 5 years, 7 day low flow, or a flow that is equaled or exceeded for a given proportion (e.g. 95%) of the time. Historic flow methods are not directly related to a given management objective. An assumption is made that the existing values will be sustained by a flow that has been experienced before in the historic flow record. Another problem with the method is that the level of protection afforded by the minimum flow is variable because flow regimes are variable among different types of rivers. Thus the ‘effects’ of a flow statistic used to set a minimum flow will also vary among rivers. For example a once in 5 years, 7day low flow in a stable spring fed stream may be a flow that is very similar to a normal flow. In contrast, the once in 5 years 7day low flow in a highly variable hill-fed river may be very low. The most detailed approach to setting flows is the IFIM. The method describes the change in depth, width and velocity, which together define habitat, with the change in flow. A particular feature of many hydraulic characteristics, such as depth, width, and velocity, is that they do not change linearly with a change in flow. The change of in-stream habitat with flow, therefore, is also non-linear. As a result, a set reduction in flow may result in a larger reduction in available habitat in one stream than in another. The IFIM overcomes the problem of non-linear habitat/flow relationships by developing mathematical descriptions of these relationships between habitat and flow that are specific to the critical river reach being considered. Where rivers are smaller, the defined minimum flow will be proportionally larger because the available habitat in smaller rivers tends to reduce at a higher rate with change in flow than in larger rivers.

There is no single best method, approach or framework to determine the environmental flow. A number of existing methods for determining an environmental flow were reviewed here. Functional analysis and habitat modeling are the most widely applied approaches in impact assessment or restoration planning for single or multiple stretches of a river. These assessment methodologies can help to set management rules and

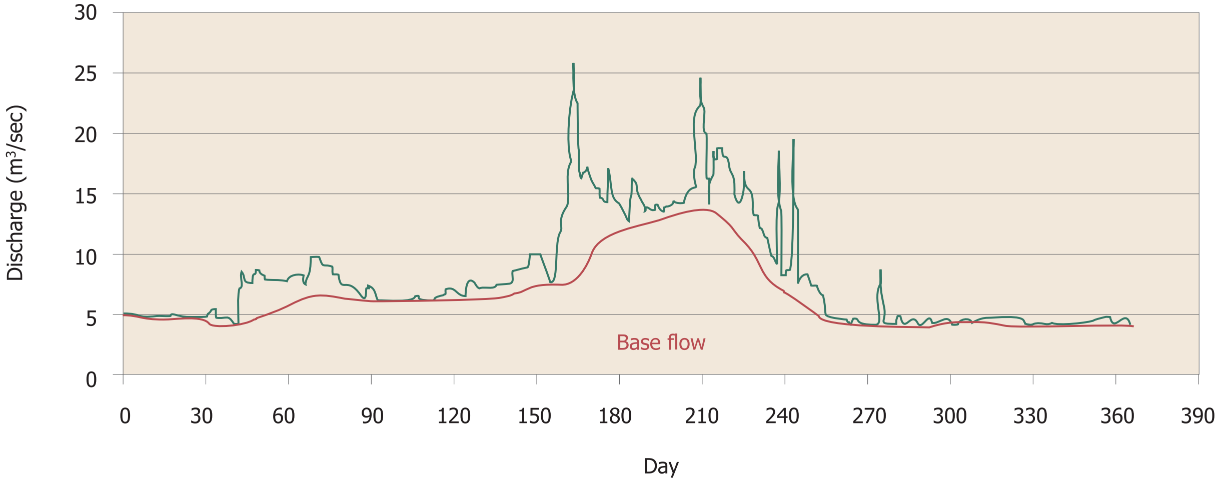

Figure 2.21. Base flow at the Sarab Sedali station in the normal year (1986).

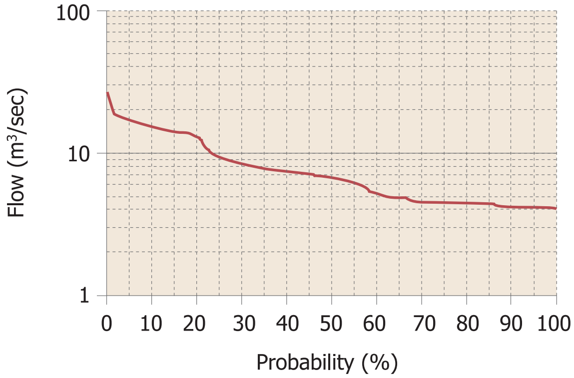

Figure 2.22. FDC of the Sarab Sedali station in the normal year (1986).

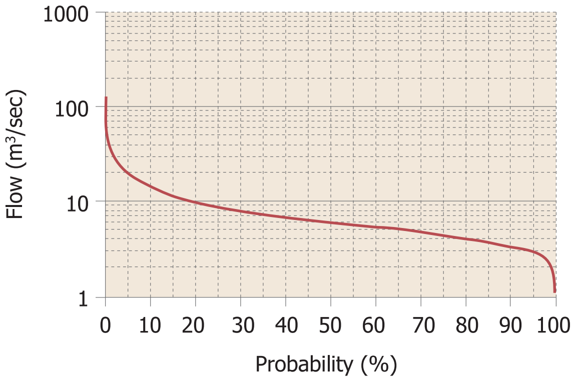

Figure 2.23. Long-term daily FDC of the Sarab Sedali station.

monitor their consequences on river health. Environmental flow setting can best be done within the context of wider assessment frameworks that contribute to river basin planning. These frameworks are part of Integrated Water Resources Management and assess both the wider situation and river health objectives. Stakeholder participation to solve existing problems and include scenario-based evaluations of alternative flow regimes should be considered (Dyson *et al*., 2003).

In this section, some EFR values for Sarab Sedali station are surveyed. As mentioned before, basic data for making stream flow frequency analysis was obtained from the Iran Tamab database. The Iran Tamab data was considered as the base data for all studies and development in Iran.

Mean daily discharges were used to analyze stream flow volumes and frequencies. As Sarab Sedali gauge station has long-term records it was used to evaluate extended periods of drought.

Gauge data is published as mean daily discharge in cubic meter per second. As shown in Figure 2.13, 1986 was a normal year. The base flow (purple line) and FDC for this year are presented in Figures 2.21 and 2.22. A long-term (45 year) daily FDC for this station is presented in Figure 2.23.

The normal year flow and monthly FDC results in low probabilities which are close to each other. But long-term daily flow and monthly FDC results in low probabilities which are very different.

To find the in-stream flow requirements, the 1, 7, and 30 day durations, and the frequency of the 5 and 10 year mean discharges– such as (7Q10), (1Q10), and (30Q5) – were determined. A 7 day and 30 day moving average were applied for the daily data and the minimum value of each year determined. All frequency analysis was made using the Pearson Type III probability method .All the analysis results are presented in a chart shown in Figure 2.24 and Table 2.6.

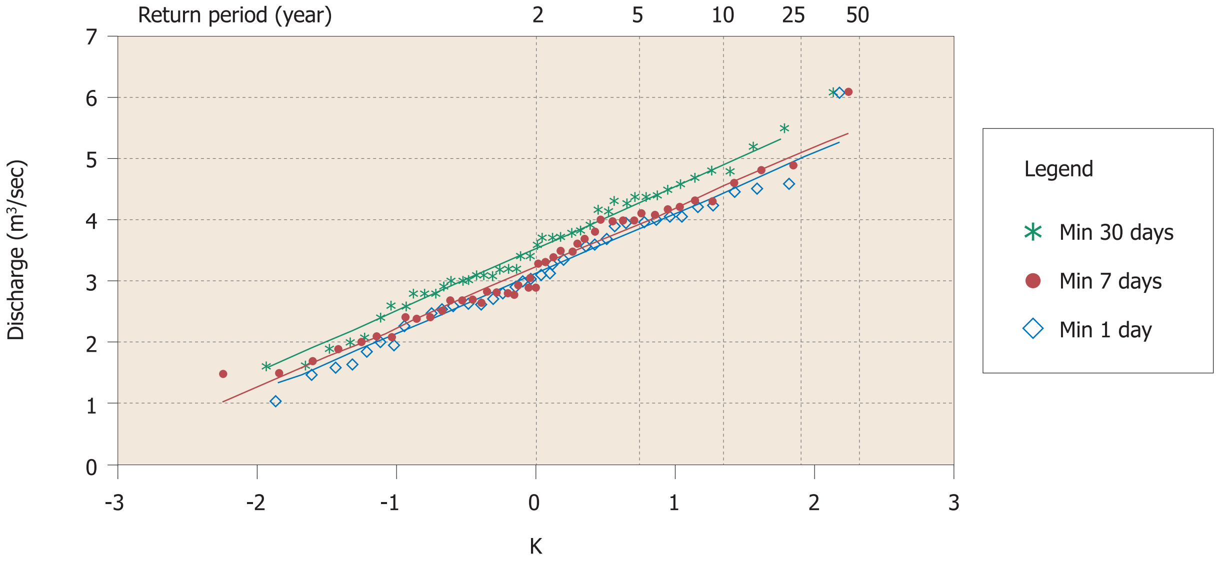

Figure 2.24. Pearson Type III Q-Q plot of the minimum 1, 7, and 30 day durations of the Sarab Sedali station.

Table 2.6. The 1, 7, and 30 day durations, in different return periods of the Sarab Sedali station.

Occurrence probability (%)	**99**	**98**	**96**	**95**	**90**	**80**	**50**	**20**	**10**	**5**	**4**	**2**	**1**
Statues	**Dry period**						**Normal**	**Wet period**					
Return period (year)	**100**	**50**	**25**	**20**	**10**	**5**	**2**	**5**	**10**	**20**	**25**	**50**	**100**
Min. 1 day	1.3	1.4	1.6	1.7	2.0	2.3	**3.1**	4.0	4.4	4.9	5.0	5.3	5.7
Min. 7 day	1.5	1.6	1.8	1.8	2.1	2.4	**3.2**	4.0	4.5	5.0	5.1	5.5	5.8
Min. 30 day	1.6	1.7	1.9	2.0	2.3	2.7	**3.5**	4.4	4.9	5.3	5.4	5.7	6.0

The non-exceedence probabilities for the 4% chance flows (1 time in 25 years) of Table 2.4 are compared to the SD of the actual stream flow records in Table 2.7. All EFR values are compared to the 30 year average stream flow records shown in Figure 2.25.

Working with daily flow data may not be a major problem in itself as some EF methods successfully work with good quality monthly flow data as mentioned above. The minimum requirement for environmental flow determination at any station in a river basin is, therefore, a sufficiently long (30 year) monthly flow time series reflecting, as much as possible, the pattern of the natural flow variability.

Table 2.7. Comparison of the 4% (1 time in 25 years) monthly flow and one SD of the actual stream flow at Sarab Sedali station.

Month	**P(96%) or return period (25 years)**	**1 SD(m^3/sec)**
Oct	2.8	1.31
Nov	4.1	2.39
Dec	1.7	3.78
Jan	5.3	2.60
Feb	4.4	2.46
Mar	6.1	4.06
Apr	6.5	6.68
May	0.6	8.02
Jun	1.7	3.55
Jul	1.7	1.77
Aug	1.7	1.39
Sep	2.1	1.34

In some stations also the monthly 90% FDC values are zero. As other researchers have emphasized, making decision as to which method is best is very difficult. In this instance it was decided that, a minimum value should be considered.

In this study, it has been assumed that in order to maintain the natural, or slightly modified, habitats along the rivers, the minimum value of the EFR in this region should be 15 % of the MAR.

The amount of water that should be reserved for environmental purposes in each of the 53 sub-basins was determined. Also, by subtracting monthly flow data from the EFRs, the available water for allocation to the SI areas of all the sub-basins was obtained. There is a point that should be noted. All the above mentioned EFR methods were developed for a single river, but, in the KRB with its 53 selected sub-basins, the case is somewhat complex. The allocated EF flows upstream are not consumed along the river and the amount of the allocated flow at the upper sub-basins should be subtracted from the downstream EFR.

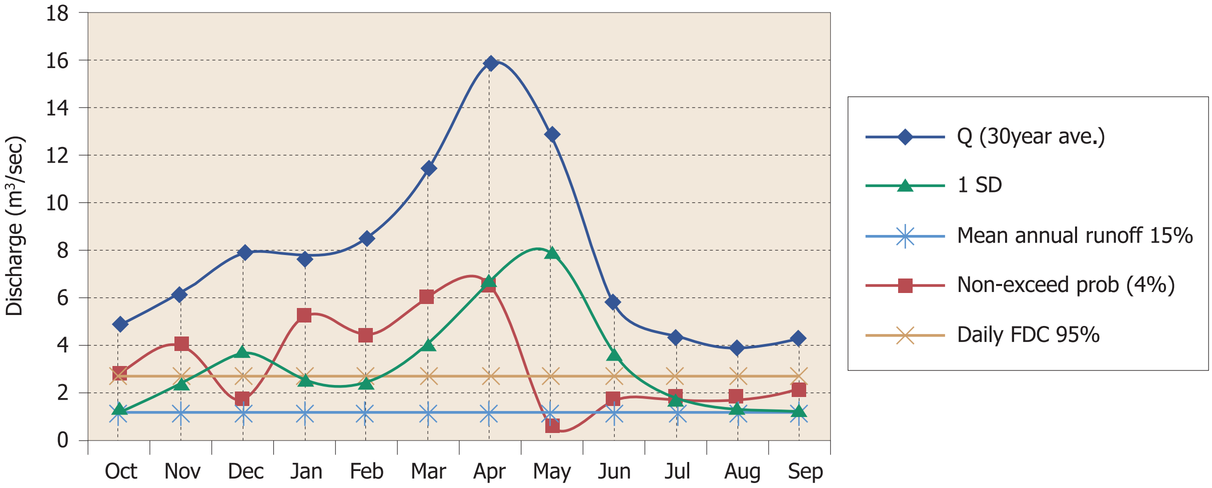

Figure 2.25. Comparison of all EFR values with the 30 year mean observed values at Sarab Sedali station.

For simplicity, 15 % of the MAR was considered as the base and subtracted from the observed data.

2.2.6. Flow allocation and assessment of different scenarios of SI

Water has become an increasingly scarce resource that requires careful economic and environmental management. The available water of each sub-basin should be considered according to the monthly base flow of the river and the available data. The future situation is simulated by assuming various scenarios of SI in the upstream sub-basins of the KRB and determining the water demand and available water at each hydrometric station. The potential for SI at the upstream sub-basins is known (Figure 2.14). The amount of available flow is known at the gauge stations.

It is common to use data covering period of 10 years. Smakhtin and Anputhas (2006) used stations with a minimum of 10 years of observations (provided they had no missing data); stations with longer records were included (even if they had some missing data).In this study, an index period of 30 years of complete data was set for the inclusion of upstream and downstream stations in determining flow allocations.

Conflicts between water users often arise in regional water resource allocation. Even though the water authority can use water laws to resolve such conflicts, a technical analysis tool that allows the combination of the science and art of system analysis is often helpful for conflict negotiations.

According to the on-farm water balance relationships of the selected upstream stations, and according to the iso-potential map for SI in the KRB, various sub-basin scenarios of SI management in the upstream areas of the KRB will be considered and the proportional water demand determined.

To extend the analysis, an additional scenario was considered, which is based on a physical setting similar to the reference scenario (the normal condition), but assumes an EFR allocation of water among the sub-basins.

The analysis of the monthly flow data has yielded some interesting results. The data from many stream flow gauging stations indicate that the continuous flow period is decreasing. This can have an impact on EFRs and licensing decisions, such as the suitable period for extracting flow from the streams. Another scenario of water allocation for SI that should be considered is the drought situation. A higher level of water stress was considered, with the (river) resource availability set at 80% of the occurrence probability as a drought condition.

A fairly accurate knowledge of the climatic conditions of the district, a good understanding of the principles of agriculture without irrigation under low rainfall, and a vigorous application of these principles as adapted to the local climatic conditions will make dry-farm failures a rarity. In drought years, it might be feasible to apply SI by pumping groundwater, or by using groundwater to augment in-stream flow so that additional irrigation diversions could be permitted. There are important hydrological concerns about doing so on a large scale, as there is evidence that such pumping would have adverse effects on local aquifers, private wells, public drinking water supplies, and sub-surface irrigation in nearby areas.

The goal of this scenario is to ensure crop establishment with SI to maximize the effectiveness and productivity of wheat. The following water requirements were considered as input data in the field:

- Early sowing – single irrigation of 75 mm at planting time + no irrigation in the spring
- No irrigation at planting time + two irrigations of 50 mm each in the spring
- Single irrigation of 75 mm at planting time + two irrigations of 50 mm each in the spring.

The following water requirements were considered as input data for diversions from the river:

- Early sowing –single irrigation of 100 mm at planting time (October or November) + no irrigation in the spring (April or May) during the heading to flowering stage
- No irrigation at planting time + two irrigations of 75 mm each in the spring
- Single irrigation of 100 mm at planting time + two irrigations of 75 mm each in the spring.

The early sowing date was usually between 10 and 15 days before the conventional planting time. The water resources for irrigation were from different sources, including pumping from the river, groundwater, spring, traditional canal, and qanats. Spring irrigation was applied during the heading to flowering stage. The irrigation methods were according to the farmers' practices and they were often border and basin surface irrigations.

Based on the computed 30 year mean flows for each station, the net measured inflow (outflow minus the sum of inflows) for each of the 53 watersheds was computed.

A FORTRAN computer program was prepared (see Appendix I) to allocate water for different scenarios – normal condition, normal with EFR, drought, and drought with EFR. This program was developed to calculate the water allocation of each sub-basin taking into account different priorities(first slopes from 0 to 5 %, then slopes from 5 to 8%, next slopes from 8 to 12%, and, finally, slope from 12 to 20%) and then to assess and route the reductions of water from the upper sub-basins to the Karkheh Dam. A FORTRAN programmed algorithm makes it possible to allocate the water based on the priorities or following an equity principle (all demands satisfied in the same proportion).

By applying this computer program, the actual areas suitable for the development of SI and the flows allowable for allocation are calculated along the rivers. By comparing the flows to Karkheh Dam in the above four scenarios, the impacts of the scenarios on stream flows will be evaluated along each sub-basin and, subsequently, for the whole basin.

This program identifies the SI areas in the upper KRB sub-basins for different land suitability, irrigation, and flow scenarios.

The input files are:

- Flow.csv: monthly flow of each sub-basin (m^3/s) (all monthly data, start in October)
- Area.csv (potential) irrigation area for each sub-basin (km^2)
- Irri.csv monthly irrigation requirements for each sub-basin (mm)
- Route.csv routing scheme for the sub-basins

The output files include:

- Flowx.csv: monthly outflow after irrigation abstraction for each sub-basin
- Areaw.csv: monthly irrigated area for each sub-basin
- Subbasin.csv: monthly flows and areas by sub-basin
- Basin.csv: monthly and annual outflows, areas, and irrigation volumes for the basin

The input files (scenarios information) are prepared in standard comma separated values (csv) format which can be easily edited in Microsoft Excel.

After checking

- The available flow (m^3/s) of a sub-basin for each month
- The net available flow (m^3/s) of the sub-basin for each month
- The flow (m^3/s) generated in the sub-basin (outflow minus inflow of upstream sub-basins)
- The leftover outflow (m^3/s) of each sub-basin for each month
- The actual available flow (m^3/s) of the sub-basin for each month

The net flow plus any leftover outflow from the upstream sub-basins are calculated.

Then after the following conversions:

- The monthly flow (m^3/s) out of the basin
- The monthly leftover flow (m^3/s) out of basin
- The annual flow (m^3/s) out of basin
- The annual leftover flow (m^3/s) out of basin
- The available irrigation area for each sub-basin (km^2)

Some outputs are calculated.

These outputs include:

- The suitable irrigation area (km^2) for each sub-basin and month
- The feasible irrigated area (km^2) for each sub-basin and month
- The suitable irrigation area (km^2) for the complete basin per month
- The feasible irrigated area (km^2) for the complete basin per month
- The suitable irrigation area (km^2) for the complete basin and year
- The feasible irrigated area (km^2) for the complete basin and year
- The monthly irrigation requirement (mm) for each sub-basin
- The monthly irrigation water volume (m^3/month) of the complete basin

- The annual irrigation water volume (m^3/year) for the complete basin.

To find the unknown parameters mentioned above, it is necessary to scan the whole basin by defining:

- The basin outlet
- The basin most downstream
- The independent sub-basins (sub-basins that have no basins upstream)
- The number of upstream basins for a downstream basin

And then compute the net available flow – the flow generated in each sub-basin (the outflow minus the incoming flow from the upstream sub-basins)

The net flow calculation should be started from downstream to keep track of downstream allocations or losses. It is necessary to find any basin that does not have any sub-basins upstream and to find all the upstream sub-basins that flow into a particular downstream one. The net flow is then the total downstream allocations or losses minus the upstream inflows. If the downstream outflow is less than the inflows from the upstream sub-basins a relative adjustment to the upstream sub-basins should be considered. The sum of all net available flows from all sub-basins should be equal to the outflow of the most downstream sub-basin (outlet).

To compute the irrigated area (km^2), the leftover outflow (m^3/month) for all months and the leftover outflow to the downstream sub-basin (the actual available flow) should be added. The whole basin should be scanned from the top sub-basin upstream to determine, first the sub-basins with zero or no upstream sub-basins, then all sub-basins with just one upstream sub-basin, then all sub-basins with just two upstream sub-basins, and so on, continuing up to 52 upstream sub-basins.

Figure 2.26 displays the flow chart of the program. Appendix1 presents sample input and output files and the FORTRAN code of the program.

2.3. Results and discussion

The approach used to evaluate the effects of various SI strategies upstream of the Karkheh Dam on the amount of water flowing into the dam, indicates that, although this practice has great impact on yield and WP, it does not reduce substantially the flow to the Karkheh reservoir. In this study the following stages are reviewed:

- Assessment of the water demand of each sub-basin
- Simulation of a water allocation pattern
- Assessment of the response of each sub-basin to the scenarios, the available and allocated flow.

The ultimate goal of the first two processes is to obtain for each sub-basin a water allocation which is representative of the prevailing conditions of the irrigation requirements, and resource and stream flow availability averaged over 30 years.

The third process then intends to evaluate the interaction and effect of the allocated water on the different components in each sub-basin and the Karkheh Dam.

The water demand of a sub-basin is calculated by aggregating the irrigation requirements of the SI and environmental needs. The process also considers a possible contribution from local supply sources, including groundwater and surface water stored in drainage canals and rivers. Local supply sources, managed according to specific rules, thus possibly act as a buffer for the main river supply. The program determines the SI

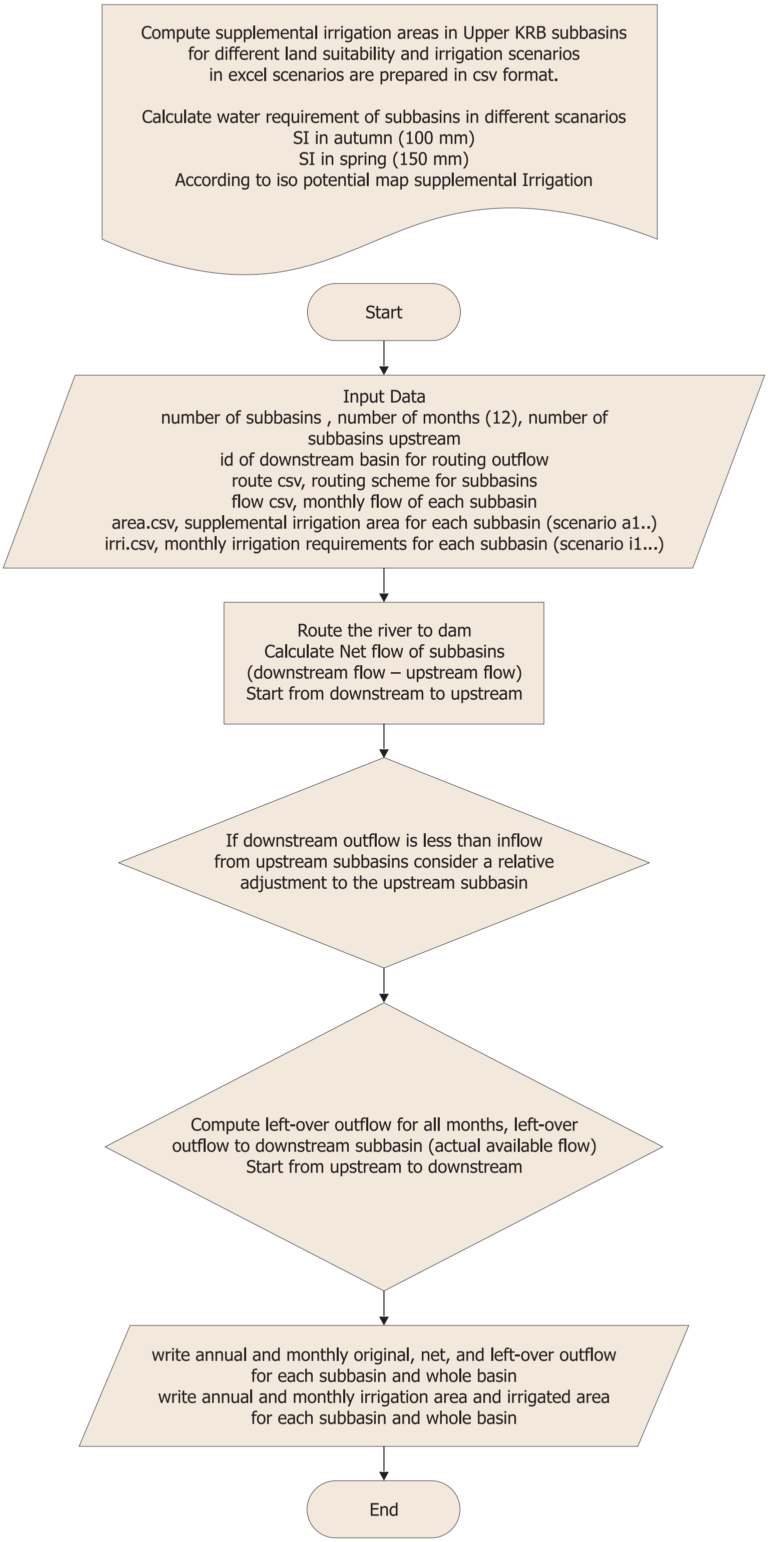

Figure 2.26. Flow chart of the allocation program.

requirement of each sub-basin, taking into consideration the various pre-defined scenarios. Sub-basin water demands constitute the main inputs to the water allocation process of the system. This process takes into account the physical constraints of the main river network, the water resources available close to the irrigation system, the water allocation policy, and possible downstream water requirements.

The allocations of water can be increased or decreased as more or less water becomes available for distribution within the district. The critical factors affecting the water management problem are the temporal characteristics associated with the objectives of the upstream and downstream basins.

Figures 2.27 to 2.30 show the SI areas of the sub-basins for different slopes under normal flow conditions, normal flow conditions with EFR consideration, flow rate under drought conditions, and drought flow conditions with EFR consideration. Tables Apx-2.3 to Apx-2.6 display the suitable and minimum SI areas of the sub-basins for different slopes under normal flow conditions, normal flow conditions with EFR, flow rate under drought conditions, and drought flow conditions with EFR. Tables Apx-2.7 to Apx-2.10 show the basin totals for SI development for different slopes under normal flow conditions, normal flow conditions with EFR, drought flow conditions, and drought flow conditions with EFR. In Tables Apx-2.3 to Apx-2.10, it should be noted that the planting dates for three sub-basins, Jelogir (22), Payepol (33), and Polezal (39), start in November and end in May(see Appendix 1:irri.csv).

Figure 2.31 shows a comparison of feasible SI areas for different slopes under different flow scenarios.

As discussed before, water allocated upstream for EFR is not consumed along the river and in the normal scenario each sub-basin will have a leftover outflow after the SI water has been withdrawn. In some sub-basins this water is sufficient for EFRs. Figure 2.32 shows a comparison of the environmental flow with the leftover outflow of the sub-basins under normal condition for the 0 to 5% slope priority in October. Table Apx-2.11 shows a comparison of the environmental flow with the leftover outflow of the sub-basins for different slopes under normal flow conditions.

Finally, comparing flow reductions arising from the interactions of the upstream and downstream SI scenarios and assessing the effects of the different scenarios for SI on the upstream sub-basins of the KRB, the quantity of flow to the Karkheh Dam can be evaluated. Tables Apx-2.12 to 2.22 show the irrigated areas and the annual and monthly decreases in stream flows to the Karkheh Dam relative to the available flows in the situation.

The estimated outflows before and after applying the SI strategies allow evaluation of:

- The impacts of different SI strategies on stream flow
- Assessment of the water demand at each sub-basin
- The water allocation pattern
- The response of each sub-basin to SI intervention
- The available and allocated water based on each strategy.

The water allocations may be adjusted based on water availability and priorities and the comparative benefits of the various uses within the basin. The critical factors affecting water management are the temporal and spatial characteristics as associated with the national objectives of the upstream/downstream development. The expected suitable SI area under the normal (average) conditions is 1945 km^2; under the normal with environmental flow conditions is 1362 km^2, under, drought. Conditions are 975 km^2, and under drought with environmental flow conditions is 692 km^2. The corresponding reductions in the downstream flows are 15.2%, 15.7%, 9.5%, and 8.6%of the available flow. Thus the results indicate that implementing SI in the rainfed areas does not substantially reduce the average annual flow to the Karkheh reservoir. At the same time, SI provides considerable benefits for the yield and WP of the upper KRB according to ongoing research at the selected sites. In addition to the environmental flow there is a surplus flow from most sub-basins.

It is recommended using SI in the spring, or for a single irrigation in autumn with early sowing. This maximizes in the upstream KRB. Further research should be undertaken to evaluate an EF allocation using the surplus water from the 53 sub-basins of the KRB. A complex, detailed soil map could help with the allocation to permit a more precise distribution of the SI water to more suitable lands. The methodology, the criteria, and the scenarios may be refined further by including socioeconomic factors. In particular, the predicted changes in farm incomes under the proposed options may help influence policies for the reallocation of available water resources.

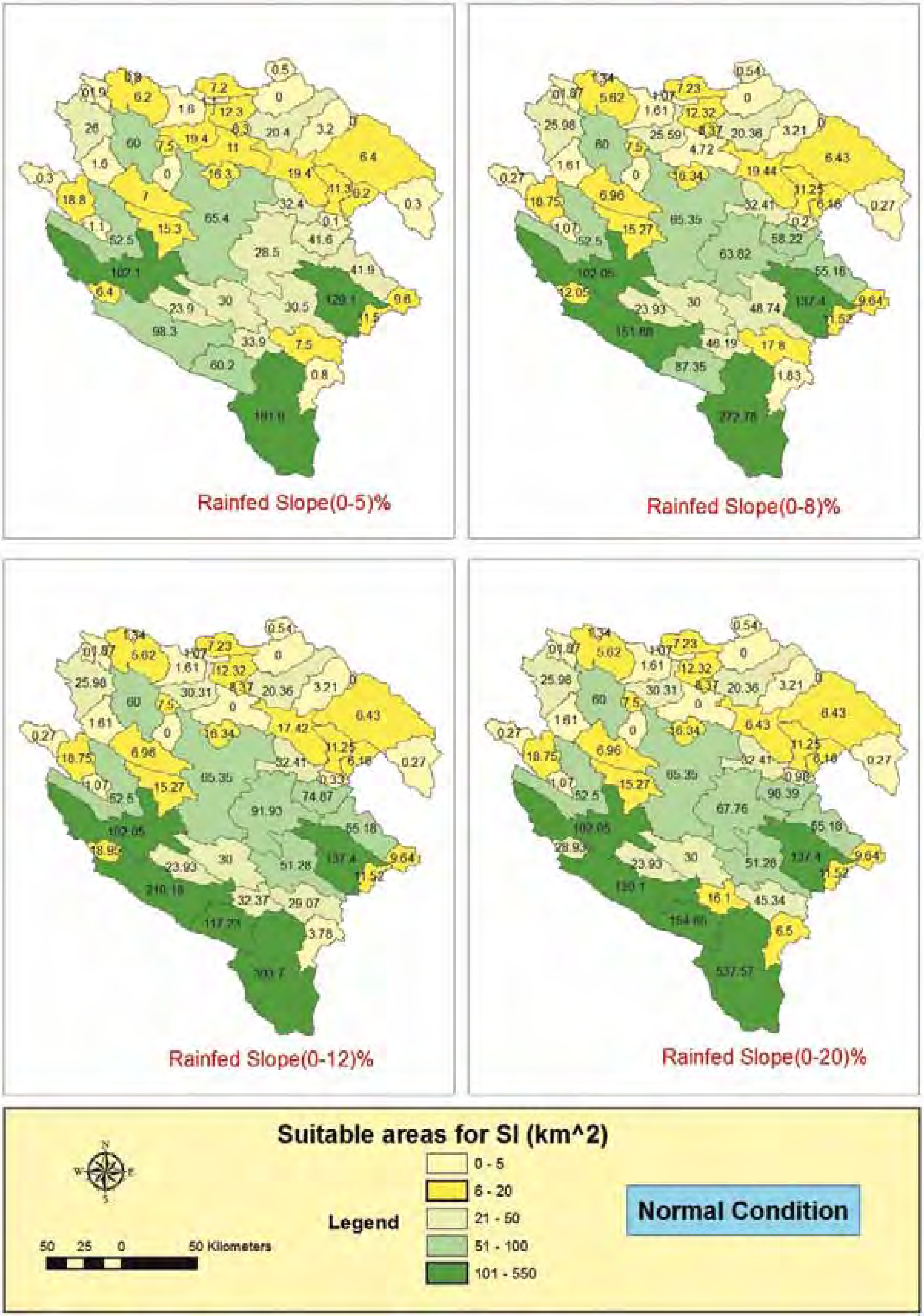

Figure 2.27. Sub-basins areas of different slopes suitable for SI under normal flow conditions.

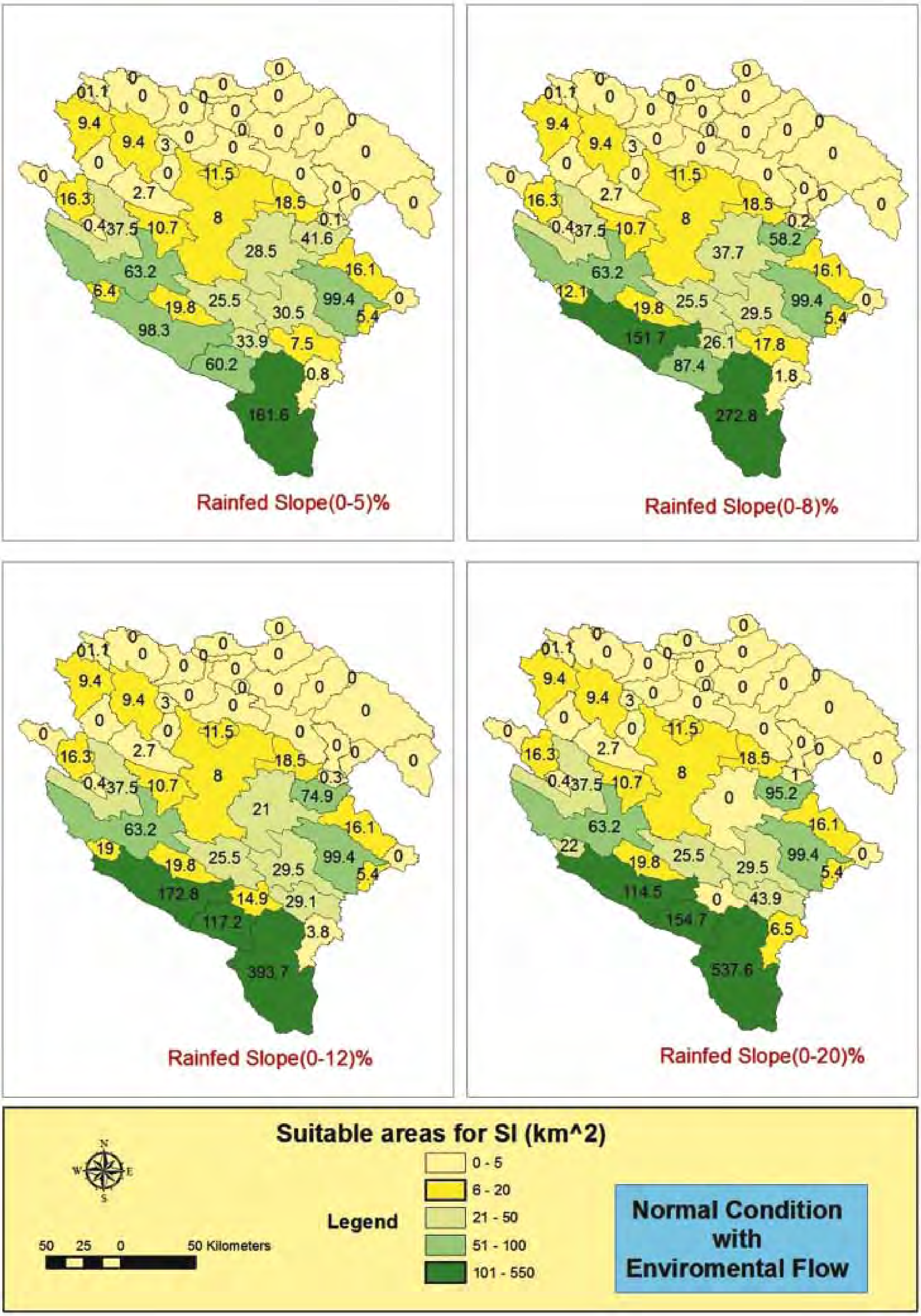

Figure 2.28. Sub-basin areas of different slopes suitable for SI under normal flow conditions with EFR consideration.

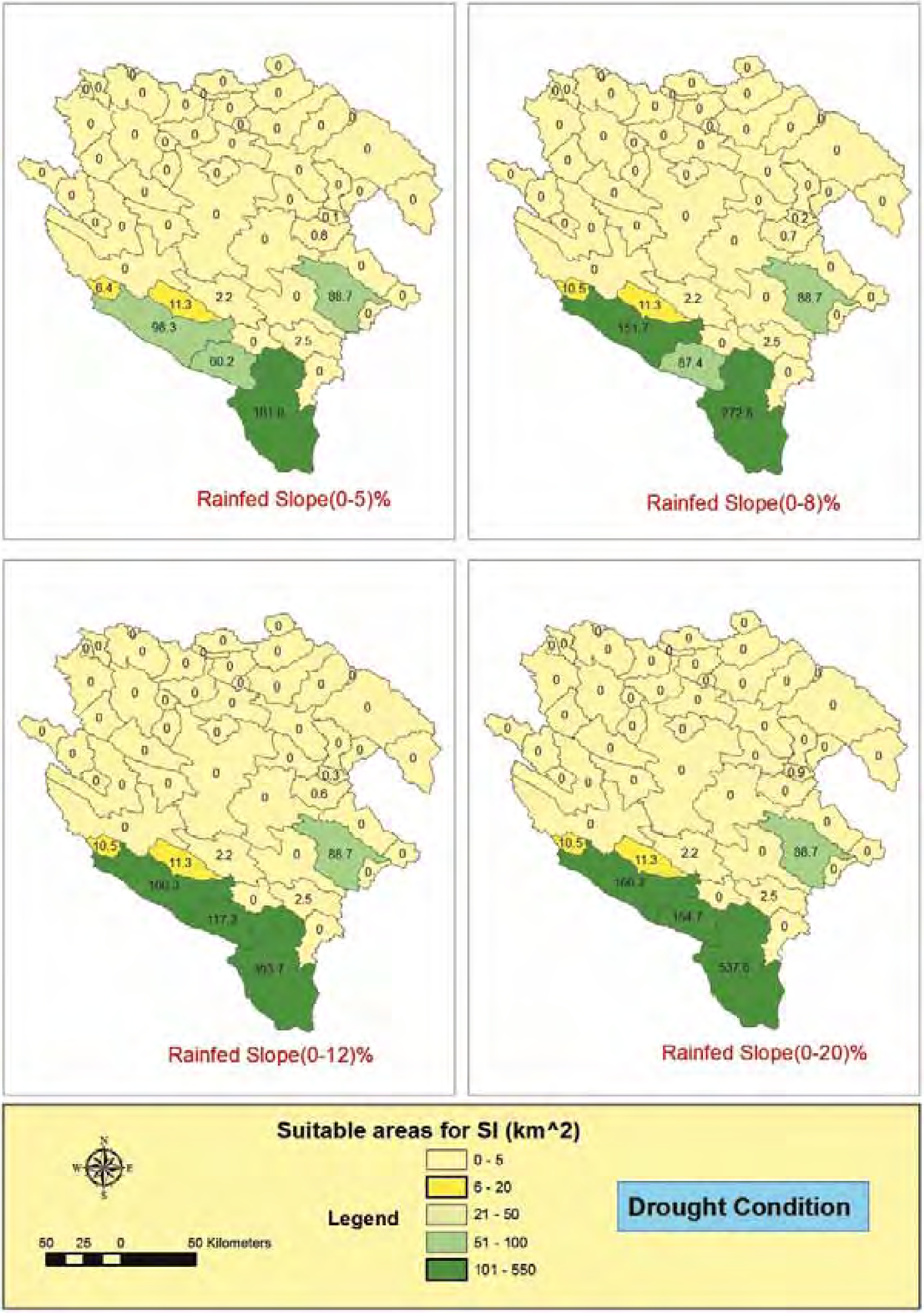

Figure 2.29. Sub-basin areas of different slopes suitable for SI under drought condition.

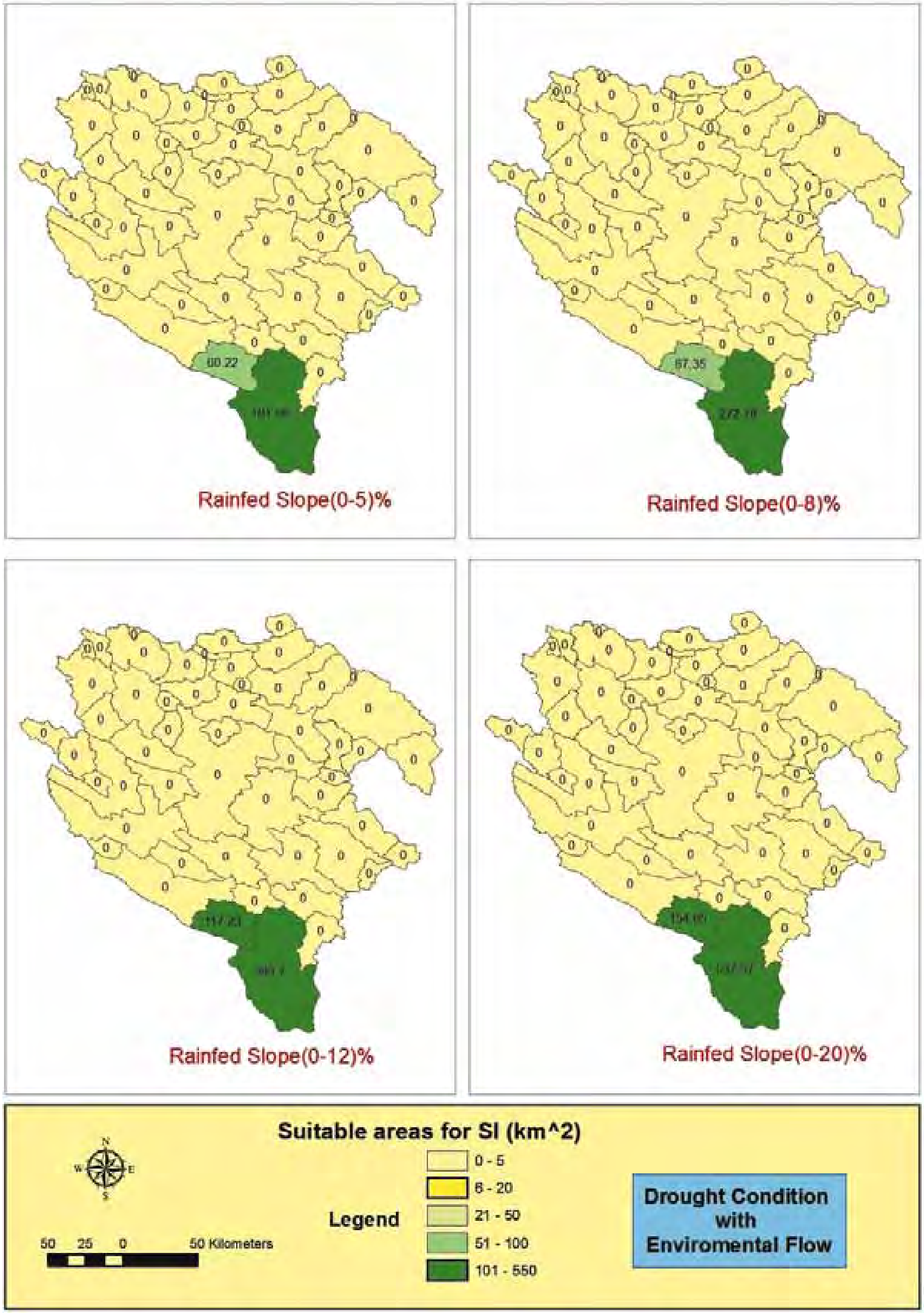

Figure 2.30. Sub-basins areas of different slopes suitable for SI under drought flow conditions with EFR consideration.

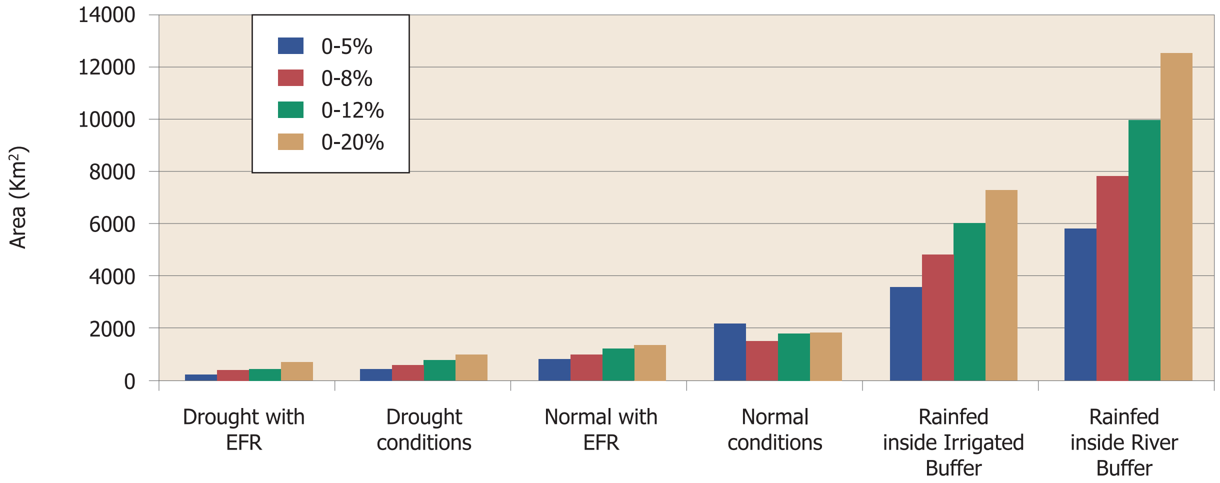

Figure 2.31. SI areas for different slopes under different flow scenarios.

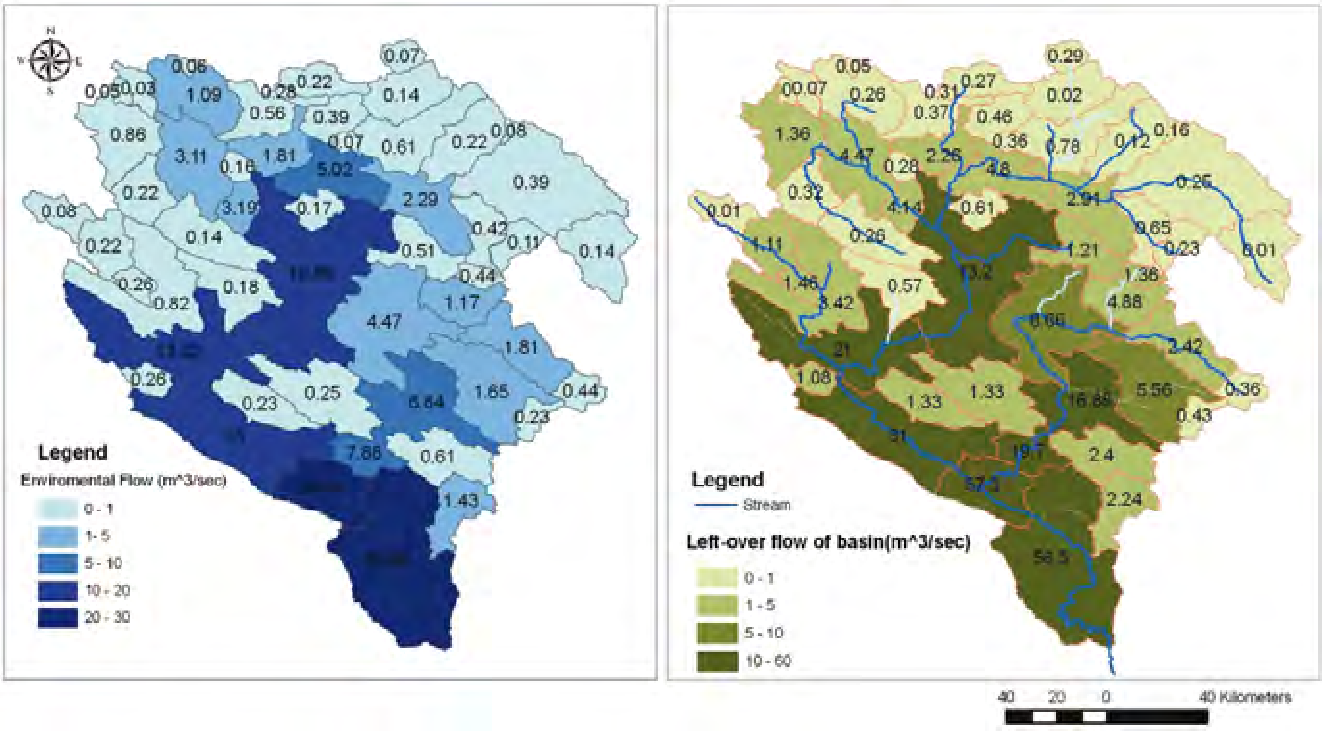

Figure 2.32. Comparison of environmental flows with the leftover outflows of sub-basins with slopes from 0 to 5%undernormal conditions in October.

Chapter 3.

Effects of Supplemental Irrigation on Downstream Water Quality

Chapter 3: Effects of Supplemental Irrigation on Downstream Water Quality

3.1. Introduction

The KRB has traditionally been the central point of agricultural activities in Iran. The relative availability of irrigation water and favorable climatic conditions make the basin suitable for growing a wide range of crops. Two major agricultural production systems prevail in the basin. A rainfed system prevails upstream of the newly built Karkheh Dam, and the fully irrigated areas are located mainly downstream of the dam. A SI practice for rainfed crops is recommended to improve water management and increase WP at the upstream KRB. But, rainfed areas suitable for SI are not isolated; rather, they are part of the river basin competing with other water users. Water 'savings' at one place are likely to reduce return flows and increase water salinity for other users downstream in the basin (Seckler, 1996). Therefore, evaluation of the present basin-wide water balance and exploration of the effects of different water management scenarios on water quantity and quality along the Karkheh River is necessary.

As water management includes many aspects and changes upstream in a basin these are likely to affect water quantity and quality downstream, so a basin scale approach is essential. Simulation models have proved to be very useful in reaching this goal in two ways. First, they can be used to fill in the data gaps in the measurements in terms of spatial and temporal resolution, or where data is lacking due to difficulties in their measurements. An example of the latter is the distinction between soil evaporation, considered as a loss in agronomy terms, and crop transpiration. This distinction is difficult to measure, but estimates can be made easily using simulation models (Droogers, 2000). A second application of the models is for scenario analyses; to answer the 'what happens if? 'Questions. An example of this is given by Voogt *et al*. (2000), where different scenarios were analyzed considering the distribution of surface water between irrigation and a wetland.

Models differ in their complexity and the soundness of their physical basis. For the detailed analysis of basin hydrology, including rainfall-runoff, land cover, groundwater, and hydraulics, comprehensive models are required (e.g., Kite, 1998). However, input requirements in terms of data, time, and knowledge, for these physically based basin models are often lacking. For the KRB, a simplified approach was tested. A water balance model, based on a spreadsheet, was developed to study water quantity and salinity problems at the river basin scale. Current and past water management was analyzed and scenarios were defined and evaluated using the model developed to improve water management.

In summary, this study explores the application of a simplified basin scale water quantity and salinity model, to evaluate the effect of different scenarios for SI, under normal conditions, on the water quantity and quality of the Karkheh River and Karkheh Dam.

3.2. Materials and methods

3.2.1. Simulation model

The main objective of the simulation model developed, the WSBM, was to create a simple and transparent water and salt accounting model, to be used for quick analyses of river basin processes. The model focuses on current water consumption and future scenarios for SI and the associated return flows from these systems. In order to accomplish this, we decided to create the model in a spreadsheet to facilitate data input, transparency, and flexibility. Moreover, the model was setup in a kind of object oriented style to support this transparency and flexibility.

The WSBM assumes that the river and its tributaries are divided into nodes with a reach defined between two successive nodes. The nodes are located at typical points on the river where stream gauges are present or output is required (Figures 1.1 to 1.3). Water extractions, or supplies, occur only in the reaches. Using this approach, water and salt flow along the river can be simulated by subtracting extractions, or adding supplies, from one node to get the value for the next node. As mentioned before, extractions are defined for current water consumption and SI supplies. Future extractions of water for SI, the return flow as a percentage of the extraction, and the accumulation of salt as a percentage of the total inflow must be specified. Obviously, to explore the effects of different interactions the values can be either real data or hypothetical values. The whole model was setup to run with a monthly time step and it was assumed that the response time of the river was within one month, so no time lag in water and salt flows between months occurs.

Four statistical parameters were used to compare the observed and simulated water salinity (in terms of EC). The Root Mean Square Error (RMSE, dS/m) is defined as:

$$\mathrm{RMSE} = \sqrt{\frac{\Sigma\,(\mathrm{Obs{-}Sim})}{n}} \qquad (3\text{-}1)$$

where, Obs is the observed EC (dS/m), Sim is the simulated EC (dS/m), and n is the number of observations.

Another statistical parameter used is the coefficient of determination, R^2:

$$R^2 = \frac{[\Sigma(X - \bar{X})(Y - \bar{Y})]^2}{\Sigma(X - \bar{X})^2\,\Sigma(Y - \bar{Y})^2} \qquad (3\text{-}2)$$

where, X and Y are the observed and simulated EC (dS/m), $\bar{X}$ and $\bar{Y}$ are the average observed and simulated EC (dS/m).

The third and fourth statistical parameters are the mean absolute error (MAE) and the mean error (ME) between the observed and simulated EC. These are used to reveal an under- or over-estimation of the model.

$$\mathrm{AME} = \frac{\Sigma_{i=1}^{n} |Obs - Sim|}{n} \qquad (3\text{-}3)$$

$$\mathrm{ME} = \frac{\Sigma_{i=1}^{n} (Obs - Sim)}{n} \qquad (3\text{-}4)$$

3.2.2. Input data

In the upper KRB, there are 70 hydrometric stations in the main and sub-branches of the river (Figure 3.1). At these stations, the water regime, sediment densities, and chemical quality and salinity are measured. The most extensive statistical data on this river have been collected since 1954 from the Gharasou River at the Merk and Gharebaghestan river stations.

Thirteen stations have been closed and six stations are relatively new, having been established in 1991 and 1992. The monthly data of the 53 selected stations are used to evaluate the effect of different scenarios for SI on the water quality of the Karkheh River and Karkheh Dam. A schematic representation of the stream network can be seen in Figure 1.3. The 10 main selected stations are

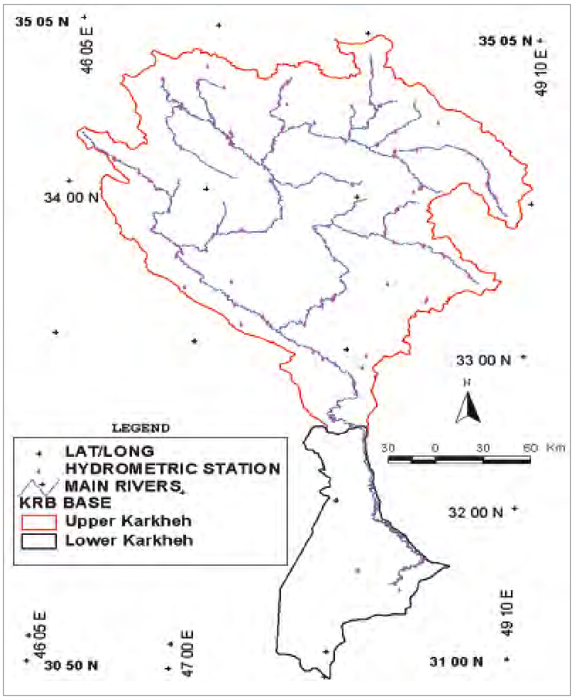

Figure 3.1. Hydrometric stations in the KRB.

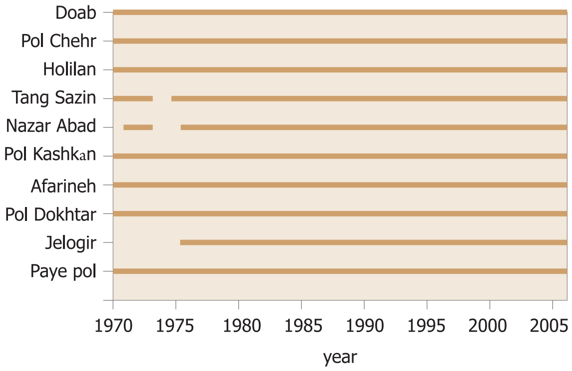

Figure 3.2. The availability of inflow data of the main selected stations.

shown in Figure 3.2. The data can be divided into that required to run the model (inflow, extractions, and salinity) and that needed to verify the model performance (the EC at the nodes). There are some stations with more than 30 years' worth of data, but some data are missing. For the missing data, it was assumed that a data item for a particular month was equal to the average of the values for the same months from the other years. The model performance was checked at the 10 main selected stations along the river. The availability of the monthly inflow data at the main selected stations is shown in Figure 3.2.

For all SI extractions, a return flow was assumed. Somewhat arbitrarily, this was set at 5%. This relatively low value was assumed to be realistic as this is the overall SI return flow, so internal return flows within a scheme are not considered. Moreover, water scarce areas tend to have low return flows. Salt inflow to the SI was equal to the amount of water inflow multiplied by the salinity level at the intake node. A fixed amount of salt accumulation was assumed, which can percolate down to the deep groundwater, be taken up by the crop, and stored in the soil profile. This accumulation was assumed to be 75% of the total salt inflow, so that a salt return flow of 25% is assumed. This salt return flow of 25% combined with the water return flow of 5% induces a temporary buildup of salinity levels in the river. The accumulated soil salinity in the root zone percolated down to the deep groundwater during the precipitation season and thus the soil salinity was decreased to the normal level.

3.2.3. Data generation and model calibration

The model was setup for a 30year period (1975-2005). A missing data item in a given month of one year was assumed to have the same value as the average of the values for the same month of the other years, as described before. The recorded flow data in a selected station (Figure 1.3) were used to define some unknown required input data, such as water consumption for irrigation/SI and domestic/industrial extractions. After the calibration of these data, a generalized model was created taking the average simulated flow for each month for the period 1975-2005. This generalized model is used for scenario analyses.

3.2.4. Scenarios

The generalized model, as described above, was used to explore different alternatives in terms of SI. In the upper catchments, rainfed cropping systems are prevalent, but some supplemental and full irrigation systems are also present. The cropping systems in the rainfed areas cover nearly 894,000 ha and are predominantly cereals in rotation with legumes. Wheat occupies 53% of the rainfed lands, barley, 23%, and chickpea 22%. The average grain production per unit area is rather low – 920 kg/ha for wheat, 950 kg/ha for barley, and about 500 kg/ha for chickpeas. The irrigation WP ranges from 0.3 to 0.5 kg/m^3 (Jamab Consulting Engineers, 1999; Moemeni, 2003). The upper catchments are the most suitable rainfed zones of the country, with long-term annual precipitation of between 350 and 500 mm. However, because of the non-uniform distribution of the precipitation and rainfall fluctuations between seasons, as well as variations in agro-climatic conditions and lack of appropriate agro-management measures, the WP is very low (about 0.3 kg/m^3)Therefore, from the range of possible scenarios, four scenarios have been selected for improved WP and further analyses.

In the mainly rainfed areas, the growing season is short, and, therefore, the yields of the rainfed cereals are generally lower than that expected where rainfall exceeds 400 mm. One of the causes of this low yield is the delay in the early season rainfall that results in late sowing, thereby exposing the crop to cold and frost damage. The result is a poor stand of the crop that continues throughout the growing season and which cannot be compensated for by rainfall later in the season. Significant yield decreases as a consequence of such phenomena have been observed in research by the Ryland Agricultural Research Institute and ICARDA in other rainfed areas of Iran. One potential solution is to plant early and apply SI. The use of SI for early planting has shown impressive results in increasing crop WP in similar areas of Iran and the Turkish highlands (Tavakoli and Oweis, 2004). Therefore, the first scenario was setup to analyze the effect of a single SI of 75 mm in October before frost occurs.

The relationships between crop yields and water use are complicated. Yield may depend on when the water is applied or on the amount supplied. Information on the optimal scheduling of limited amounts of water to maximize yields of high quality crops are essential if irrigation water is to be used most efficiently (Al-Kaisi *et al*., 1997). The various crop development stages possess different sensitivities to moisture stress (FAO, 1979; English and Nakamura, 1989; Ghahraman and Sepaskhah, 1997). Timing, duration, and the degree of water stress all affect yield. A sensitivity analysis at various growth stages of winter wheat in China proposed a single irrigation in wet years, two irrigations in normal years, and three in dry years to produce maximum profits. The timing of the irrigations would be at jointing to booting for the single irrigation, at jointing and heading to milky for the two irrigations, and before over wintering, jointing, and heading to milky for the three irrigations. Therefore, the second scenario was adopted to analyze the effects of a single SI of75 mm in the spring at the heading stage. A third defined scenario was the effect of two SI, each of 75 mm, one in October (autumn) and the other in the spring at the heading stage. The last scenario was developed to study the effects of two SIs, each of 75 mm, in the spring at the heading and milky stages.

3.3. Results

3.3.1. Model performance

After completing the model and including the data, the model was tested. Some preliminary test runs showed that the performance of the model for the 53 selected sub-basins was more or less accurate, showing a little lower or higher estimated salinity in term of EC at the different nodes as compared to the measured data.

The performance of the model was evaluated at 10 selected stations along the Karkheh River, using recorded and simulated EC. Figure 3.3 and Table 3.1 show this comparison and some statistics.

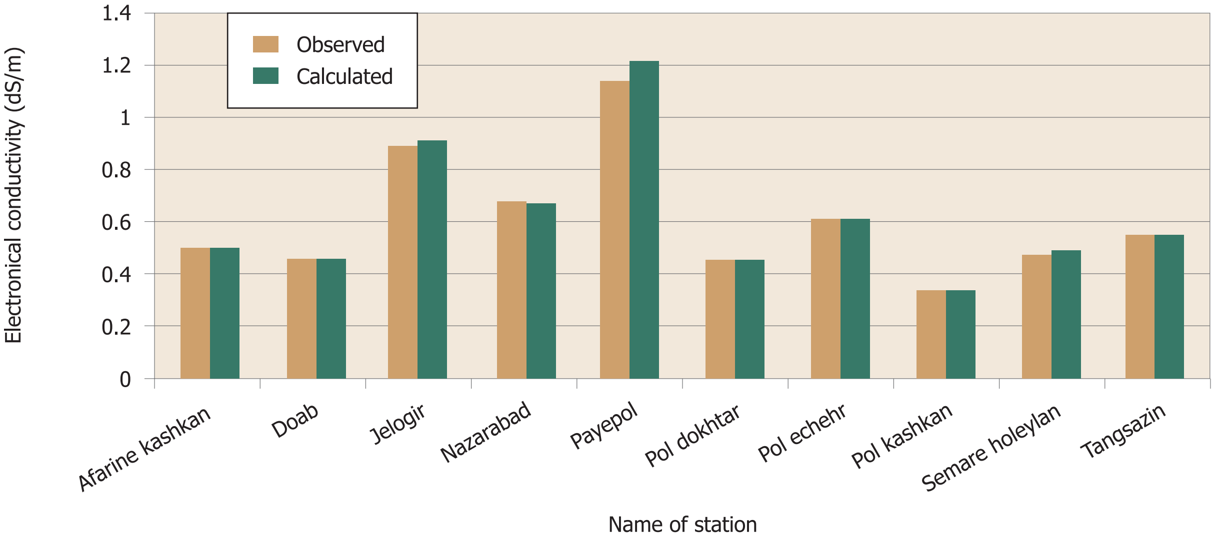

Figure 3.3. Average observed and simulated salinity levels (EC) along the Karkheh River (1995-2005).

Table 3.1. Comparison between observed and calculated monthly EC for some stations along the Karkheh River.

Node	RMSE (dS/m)	R^2	Meanabsolute error (dS/m)	Meanerror (dS/m)
Afarine Kashkan	0.016	0.873	0.456	-0.456
Doab	0.015	0.938	0.449	-0.449
Jelogir	0.012	0.870	0.483	-0.483
Nazarabad	0.012	0.920	0.553	-0.553
Payepol	0.038	0.939	0.687	-0.685
Polechehr	0.013	0.744	0.327	-0.327
Poldokhtar	0.026	0.838	0.504	-0.503
Pol Kashkan	0.026	0.861	0.608	-0.607
Semare Holeylan	0.070	0.927	0.895	-0.890
Tangsazin	0.133	0.817	1.144	-1.126

The calculated values were close to the observed ones, especially for most of the upstream nodes.

The observed salinity levels at the 53 selected stations are displayed in Figure 3.4. For the upstream part of the basin, salinity levels are around 0.5 dS/m, and not much fluctuation occurs. For the middle-part of the basin, levels have increased to about 0.7 dS/m, with some peaks reaching levels up to 0.9 dS/m. High fluctuations occur at the tail end of the upper Karkheh basin, with average salinity values of around 2.5 dS/m, if water levels are low, such as at the end of 1999 and at the beginning of 2000 for Payepole (the outlet of all sub-basins upstream of the Karkheh Dam).

3.3.2. Water quantity and quality in current situation at upper Karkheh basin

The upper Karkheh basin is divided into four main sub-basins– Gamasiab, Gharasou, Saymareh, and Kashkan– which depend on the river’s location and the general slope of the land. The direction of water flow in the basin is from north to south. The Karkheh River is formed by the merging of two main branches, the Gamasiab and the Saymareh (Figure 1.1 to 1.3). They join each other at the end of the Kermanshah plain, where the rivers called the Saymareh. The Saymareh then joins with the Kashkan River (another main branch of the western parts of the basin) and is then called the Karkheh. The main sub-

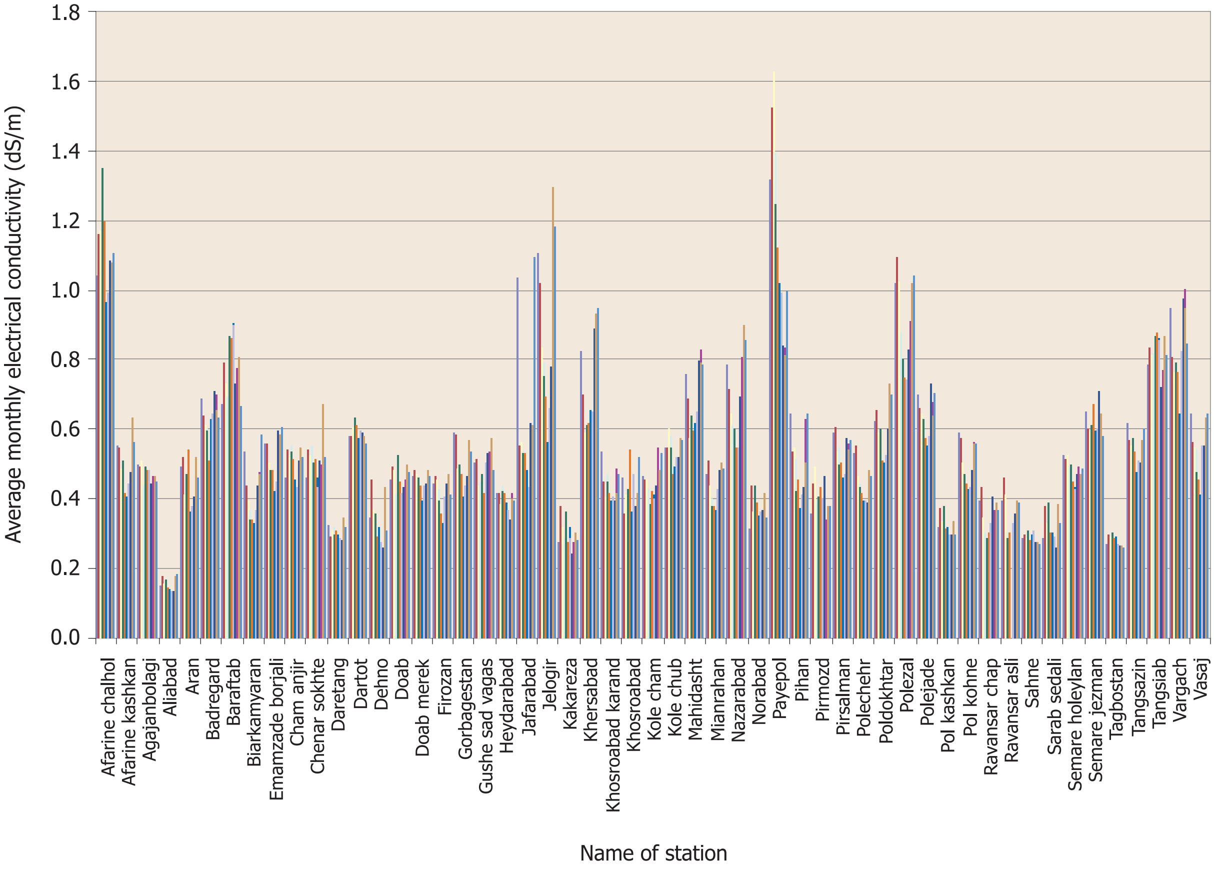

Figure 3.4. Average observed monthly EC values along the Karkheh River (2000).

basins and hydrographic network of the basin is shown in Figure 3.5.

Figure 3.5. Main sub-basins and hydrographic network of the KRB.

3.3.3. Water quantity and quality of the Gamasiab main sub-basin

This main sub-basin includes the branches of the Gamasiab River –the Nahavand, Mlayer, Toyserkan, Khorram-roud, and Dirineh-roud rivers. After receiving water from its sub-branches, the Gamasiab joins the Gharasou in the Bakhtaran Plain. Most of the agricultural lands at the upper end of the basin are located in this sub-basin. Based on the statistical information of the Polchehr station, the average discharge of the Gamasiab River into the Gamasiab sub-basin is 33.44 m^3/s and the salinity level is about 0.5 dS/m. Its maximum flow occurs in April –100 m^3/s– and the minimum water flow occurs in August –2.83 m^3/s (Figure 3.6).

3.3.4. Water quantity and quality of the Gharasou main sub-basin

The Gharasou River is located in the northwest part of the basin, and its initial branch is the Merek River, which drains into the Mahidasht plain. The river continues in a northwest-southeast direction and merges with the Gamasiab in southwestern Kermanshah. There are large agricultural areas here and Kermanshah city is located in this sub-basin. Gharebaghestan is the main water station of this sub-basin. Based on statistical data, the annual average

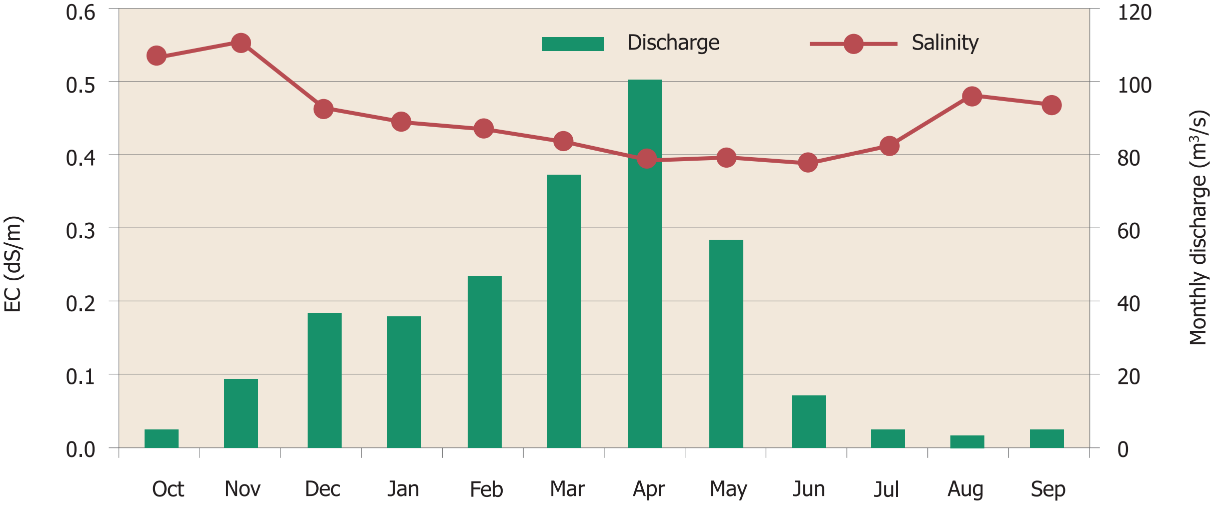

Figure 3.6. Average monthly discharge and salinity level at Gamasiab sub-basin.

discharge in the sub-basin is 21.3 m³/s with a salinity level of 0.5 dS/m. The maximum discharge of the river is 63.6 m³/s in April, and the minimum is 3.95 m³/s in August (Figure 3.7).

3.3.5. Water quantity and quality of Saymareh main sub-basin

The Saymareh River is formed by the Gamasiab and Gharasou rivers. Several sub-branches join the river, which then joins the Kashkan River. The Karkheh River is formed where the Kashkan River joins the Saymareh. In comparison to the other three sub-basins in the upper part of the KRB, the average discharge of the Saymareh River is 72.4 m³/s and its salinity level is about 0.5 dS/m (Figure 3.8).

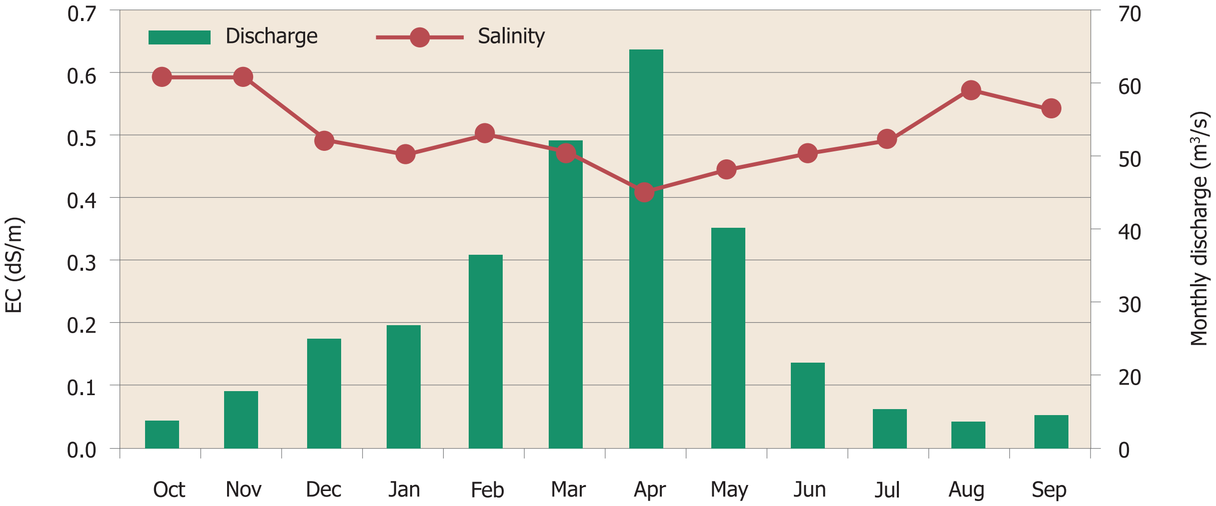

Figure 3.7. Average monthly discharge and salinity level at the Gharasou sub-basin.

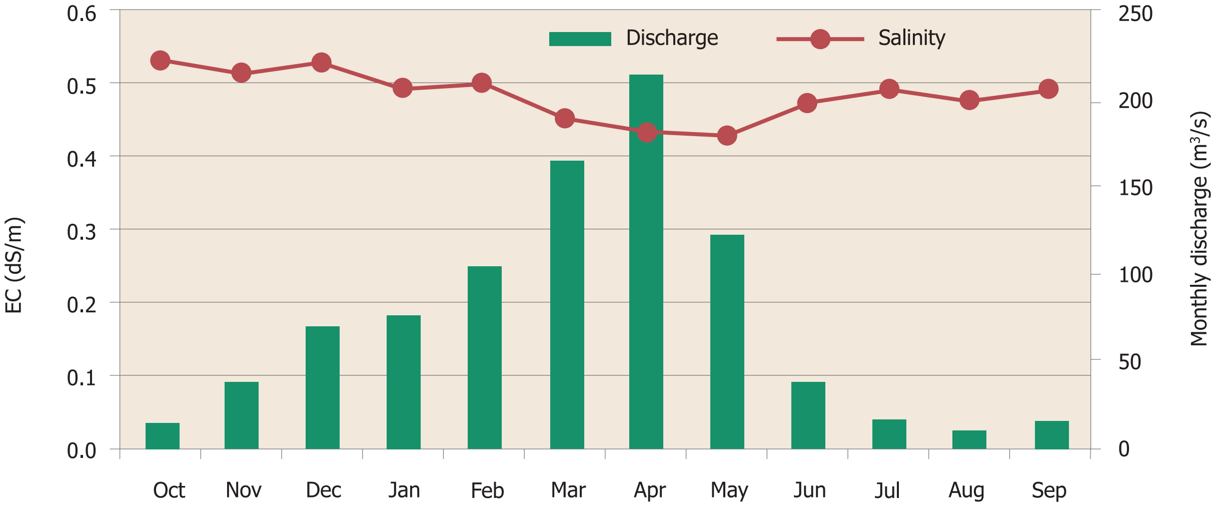

Figure 3.8. Average monthly discharge and salinity level at the Saymareh sub-basin.

3.3.6. Water quantity and quality of the Kashkan main sub-basin

This sub-basin includes the KRB, which comprises the joining of the Haroud, Doabo-shotor, Khorram-roud, and Madian-roud rivers. Based on the statistical information of the Poledokhtar station, the average discharge of the sub-basin is 52.5 m³/s with a salinity level of around the 0.6 dS/m. The maximum discharge is 131.2 m³/s in April and the minimum discharge is 15.5 m³/s in August (Figure 3.9).

3.3.7. Scenarios

The average monthly results of the model were used to generate a standard model– the baseline – to evaluate the effects of the different scenarios. The potential area for SI was calculated according to the available water and suitability of the area by an ongoing project in the upper KRB. The potential area for the first scenario– a single SI of75 mm in the autumn at planting time – is about 140,000 ha. This scenario has a significant effect on part of the Karkheh River and its branches, as the volume of SI extractions is relatively high. The greatest decrease in discharge and increase in salinity can be seen at the Polecheher station in Gamasiab sub-basin (Figure 3.10).

At the Payepole station, average flows during the SI season (October) are reduced by 67% from 56.5 m³/s to 18.7 m³/s. Moreover, salinity levels will increase substantially, with the average values in the growing season going up from 1.3 to 2.7 dS/m. This scenario has no significant effect on the water quantity and quality of the Karkheh Dam. Annual water quantity decreased 1.8% and salinity, in term of EC, increased0.8%.

The second defined scenario was the effect of a single SI of 75 mm in the spring (May) at the heading stage. The potential area for this scenario is around 200,000 ha. The scenario had no significant effect on the water quality and quantity of the Karkheh River and its branches, because the amount of water extraction for SI was relatively low compared to the river flow. At the Payepole station, the average monthly inflow in May increased significantly compared to that of October, going up from 56.5 to 284.1 m³/s.

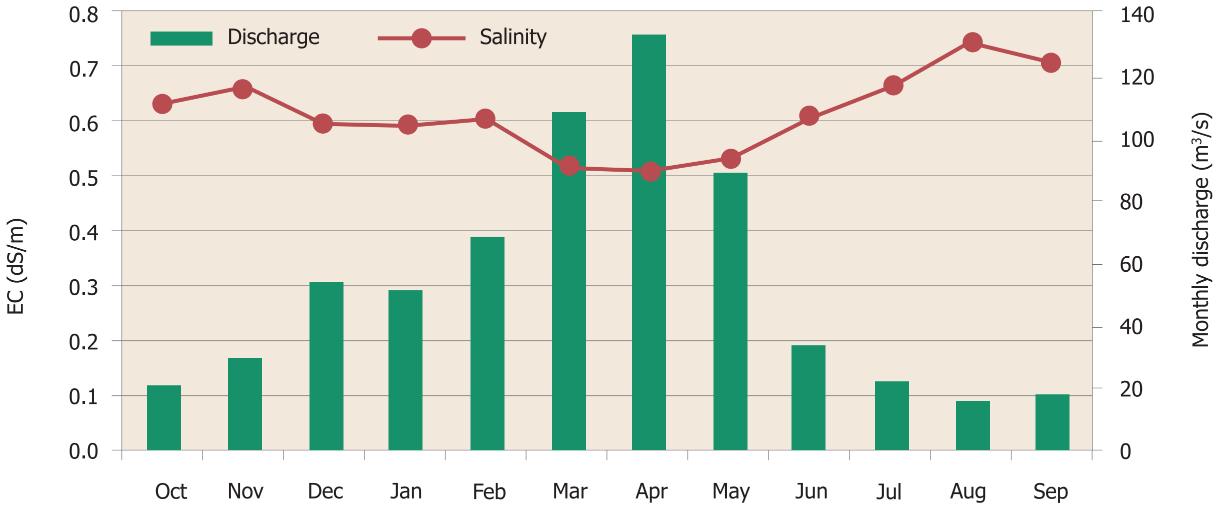

Figure 3.9. Average monthly discharge and salinity level at the Kashkan sub-basin.

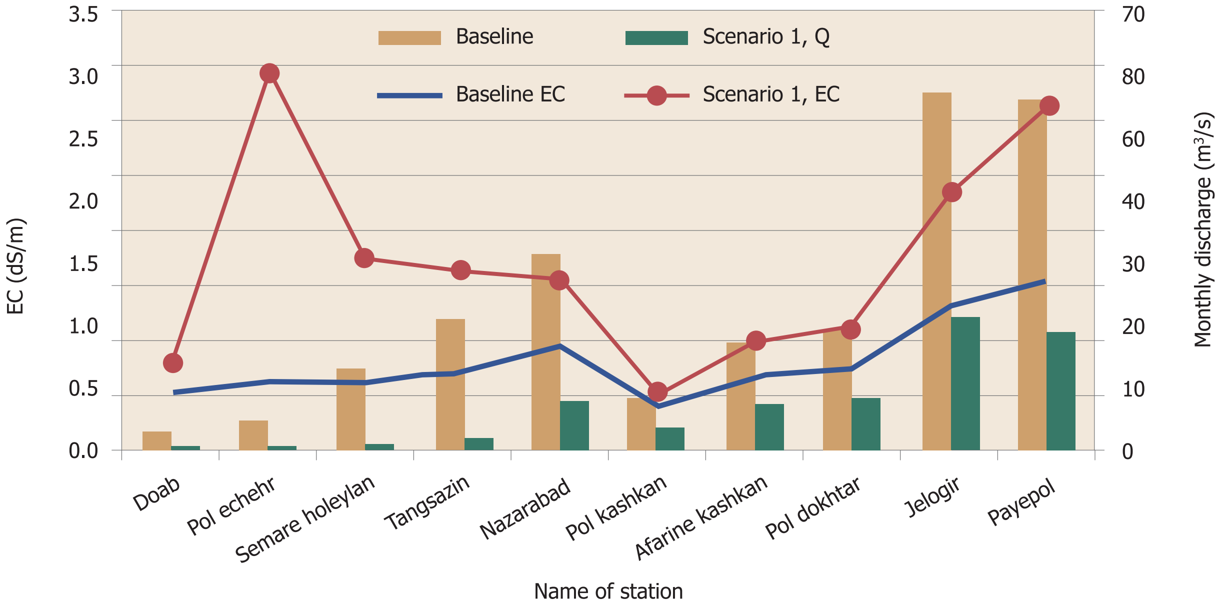

Figure 3.10. Effect of water extraction for SI, scenario 1 (at planting time), on discharge and salinity levels as compared to the baseline.

Based on the simulated data, the average discharge during the SI season (May) at this station decreased by 25% –from 248.1 to 186.6 m^3/s. Because of the increased inflow at the different nodes and the relatively low level of water extraction for SI, this scenario has some effect on the water quantity and quality of the Karkheh River and Karkheh Dam. The annual water quantity decreased by 4.9% and water salinity increased 3.1% (Figure 3.11).

The third defined scenario was the effect of two SI, each of 75 mm, one in the autumn and the other in spring at the heading stage. This scenario was a combination of scenarios 1 and 2and the results were the same as those of scenarios 1 and 2. However, the annual water quantity at the Karkheh Dam decreased 5.9% and water salinity increased by 3.9%.

The last developed scenario was that of two SI in spring at the heading and milky stages. The result of the SI at the heading stage was the same as that in scenario 2. Based on the results of scenario 4, about 200,000 ha of SI– 75 mm in spring (June) at the milky stage – decreased the water quality and quantity of the Karkheh River and its branches to some extent. At the Payepole station, the average monthly inflow from March to June increased significantly compared to October, but the salinity level of the water decreased along the river. However, the salinity values are low and less than 1.2 dS/m (Figure. 3.12). The annual water quantity of the Karkheh Dam decreased by 6.8% and water salinity increased 4.1%.

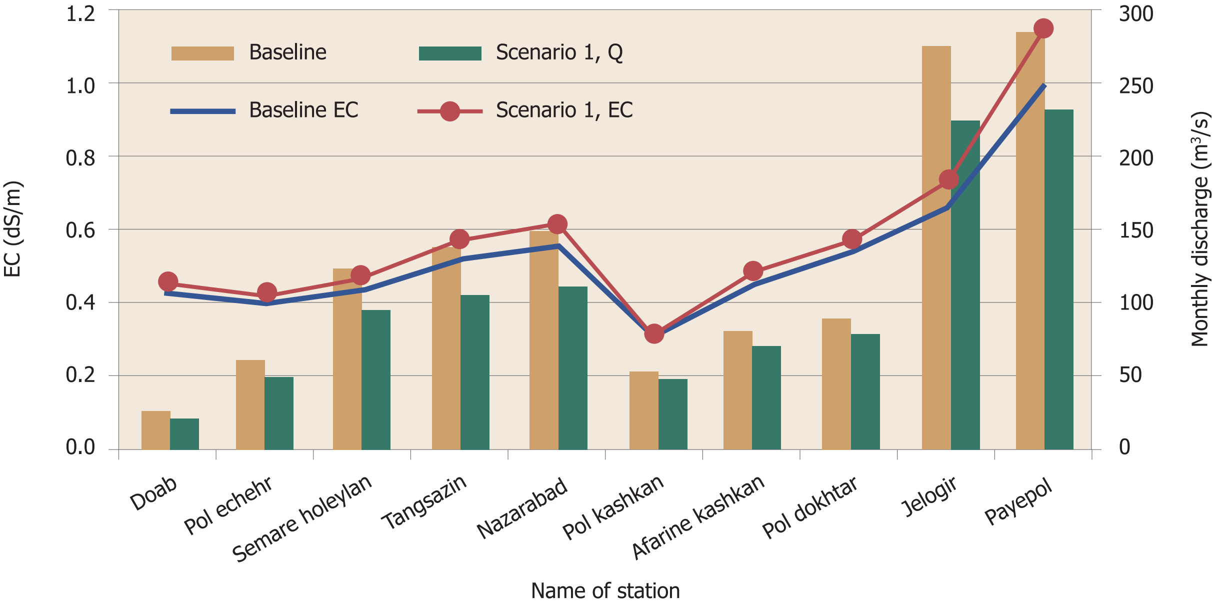

Figure 3.11. Effect of water extraction for SI, scenario 2 (applying SI in May), on discharge and salinity levels as compared to the baseline.

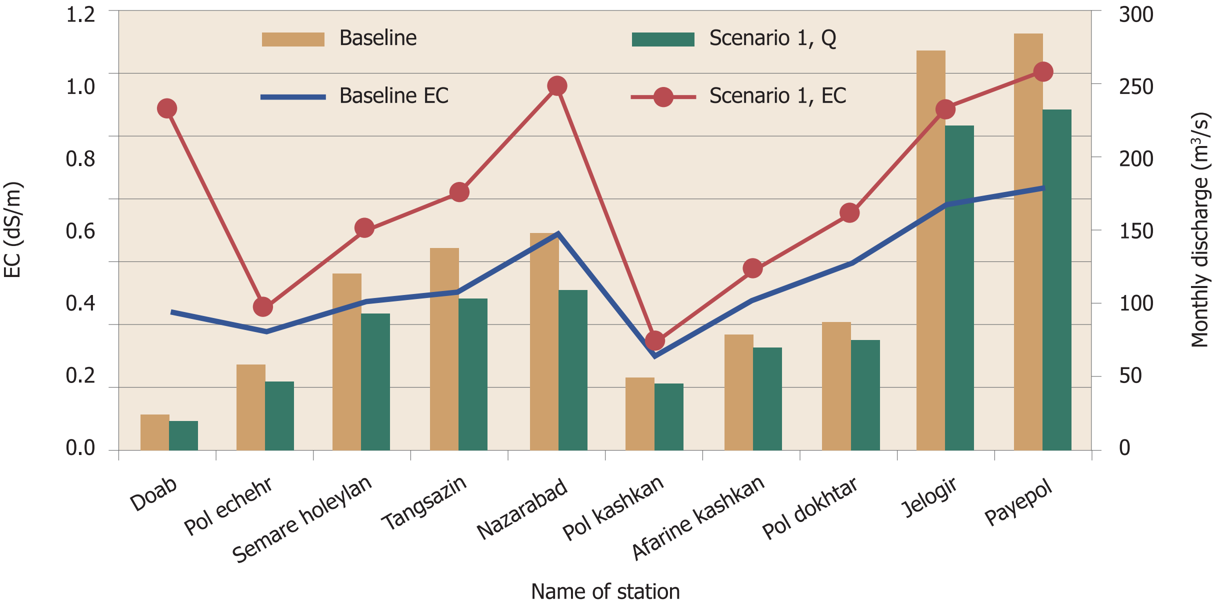

Figure 3.12. Effect of water extraction for SI, scenario 4 (applying SI in June), on the discharge and salinity levels as compared to the baseline.

3.3.8. Conclusions

The model developed for this study is an example of how, at the basin scale, water quantity and salinity analyses can be performed in a clear, transparent, and swift way. Four steps can be distinguished in this study:

- The development of the model
- Verification and calibration of the model
- Generalizing the model
- Scenario analyses based on the generalized model.

The model itself was developed in a spreadsheet using an object oriented mode, which makes the inclusion of additional components in the river layout fairly straightforward. Moreover, data entry, analysis of results, and plotting can be all done in the same spreadsheet environment. For the Karkheh River, the model can produce reliable results as compared with the observed data. The generalized model, developed by using the average simulated results for the last 30 years, is a transparent and easy-to-use tool for scenario analyses. The advantage of such a simplified model is that an unlimited number of scenarios can be analyzed in a very short time frame.

The scenarios defined here have been selected to demonstrate the application of the model, but additional scenarios can be developed and evaluated. The increased efficiency scenario showed that an apparent water extraction for SI in October has a significant impact on the water quality and quantity of the Karkheh River. A basin scale evaluation is therefore essential before expensive, efficient irrigation techniques for SI are introduced. Leaching will be lower with a higher risk of salt accumulation in the soil. A detailed, field scale soil-water-crop analysis can reveal these complex interactions (e.g. Droogers *et al*., 2000). The last scenario considered here, two SI each of 75 mm in the spring at the heading and milky stages had only a minor effect on the water quality and quantity of the Karkheh River and Karkheh Dam. There are two main reasons for this; the extractions were relatively low in comparison to the river discharge and the water salinity level was low.

Some general conclusions can be drawn from this study. The water quantity and quality of flows to the Karkheh Dam are sufficient and suitable for any further use. A further expansion of SI on the upper KRB can only be accomplished by analyzing the effects of water quality and quantity on the Karkheh River and Karkheh Dam. Improving field scale management, using more productive crops, and decreasing non-beneficial evaporation are important ways of achieving higher productivity in terms of crop produced per cubic meter of water used for agriculture.

3.4. Conclusions and recommendations

By comparing the results of three flow situations of the Karkheh River before and after applying different SI scenarios, the impacts of these different scenarios on stream flow can be evaluated at each sub-basin and, subsequently, for the basin as a whole. Under normal flow conditions, the maximum area can be covered with a reduction in the downstream flow of about 15.2%. The scenario which considers EFR covers a small area with no environmental effect. As discussed previously; because of the leftover flow, these two scenarios should be combined. The last scenario – drought conditions – dictates a stress condition and poses more limitations on the flow data. In this study, an 80% occurrence probability was considered as hydrological drought and droughts are assumed to happen at the same time in the whole basin. Simultaneously drought coverage of the whole basin may not happen. Further research should be made on the temporal and spatial variations of droughts in the KRB. In case of a water shortage, it might be fair for various sub-basins to share the water.

However, it is recommended that spring SI be emphasized under the KRB conditions because of water availability. Environmental flow for maintaining the ecosystem should not be neglected, with 15% of the MAR being the minimum allocation. Further research should be done on this case, especially for multi network systems and basin-wide analysis .In addition to the hydrology based methods, ecologically based methods should be considered. A detailed soil map can be very useful for allocating the SI water more precisely. The methodology, the criteria, and the SI scenarios may be refined further with a contribution from policy makers.

It is difficult to express as a single objective the water management goals of a complex situation such as the KRB. Even in a year with larger than normal rainfall, conflicts between various planning objectives may still exist. Therefore, it is appropriate to deal with the problem using a multiple objective (criteria) modeling approach. The model developed here can be used to promote an understanding and aid in the development of water allocation options for the communities that rely on the Karkheh River for their water supply. In the KRB, the water resources analyses are based on recorded stream flow data in addition to the normal available historical stream flow time series. As part of these activities, maps have been developed to help decision makers from the basin come to an agreement on the allocation of water in the upper KRB. Such a model may prove to be useful in assisting the KRB decision makers in negotiating agreements between the sub-basins of the KRB.

The major constraints related to this work include data limitations and the simplifying assumptions.

The goal is to develop an easy tool which will quickly identify suitable alternatives for water management. Such a tool can then be discussed, debated, modified, and simulated in greater detail. The objective of water resources analysis is to provide analytical decision-making tools for the optimum use of the available resources and to facilitate development planning to improve WUE with SI techniques. To incorporate the complexities discussed above, the following items were included in the program. The historic records of flows in the sub-basins were used as measures of the flows to the dam. Water demands were assumed constant over the modeling period. Several indices and data sets appear in the water allocation model equations. These define the basic elements of the model, such as time periods, river nodes, links between elements of the system, and so on. Several system variables are necessary to define its dynamic characteristics, such as flow through river nodes, storage and leftovers, etc. The time step used in the model is one month, which may be suitable for water resources allocation on a macro-level, but may not have meaning for some of the physical processes (e.g., flood control). The interaction of surface water and groundwater has been greatly simplified.

The rainfed Kc variation and crop stages of the Honam and Merek sites and a Kc map of the whole basin should be prepared.

It is assumed that rainfed crops are cultivated in suitable soils. It is recommended that for the future studies a high resolution soil map be prepared.

It is also recommended that more detailed studies be undertaken for priority areas to investigate the surface water-groundwater interactions, which are evident in some of the catchments of the KRB region. These studies should be undertaken in close consultation with ICARDA, AERI, the water authorities, and stakeholders. The Regional Water Authorities are responsible for the equitable allocation of the surface water resources in the KRB. At present, the allocation and licensing of surface water throughout the country is not undertaken in a systematic manner. Different approaches are used in each region and there is a lack of consistency in the data used to determine the sustainable yield from catchments.

This activity mainly provides information on agricultural WP as a consequence of SI development and the environmental consequences of improving WP at the basin level. Assessment of the upstream/downstream relationships and the potential impacts of supplemental and improved irrigation management downstream were assessed by different scenarios. Introducing improved dry farming packages can decrease soil erosion and the sediment load that could fill up the reservoir of the Karkheh Dam. Further research should be conducted on these subjects using the base scenarios of this research. The SI improves the yields and stabilizes rainfed production. However, using surface water for irrigation upstream may affect allocations downstream and ground water sustainability in the basin. Assessment of these and other similar impacts of the project can help with policy decisions regarding the extent of and locations for the expansion of different technical options.

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Appendices

Table Apx-1.1. Land use information of different sub-basins (km^2)

No.	Station	Total basin area	Net area/ sub-basin	Bare lands	Dry farming	Forest	Irrigated farming	Range	Rock out crops	Saline soils	Scattered dry farming	Urban	Sum (Bare lands to Urban columns)	Total rainfed
1	Afarine chalhol	811.32	811.32	0.00	0.00	646.75	9.89	69.41	0.00	0.00	72.45	0.00	798.50	72.45
2	Afarine kashkan	6,830.16	1,354.42	0.00	0.84	1,098.66	46.61	32.99	8.26	0.00	163.80	0.00	1351.16	164.64
3	Agajanbolagi	220.21	220.21	0.00	37.59	0.00	42.12	59.26	0.00	0.00	51.59	0.00	190.55	89.17
4	Aliabad	40.10	40.10	0.00	0.00	0.00	2.62	32.57	0.00	0.00	0.00	0.00	35.19	0.00
5	Aran	2,016.77	1,055.26	13.54	311.81	0.00	199.72	342.62	33.97	0.00	131.83	3.22	1,036.72	443.64
6	Badregard	1,144.74	205.31	0.00	86.79	88.80	8.83	20.88	0.00	0.00	0.00	0.00	205.31	86.79
7	Baraftab	1,140.46	1,140.46	0.00	512.62	240.79	96.73	14.55	5.11	0.00	47.21	0.73	917.75	559.84
8	Biarkamyaran	49.44	49.44	0.00	28.35	0.00	0.00	17.50	0.00	0.00	0.00	0.00	45.85	28.35
9	Emamzade borjali	421.60	421.60	0.00	204.46	0.00	68.41	84.12	0.12	0.00	52.34	1.96	411.40	256.80
10	Cham anjir	1,637.34	1,413.49	0.00	330.67	596.43	90.05	195.83	46.26	0.00	135.35	1.95	1,396.55	466.02
11	Chenar sokhte	223.85	223.85	0.60	35.00	91.92	16.32	33.70	7.99	0.00	19.35	0.00	204.89	54.35
12	Daretang	167.62	167.62	0.00	3.21	0.00	12.42	111.71	35.52	0.00	4.74	0.00	167.60	7.96
13	Dartot	2,626.26	1,481.52	0.00	518.92	553.12	64.62	191.94	10.14	0.00	109.83	0.00	1448.56	628.75
14	Dehno	280.84	280.84	0.00	85.46	0.00	21.95	113.68	0.00	0.00	35.71	0.00	256.80	121.17
15	Doab	7,759.89	963.41	0.48	125.42	0.00	252.71	111.54	0.77	0.00	472.49	0.00	963.41	597.91
16	Doab merek	2,718.67	957.91	0.00	589.45	1.61	97.01	165.57	0.00	0.00	99.61	0.00	953.26	689.06
17	Firozan	859.01	818.91	0.84	157.63	0.00	207.03	304.59	0.60	0.00	131.33	0.00	802.03	288.96
18	Gorbagestan	5,370.79	328.03	0.00	92.81	0.00	25.51	176.88	0.00	0.00	32.83	0.00	328.03	125.64
19	Gushe sad vagas	798.11	475.90	0.17	35.54	0.00	133.55	30.61	11.25	0.00	264.78	0.00	475.89	300.32
20	Heydarabad	2,167.18	580.13	0.00	61.11	0.00	81.09	360.92	22.61	0.00	54.40	0.00	580.12	115.50
21	Jafarabad	322.21	322.21	0.00	113.32	0.00	80.01	29.37	0.00	0.00	95.65	0.00	318.35	208.97

Note: The net area/sub-basin, for intermediate basins, is the area between two stream flow gauge stations along one river as shown in Figure 1.3.

Table Apx-1.1. (Continued).

No.	Station	Total basin area	Net area/ sub-basin	Bare lands	Dry farming	Forest	Irrigated farming	Range	Rock out crops	Saline soils	Scattered dry farming	Urban	Sum (Bare lands to Urban columns)	Total rainfed
22	Jelogir	39,196.27	931.92	0.00	103.31	350.94	43.11	149.55	115.80	0.00	167.54	0.54	930.79	270.84
23	Kakareza	1,152.37	871.53	0.00	157.47	97.49	112.93	412.18	18.79	0.00	40.03	0.00	838.89	197.50
24	Khersabad	1,438.43	564.49	0.00	212.26	72.99	214.62	27.94	0.00	0.00	36.62	0.00	564.42	248.88
25	Khosroabad karand	373.85	373.85	0.00	71.60	155.56	11.82	1.84	3.91	0.00	96.21	0.00	340.95	167.81
26	Khosroabad shahab	961.51	741.29	0.00	112.30	0.00	267.28	239.52	10.93	0.00	83.04	0.00	713.06	195.34
27	Kole cham	939.43	468.09	0.00	75.70	0.00	42.80	243.29	26.06	0.00	80.24	0.00	468.09	155.93
28	Kole chub	468.09	565.58	0.00	114.78	267.29	26.51	37.94	0.00	0.00	107.00	0.00	553.52	221.78
29	Mahidasht	873.93	873.93	0.00	389.69	133.33	69.37	78.96	7.54	0.00	195.04	0.00	873.93	584.73
30	Mianrahan	1,118.97	584.89	0.00	94.82	0.00	69.52	342.19	0.00	0.00	73.30	0.00	579.84	168.13
31	Nazarabad	28,324.53	2,007.44	0.00	359.26	868.65	81.44	239.76	159.96	0.00	287.52	0.00	1,996.60	646.78
32	Norabad	618.95	618.95	0.00	251.34	0.00	138.04	191.39	2.18	0.00	35.16	0.83	618.95	286.51
33	Payepol	42,908.38	3,110.54	0.00	698.90	512.71	32.14	1,584.77	15.63	0.00	229.54	0.00	3,073.68	928.44
34	Pihan	884.92	884.92	4.38	137.11	0.00	142.59	56.93	9.29	0.00	463.73	0.00	814.04	600.85
35	Pirmozd	1,024.21	974.77	0.00	407.59	0.00	96.22	445.15	9.31	0.00	4.05	2.23	964.56	411.65
36	Pirsalman	534.07	112.48	0.00	14.52	0.00	11.06	54.59	0.00	0.00	32.04	0.00	112.21	46.56
37	Polechehr	10,890.84	871.53	0.00	152.54	0.00	109.62	392.43	28.44	0.00	186.27	2.24	871.53	338.81
38	Poldokhtar	7365.83	480.49	0.00	26.64	286.05	25.93	6.11	21.08	0.00	114.62	0.05	480.49	141.26
39	Polezal	601.58	601.58	0.00	0.31	512.46	1.35	15.83	33.34	0.00	11.32	0.00	574.61	11.64
40	Polejade	309.21	309.21	0.00	105.35	0.00	35.14	126.10	0.00	0.00	42.62	0.00	309.21	147.97
41	Pol kashkan	3,838.40	1,896.60	0.00	137.45	1,259.45	87.65	109.86	76.35	0.00	225.87	0.00	1,896.63	363.32
42	Pol kohne	5,042.76	1,146.24	0.00	536.16	0.00	142.18	350.93	3.98	0.00	107.21	5.79	1,146.24	643.37
43	Ravansar chap	82.33	82.33	0.00	49.68	3.07	2.18	24.78	0.00	0.00	0.00	0.00	79.70	49.68

Note: The net area/sub-basin, for intermediate basins, is the area between two stream flow gauge stations along one river as shown in Figure 1.3

Table Apx-1.1. (Continued).

No.	Station	Total basin area	Net area/ sub-basin	Bare lands	Dry farming	Forest	Irrigated farming	Range	Rock out crops	Saline soils	Scattered dry farming	Urban	Sum (Bare lands to Urban columns)	Total rainfed
44	Ravansar asli	240.00	239.65	0.00	44.32	12.13	1.88	139.52	0.00	0.00	20.04	0.00	217.89	64.36
45	Sahne	92.24	92.24	0.00	20.30	0.00	6.29	46.67	2.33	0.00	16.66	0.00	92.24	36.96
46	Sarab sedali	789.43	621.81	0.00	114.74	0.00	163.02	224.35	46.71	0.00	72.42	0.51	621.74	187.17
47	Semare holeylan	21,198.30	3,428.38	0.00	390.14	1,682.01	125.37	574.30	78.58	0.00	577.98	0.00	3,428.38	968.12
48	Semare jezman	731.95	731.95	0.00	44.97	494.25	13.12	31.50	27.00	0.00	121.12	0.00	731.95	166.08
49	Tagbostan	153.64	153.64	0.00	44.54	0.00	0.00	65.17	43.93	0.00	0.00	0.00	153.64	44.54
50	Tangsazin	26,727.14	2,170.63	0.00	512.11	1,224.48	76.44	71.69	53.02	0.00	218.75	0.00	2,156.49	730.86
51	Tangsiab	615.35	615.35	0.00	252.04	142.68	22.79	93.80	24.17	0.00	79.87	0.00	615.35	331.91
52	Vargach	232.42	232.42	0.00	81.05	111.52	7.32	0.00	32.01	0.00	0.00	0.00	231.90	81.05
53	Vasaj	3,122.60	2,237.68	5.76	485.36	0.00	345.43	597.68	50.37	54.14	609.39	0.00	2148.12	1,094.75
KRB upstream			42,908.34	25.77	9,529.36	11,505.14	4,082.36	9,476.97	1,083.31	54.14	6,310.49	20.05	42,087.58	15,839.84

Note: The net area/sub-basin, for intermediate basins, is the area between two stream flow gauge stations along one river as shown in Figure 1.3.

Table Apx-1.2. Comparison of rainfed areas inside the irrigation buffers for 53 sub-basins having different slopes.

No.	**Station**	**Net area (km²)**	**Rainfed areas for different slope classes (km²)**					**Sum (km²)**	**Buffered rainfed areas with irrigated areas for different slope classes (km²)**					**Sum (km²)**
			Slope (%)						Slope (%)					
			0-5	5-8	8-12	12-20	>20		0-5	5-8	8-12	12-20	>20	
1	Afarine chalhol	72.45	7.82	11.09	12.30	18.17	22.75	72.13	3.11	4.44	4.95	5.92	5.87	24.30
2	Afarine kashkan	164.64	44.55	24.62	24.20	28.43	42.56	164.35	20.78	11.59	10.15	10.35	7.88	60.74
3	Agajanbolagi	89.17	30.35	16.17	11.07	13.66	17.33	88.59	24.12	13.72	9.23	11.26	12.39	70.70
4	Aliabad	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	Aran	443.64	174.49	66.63	58.47	67.37	76.17	443.12	84.21	28.15	23.63	22.22	21.68	179.88
6	Badregard	86.79	78.68	3.32	1.71	1.64	1.57	86.91	37.51	0.35	0.10	0.17	0.12	38.25
7	Baraftab	559.84	343.55	67.04	44.18	49.10	55.55	559.42	97.35	15.98	11.77	12.44	12.83	150.36
8	Biarkamyaran	28.35	0.98	2.06	3.55	7.49	14.08	28.16	0.00	0.00	0.00	0.00	0.00	0.00
9	Emamzade borjali	256.80	102.18	49.09	35.07	38.16	31.51	256.01	57.30	20.55	14.69	15.27	10.06	117.87
10	Cham anjir	466.02	163.29	65.69	59.85	76.88	100.16	465.86	93.58	22.70	18.76	21.82	24.01	180.87
11	Chenar sokhte	54.35	17.65	7.57	6.40	9.08	13.38	54.08	7.37	1.99	1.46	2.32	5.41	18.55
12	Daretang	7.96	0.13	0.18	0.36	1.07	6.13	7.88	0.05	0.05	0.07	0.29	1.55	2.01
13	Dartot	628.75	322.37	76.20	66.85	71.78	90.62	627.80	116.78	9.02	6.66	6.89	5.05	144.39
14	Dehno	121.17	28.99	24.37	20.42	24.90	22.34	121.02	15.77	12.01	8.28	8.18	4.01	48.25
15	Doab	597.91	109.23	50.44	50.96	98.79	288.04	597.46	89.14	31.55	28.36	44.83	67.32	261.20
16	Doab merek	689.06	403.33	76.89	65.83	77.96	64.62	688.63	169.50	11.56	10.42	14.60	8.66	214.74
17	Firozan	288.96	85.39	46.01	35.78	44.02	77.25	288.45	57.64	21.91	15.34	17.40	33.22	145.51
18	Gorbagestan	125.64	76.68	17.66	12.11	12.70	6.34	125.50	24.51	6.69	5.38	6.51	2.64	45.71
19	Gushe sad vagas	300.32	35.82	32.32	39.53	66.09	129.01	302.77	28.03	20.94	21.90	30.56	35.31	136.73
20	Heydarabad	115.50	33.22	11.60	11.74	17.20	41.40	115.17	25.83	5.34	5.12	6.54	20.48	63.30
21	Jafarabad	208.97	93.69	37.89	31.40	28.71	17.37	209.06	72.67	23.51	16.49	17.20	12.53	142.40
22	Jelogir	270.84	83.54	36.33	41.22	52.15	57.21	270.45	48.61	13.79	12.87	14.76	13.49	103.52
23	Kakareza	197.50	53.37	31.75	32.20	33.91	45.41	196.64	38.78	21.30	20.16	19.46	19.16	118.87
24	Khersabad	248.88	142.63	39.54	26.90	22.52	17.16	248.76	55.22	8.65	6.31	5.54	6.92	82.64
25	Khosroabad karand	167.81	67.44	15.14	15.79	24.18	44.48	167.04	25.59	2.58	2.58	3.53	10.93	45.21
26	Khosroabad shahab	195.34	71.09	25.12	22.42	32.56	43.81	195.00	61.23	16.51	13.50	19.82	22.70	133.76
27	Kole cham	155.93	31.58	24.07	21.89	27.19	50.99	155.72	21.64	14.81	13.12	16.23	21.39	87.19
28	Kole chub	221.78	103.42	28.10	26.52	34.27	29.10	221.43	37.30	1.61	1.66	2.71	2.99	46.28

Table Apx-1.2. (Continued).

No.	**Station**	**Net area (km^2)**	**Rainfed areas for different slope classes (km^2)**					**Sum (km^2)**	**Buffered rainfed areas with irrigated areas for different slope classes (km^2)**					**Sum (km^2)**
			Slope (%)						Slope (%)					
			0-5	5-8	8-12	12-20	>20		0-5	5-8	8-12	12-20	>20	
29	Mahidasht	584.73	392.46	66.83	47.42	46.78	31.15	584.64	108.64	4.23	1.36	1.13	0.28	115.64
30	Mianrahan	168.13	40.83	19.62	22.91	32.37	51.79	167.52	17.20	10.14	13.87	16.82	27.04	85.08
31	Nazarabad	646.78	212.00	78.40	83.80	114.42	158.43	647.06	91.70	19.46	22.65	31.09	37.84	202.73
32	Norabad	286.51	142.64	60.45	29.19	21.05	32.57	285.90	72.95	33.46	15.29	9.88	9.13	140.71
33	Payepol	928.44	233.59	147.00	156.30	178.84	212.24	927.97	46.70	11.15	8.92	7.77	3.58	78.12
34	Pihan	600.85	63.56	79.75	112.57	167.31	176.24	599.43	52.41	58.83	79.34	115.09	92.78	398.45
35	Pirmozd	411.65	166.58	57.13	45.36	56.85	85.67	411.59	103.68	20.17	16.91	19.42	31.33	191.51
36	Pirsalman	46.56	8.65	6.11	6.54	8.78	16.32	46.39	3.19	3.03	3.15	3.99	7.16	20.53
37	Polechehr	338.81	121.21	38.22	34.53	46.66	97.55	338.17	66.00	11.70	10.53	13.14	30.13	131.51
38	Poldokhtar	141.26	38.31	15.51	15.65	23.39	48.32	141.19	19.31	6.18	5.97	7.45	12.09	51.00
39	Polezal	11.64	0.80	1.03	2.07	3.07	4.65	11.62	0.00	0.00	0.00	0.00	0.00	0.00
40	Polejade	147.97	32.25	24.49	25.13	35.07	30.89	147.83	22.56	9.85	7.35	8.12	7.42	55.31
41	Pol kashkan	363.32	51.38	56.81	68.42	92.58	93.86	363.06	27.64	33.96	41.04	49.77	42.20	194.61
42	Pol kohne	643.37	466.37	47.79	36.11	43.37	49.94	643.59	259.72	6.71	4.78	5.20	10.64	287.05
43	Ravansar chap	49.68	26.85	7.28	4.96	5.52	4.98	49.59	5.35	0.65	0.15	0.14	0.40	6.68
44	Ravansar asli	64.36	20.64	6.64	6.38	8.36	22.18	64.19	1.68	0.19	0.25	0.17	0.24	2.52
45	Sahne	36.96	9.73	4.89	4.56	5.12	12.52	36.82	4.97	2.35	1.90	1.78	4.33	15.32
46	Sarab sedali	187.17	51.63	24.61	24.65	36.93	49.01	186.83	38.95	16.67	15.50	22.69	29.28	123.09
47	Semare holeylan	968.12	196.73	153.21	163.07	226.36	226.96	966.33	64.32	59.12	67.27	86.57	73.79	351.07
48	Semare jezman	166.08	48.87	26.95	25.05	31.79	32.89	165.54	7.36	6.26	5.54	5.30	2.49	26.95
49	Tagbostan	44.54	16.81	7.11	4.37	4.31	11.96	44.57	0.00	0.00	0.00	0.00	0.00	0.00
50	Tangsazin	730.86	204.28	104.49	103.96	135.40	181.35	729.48	87.44	25.71	18.29	17.90	20.99	170.34
51	Tangsiab	331.91	158.43	36.74	33.23	39.72	63.67	331.79	29.15	10.04	8.73	9.12	11.84	68.89
52	Vargach	81.05	11.58	10.92	13.63	21.10	23.72	80.95	3.05	2.28	2.55	4.06	2.21	14.16
53	Vasaj	1,094.75	379.56	175.49	157.60	207.05	171.58	1,091.28	234.33	64.37	57.06	69.45	51.18	476.39
Entire upstream KRB		15,839.84	5,801.20	2,144.34	2,006.21	2,572.18	3,296.78	15,820.71	2,681.93	757.80	691.33	842.86	896.95	5870.87

Table Apx-1.3. Comparison of rainfed areas inside the river buffer for 53 sub-basins with different slopes.

No.	**Station**	**Net area (km²)**	**Rainfed areas for different slope classes (km²)**					**Sum (km²)**	**Buffered rainfed areas within1000 m river buffer for different slope classes (km²)**					**Sum (km²)**
			Slope (%)						Slope (%)					
			0-5	5-8	8-12	12-20	>20		0-5	5-8	8-12	12-20	>20	
1	Afarine chalhol	72.45	7.82	11.09	12.30	18.17	22.75	72.13	7.51	10.28	11.27	16.27	19.62	64.96
2	Afarine kashkan	164.64	44.55	24.62	24.20	28.43	42.56	164.35	30.47	18.27	17.67	19.21	26.23	111.85
3	Agajanbolagi	89.17	30.35	16.17	11.07	13.66	17.33	88.59	10.84	6.91	5.99	6.16	3.50	33.41
4	Aliabad	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	Aran	443.64	174.49	66.63	58.47	67.37	76.17	443.12	89.88	29.17	21.67	22.20	23.83	186.74
6	Badregard	86.79	78.68	3.32	1.71	1.64	1.57	86.91	40.35	0.45	0.20	0.26	0.51	41.78
7	Baraftab	559.84	343.55	67.04	44.18	49.10	55.55	559.42	224.96	36.62	20.97	21.52	20.64	324.70
8	Biarkamyaran	28.35	0.98	2.06	3.55	7.49	14.08	28.16	0.79	1.65	2.43	4.35	6.94	16.16
9	Emamzade borjali	256.80	102.18	49.09	35.07	38.16	31.51	256.01	77.10	31.70	20.70	19.54	15.91	164.96
10	Cham anjir	466.02	163.29	65.69	59.85	76.88	100.16	465.86	129.14	44.83	37.32	42.62	51.89	305.79
11	Chenar sokhte	54.35	17.65	7.57	6.40	9.08	13.38	54.08	12.26	4.12	3.02	4.21	5.64	29.25
12	Daretang	7.96	0.13	0.18	0.36	1.07	6.13	7.88	0.13	0.07	0.13	0.64	2.47	3.45
13	Dartot	628.75	322.37	76.20	66.85	71.78	90.62	627.80	221.66	41.06	32.53	32.38	37.25	364.88
14	Dehno	121.17	28.99	24.37	20.42	24.90	22.34	121.02	23.38	20.09	16.90	21.65	18.47	100.49
15	Doab	597.91	109.23	50.44	50.96	98.79	288.04	597.46	42.52	20.92	24.85	51.99	157.76	298.02
16	Doab merek	689.06	403.33	76.89	65.83	77.96	64.62	688.63	272.34	43.83	38.92	44.17	35.68	434.95
17	Firozan	288.96	85.39	46.01	35.78	44.02	77.25	288.45	37.68	20.53	15.48	18.09	26.98	118.75
18	Gorbagestan	125.64	76.68	17.66	12.11	12.70	6.34	125.50	32.36	11.14	8.78	9.99	3.30	65.56
19	Gushe sad vagas	300.32	35.82	32.32	39.53	66.09	129.01	302.77	24.89	16.51	19.21	29.94	50.33	140.88
20	Heydarabad	115.50	33.22	11.60	11.74	17.20	41.40	115.17	19.39	6.20	5.60	7.08	17.06	55.34
21	Jafarabad	208.97	93.69	37.89	31.40	28.71	17.37	209.06	43.41	13.15	9.66	12.21	8.34	86.77
22	Jelogir	270.84	83.54	36.33	41.22	52.15	57.21	270.45	60.22	27.13	29.87	37.42	40.45	195.10
23	Kakareza	197.50	53.37	31.75	32.20	33.91	45.41	196.64	41.91	23.23	20.70	18.73	25.40	129.97
24	Khersabad	248.88	142.63	39.54	26.90	22.52	17.16	248.76	88.71	20.16	12.30	9.81	4.56	135.54
25	Khosroabad karand	167.81	67.44	15.14	15.79	24.18	44.48	167.04	34.28	3.55	3.90	6.27	10.41	58.41
26	Khosroabad shahab	195.34	71.09	25.12	22.42	32.56	43.81	195.00	36.84	10.40	9.30	14.61	19.55	90.69
27	Kole cham	155.93	31.58	24.07	21.89	27.19	50.99	155.72	27.34	18.09	15.24	18.46	36.24	115.38
28	Kole chub	221.78	103.42	28.10	26.52	34.27	29.10	221.43	51.13	8.83	6.74	7.19	4.38	78.27

Table Apx-1.3. (Continued).

No.	Station	Net area (km²)	Rainfed areas for different slope classes (km²)					Sum (km²)	Buffered rainfed areas within1000 m river buffer for different slope classes (km²)					Sum (km²)
			Slope (%)						Slope (%)					
			0-5	5-8	8-12	12-20	>20		0-5	5-8	8-12	12-20	>20	
29	Mahidasht	584.73	392.46	66.83	47.42	46.78	31.15	584.64	290.38	36.56	23.60	21.52	13.83	385.90
30	Mianrahan	168.13	40.83	19.62	22.91	32.37	51.79	167.52	32.14	9.85	12.34	20.09	36.88	111.30
31	Nazarabad	646.78	212.00	78.40	83.80	114.42	158.43	647.06	98.27	53.41	58.50	81.81	100.83	392.81
32	Norabad	286.51	142.64	60.45	29.19	21.05	32.57	285.90	68.32	30.17	13.48	8.43	8.13	128.53
33	Payepol	928.44	233.59	147.00	156.30	178.84	212.24	927.97	161.56	111.22	120.92	143.87	155.12	692.69
34	Pihan	600.85	63.56	79.75	112.57	167.31	176.24	599.43	51.02	53.96	71.10	92.99	70.62	339.69
35	Pirmozd	411.65	166.58	57.13	45.36	56.85	85.67	411.59	126.86	37.64	29.29	34.25	44.64	272.69
36	Pirsalman	46.56	8.65	6.11	6.54	8.78	16.32	46.39	8.12	5.10	5.20	6.49	11.00	35.91
37	Polechehr	338.81	121.21	38.22	34.53	46.66	97.55	338.17	83.52	20.76	17.92	23.10	38.98	184.26
38	Poldokhtar	141.26	38.31	15.51	15.65	23.39	48.32	141.19	33.87	12.31	11.56	15.99	31.96	105.70
39	Polezal	11.64	0.80	1.03	2.07	3.07	4.65	11.62	0.80	1.03	1.96	2.71	4.10	10.60
40	Polejade	147.97	32.25	24.49	25.13	35.07	30.89	147.83	18.09	12.34	12.04	17.87	13.53	73.86
41	Pol kashkan	363.32	51.38	56.81	68.42	92.58	93.86	363.06	28.52	35.30	45.08	59.04	55.74	223.69
42	Pol kohne	643.37	466.37	47.79	36.11	43.37	49.94	643.59	188.23	11.57	7.57	9.16	15.85	232.37
43	Ravansar chap	49.68	26.85	7.28	4.96	5.52	4.98	49.59	19.17	3.49	2.61	3.07	1.41	29.76
44	Ravansar asli	64.36	20.64	6.64	6.38	8.36	22.18	64.19	19.80	5.41	5.04	5.61	10.97	46.83
45	Sahne	36.96	9.73	4.89	4.56	5.12	12.52	36.82	8.29	4.07	3.20	3.21	5.96	24.73
46	Sarab sedali	187.17	51.63	24.61	24.65	36.93	49.01	186.83	41.63	16.59	16.65	23.52	29.30	127.69
47	Semare holeylan	968.12	196.73	153.21	163.07	226.36	226.96	966.33	117.11	100.21	107.53	152.36	134.65	611.86
48	Semare jezman	166.08	48.87	26.95	25.05	31.79	32.89	165.54	25.74	21.55	19.97	23.86	20.15	111.27
49	Tagbostan	44.54	16.81	7.11	4.37	4.31	11.96	44.57	14.69	6.00	3.34	2.88	7.57	34.47
50	Tangsazin	730.86	204.28	104.49	103.96	135.40	181.35	729.48	150.94	70.30	66.70	79.38	88.14	455.46
51	Tangsiab	331.91	158.43	36.74	33.23	39.72	63.67	331.79	86.15	16.96	11.25	10.79	17.08	142.23
52	Vargach	81.05	11.58	10.92	13.63	21.10	23.72	80.95	6.43	5.62	6.90	10.87	10.75	40.57
53	Vasaj	1,094.75	379.56	175.49	157.60	207.05	171.58	1,091.28	197.87	72.98	57.30	66.14	58.23	452.52
Entire upstream KRB (15,839.84)		5,801.20	2,144.34	2,006.21	2,572.18	3,296.78	1,5820.71	3,559.00	1,243.27	1,142.40	1,415.98	1,658.76	9,019.41	

Table Apx-2.1. 30 year stream flow averages of 53 selected gauge stations in the upper KRB (m^3/sec).

No.	Gauge station	Drainage area (km^2)	Total data (year)	Data(1975-2004)(year)	mhr*	abn	azr	dey	bah	esf	far	ord	khr	tir	mor	shr
					Sep-Oct	Oct-Nov	Nov-Dec	Dec-Jan	Jan-feb	Feb-mar	Mar-Apr	Apr-May	May-Jun	Jun-Jul	Jul-Aug	Aug-Sep
1	Afarine chalhol	811.3	48	28	2.40	2.92	5.34	3.54	4.90	7.11	8.65	6.33	2.54	1.97	1.53	1.71
2	Afarine kashkan	6,830.2	49	29	16.88	26.66	42.90	43.98	56.59	91.67	113.36	77.77	29.89	17.90	14.37	15.02
3	Agajanbolagi	220.2	23	17	0.29	0.47	0.51	0.56	0.62	0.88	1.03	0.64	0.35	0.22	0.19	0.20
4	Aliabad	40.1	20	20	0.16	0.14	0.24	0.21	0.30	0.67	1.75	1.64	0.57	0.17	0.09	0.15
5	Aran	2,016.8	52	30	0.78	1.71	3.54	3.49	4.34	9.63	13.38	8.06	2.16	0.91	0.54	0.20
6	Badregard	1,144.7	12	12	1.46	1.58	2.23	1.79	2.06	4.95	3.06	1.80	0.41	0.43	0.42	0.49
7	Baraftab	1,140.5	25	23	1.33	2.08	2.79	1.88	2.00	2.40	2.41	1.68	0.94	0.85	0.87	0.95
8	Biarkamyaran	49.4	21	20	0.05	0.27	0.32	0.34	0.78	1.27	1.17	0.47	0.15	0.06	0.02	0.08
9	Emamzade borjali	421.6	15	14	0.27	1.38	1.60	1.59	1.83	3.28	4.20	2.23	0.43	0.16	0.13	0.16
10	Cham anjir	1,637.3	49	29	5.56	7.69	10.67	10.57	13.23	19.58	23.05	16.52	9.11	6.43	4.68	4.96
11	Chenar sokhte	223.9	13	13	0.43	0.79	1.29	1.28	2.24	3.30	4.53	2.87	0.64	0.32	0.24	0.43
12	Daretang	167.6	14	14	1.36	1.49	2.20	1.87	1.93	3.84	6.24	6.45	3.72	2.63	1.84	1.67
13	Dartot	2,626.3	22	19	3.42	6.63	9.47	5.48	7.12	9.46	8.05	5.22	3.86	2.43	2.10	2.53
14	Dehno	280.8	27	21	0.36	1.35	2.64	2.28	2.93	6.34	10.47	5.74	1.45	0.55	0.34	0.54
15	Doab	7,759.9	35	29	2.91	9.25	16.88	17.89	21.94	32.44	43.35	24.12	6.02	3.03	2.19	3.06
16	Doab merek	2,718.7	50	29	1.36	2.54	4.37	4.75	8.07	13.87	16.60	9.05	3.47	2.00	1.38	1.49
17	Firozan	859.0	49	28	0.12	0.91	1.46	1.71	2.05	2.69	5.37	2.64	0.37	0.06	0.06	0.09
18	Gorbagestan	5,370.8	51	30	4.14	8.81	17.54	19.07	30.24	48.65	63.57	35.06	13.30	6.10	3.95	4.93
19	Gushe sad vagas	798.1	34	13	0.65	2.08	3.74	3.79	3.83	5.13	6.37	4.79	1.41	0.49	0.47	0.53
20	Heydarabad	2,167.2	26	26	2.26	4.18	10.24	8.96	11.31	27.94	41.86	27.07	6.64	2.19	1.30	0.71
21	Jafarabad	322.2	19	19	0.23	0.57	1.01	0.86	1.08	1.44	1.45	0.78	0.32	0.25	0.20	0.25
22	Jelogir	39,196.3	30	30	57.3	83.7	151.0	144.0	184.1	311.0	403.5	273.1	109.9	67.0	49.4	41.1
23	Kakareza	1,152.4	48	28	2.42	4.84	8.73	9.73	14.03	28.19	39.07	22.36	6.38	3.36	2.48	2.82

*Note: Iranian months

Table Apx-2.1. (Continued).

No.	Gauge station	Drainage area (km²)	Total data (year)	Data(1975-2004)(year)	mhr*	abn	azr	dey	bah	esf	far	ord	khr	tir	mor	shr
					Sep-Oct	Oct-Nov	Nov-Dec	Dec-Jan	Jan-feb	Feb-mar	Mar-Apr	Apr-May	May-Jun	Jun-Jul	Jul-Aug	Aug-Sep
24	Khersabad	1,438.4	31	30	0.32	1.02	2.14	1.77	2.42	3.75	3.68	1.67	0.48	0.25	0.14	0.19
25	khosroabad karand	373.9	13	13	0.01	0.08	0.23	0.44	0.77	2.01	1.74	0.69	0.12	0.00	0.00	0.00
26	khosroabad shahab	961.5	14	14	0.02	0.67	1.61	1.48	1.40	1.67	2.84	0.91	0.24	0.21	0.10	0.26
27	kole cham	939.4	11	10	0.46	1.22	2.33	2.23	3.31	6.03	8.47	4.97	1.23	0.21	0.17	0.26
28	Kole Chub	468.1	13	10	1.11	1.66	1.41	1.49	1.89	2.65	2.76	1.74	0.73	0.62	0.57	0.99
29	Mahidasht	873.9	15	12	0.26	0.91	1.14	1.06	1.29	2.24	2.08	1.13	0.40	0.24	0.20	0.23
30	Mianrahan	1,119.0	17	11	0.37	1.96	3.66	3.92	4.68	9.82	14.44	4.79	0.65	0.16	0.09	0.07
31	Nazarabad	28,324.5	24	23	31.0	62.2	107.3	109.7	131.7	199.6	258.4	147.6	58.7	35.6	28.5	29.5
32	Norabad	618.9	34	29	1.21	2.64	3.53	3.38	4.16	7.19	9.38	5.13	1.61	0.88	1.08	1.00
33	Payepol	42,908.4	47	26	56.5	115.4	183.8	194.4	229.5	363.0	420.7	284.1	111.4	67.3	53.9	53.1
34	Pihan	884.9	10	10	0.01	0.19	0.55	0.85	1.77	2.02	4.78	0.45	0.09	0.03	0.01	0.41
35	Pirmozd	1,024.2	13	13	0.26	1.83	6.12	7.54	12.60	20.85	25.76	8.61	1.78	0.43	0.16	1.65
36	Pirsalman	534.1	23	23	0.31	1.34	1.96	1.99	2.60	4.30	5.62	2.83	0.71	0.30	0.21	0.36
37	Polechehr	11,471.0	50	30	4.8	18.9	36.8	36.0	46.7	74.1	100.2	57.2	14.2	4.2	2.8	5.4
38	Poldokhtar	7,365.8	49	29	19.7	29.1	52.9	50.0	66.8	106.5	131.2	87.1	32.8	21.8	15.5	16.9
39	Polezal	601.6	34	30	2.24	7.88	9.63	10.98	12.46	20.98	20.10	11.79	6.89	5.67	3.21	2.45
40	Polejade	309.2	20	20	0.61	0.70	1.04	1.25	1.45	2.22	2.80	2.04	0.64	0.43	0.26	0.32
41	Pol Kashkan	3,838.4	30	22	8.66	14.07	26.05	30.25	38.99	61.53	86.93	50.61	15.99	10.23	7.26	7.06
42	Pol Kohne	5,042.8	47	26	4.47	9.17	17.15	18.82	29.13	47.10	59.48	35.87	12.79	5.92	3.92	5.22
43	Ravansar Chap	82.3	27	27	0.00	0.03	0.25	0.59	0.82	0.71	0.58	0.51	0.36	0.15	0.04	0.02
44	Ravansar Asli	240.0	30	30	0.07	0.04	0.25	0.53	0.45	0.41	0.33	0.26	0.12	0.06	0.06	0.09
45	Sahne	92.2	12	10	0.36	0.44	0.50	0.42	0.43	0.71	0.83	0.53	0.45	0.44	0.41	0.38
46	Sarab Sedali	789.4	50	29	4.88	6.16	7.90	7.73	8.47	11.43	15.88	12.90	5.82	4.35	3.91	4.30
47	Semare Holeylan	21,198.3	44	30	13.2	36.3	68.7	74.8	102.2	164.3	213.1	121.1	36.3	14.8	9.4	14.4

Table Apx-2.1. (Continued).

No.	Gauge station	Drainage area (km²)	Total data (year)	Data(1975-2004)(year)	mhr*	abn	azr	dey	bah	esf	far	ord	khr	tir	mor	shr
					Sep-Oct	Oct-Nov	Nov-Dec	Dec-Jan	Jan-feb	Feb-mar	Mar-Apr	Apr-May	May-Jun	Jun-Jul	Jul-Aug	Aug-Sep
48	Semare Jezman	732.0	17	14	0.57	0.98	1.76	1.62	2.28	2.59	2.22	1.07	0.36	0.24	0.13	0.21
49	Tagbostan	153.6	33	26	0.28	0.44	0.63	0.60	0.73	1.78	2.98	2.89	1.68	0.62	0.25	0.16
50	Tangsazin	26,727.1	28	25	21.0	57.2	97.8	95.5	134.5	187.6	236.7	136.8	44.3	19.4	14.3	20.3
51	Tangsiab	615.4	29	28	1.33	1.61	1.98	2.21	1.68	1.81	1.73	1.34	1.11	1.10	1.07	1.19
52	Vargach	232.4	11	10	1.08	1.49	1.69	1.93	2.01	2.15	3.38	2.58	1.44	1.09	0.95	0.72
53	Vasaj	3,122.6	21	21	0.25	0.81	2.00	2.12	3.23	4.93	8.22	8.27	1.01	0.20	0.26	0.18

Table Apx-2.2. Growth stages, effective rainfall, and water requirement (mm) for full irrigation under a standard situation for a wheat crop.

Row	Name	Planting date	Item	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Total (mm)
1'	Kerman Shah	1 Oct	Stage	Initial stage	Crop dev.	Crop dev.	Crop dev.	Crop dev.	Crop dev. ,mid-season	Mid-season	Mid-season	Late season		
			Peff.	2	30	29	28	26	37	21	18	0		191
			Water req.	125	54	18	7	35	61	175	231	98		804
2	Eslam Abad	1 Nov	Stage		Initial stage	Crop dev.	Crop dev.	Crop dev.	Crop dev. mid-season	Mid-season	Mid-season	Late season		
			Peff.		23	49	36	27	66	21	13	0		235
			Water req.		26	0	0	16	0	158	214	28		442
3	Kangavr	1 Oct	Stage	Initial stage	Crop dev.	Crop dev.	Crop dev.	Crop dev.	Crop dev. ,mid-season	Mid-season	Mid-season	Late season		
			Peff.	3	28	29	17	26	31	18	17	0		169
			Water req.	118	57	11	21	26	60	164	210	83		750
4	Sarpol Zahab	1 Oct	Stage	Initial stage	Crop dev.	Crop dev.	Crop dev.	Crop dev.	Crop dev. ,mid-season	Mid-season	Mid-season	Late season		
			Peff.	0	26	45	28	36	55	24	12	0		226
			Water req.	144	69	0	21	31	40	169	222	54		750
5	Ravan Sar	1 Oct	Stage	Initial stage	Crop dev.	Crop dev.	Crop dev.	Crop dev.	Crop dev. ,mid-season	Mid-season	Mid-season	Late season		
			Peff.	0	29	38	44	33	58	32	16	0		250
			Water req.	164	62	3	0	16	20	163	262	124		814
6	Sar Rod Kermansh	1 Oct	Stage	Initial stage	Crop dev.	Crop dev.	Crop dev.	Crop dev.	Crop dev. ,mid-season	Mid-season	Mid-season	Late season		
			Peff.	0	16	25	28	23	52	19	21	0		184
			Water req.	166	104	30	11	34	45	197	250	126		963
7	Gilan Garb	1 Oct	Stage	Initial stage	Crop dev.	Crop dev.	Crop dev.	Crop dev.	Crop dev. ,mid-season	Mid-season	Mid-season	Late season		
			Peff.	0	24	39	58	43	39	21	0	0		224
			Water req.	117	52	0	0	12	55	157	202	43		638

Table Apx-2.2. (Continued).

Row	Name	Planting date	Item	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Total (mm)
8	Shah Abad Garb	1 Nov	Stage		Initial stage	Crop dev.	Crop dev.	Crop dev.	Crop dev. mid-season	Mid-season	Mid-season	Lateseason		
			Peff.		5	59	44	29	49	37	7	0		230
			Water req.		46	0	0	13	8	108	194	34		403
9	Krnd Garb	1 Nov	Stage		Initial stage	Crop dev.	Crop dev.	Crop dev.	Crop dev. mid-season	Mid-season	Mid-season	Late season		
			Peff.		20	32	26	32	42	29	28	0		209
			Water req.		27	2	3	10	38	148	196	37		461
10	Khoram Abad	1 Oct	Stage	Initial stage	Crop dev.	Crop dev.	Crop dev.	Crop dev.	Crop dev.,mid-season	Mid-season	Mid-season	Late season		
			Peff.	1	21	46	36	45	48	24	20	0		241
			Water req.	104	48	0	0	0	28	126	192	84		582
11	Brojerd	1 Oct	Stage	Initial stage	Crop dev.	Crop dev.	Crop dev.	Crop dev.	Crop dev. ,mid-season	Mid-season	Mid-season	Late season		
			Peff.	0	33	33	18	25	51	25	23	0		208
			Water req.	143	74	45	44	64	55	202	264	242		1133
12	Alashtr	1 Oct	Stage	Initial stage	Crop dev.	Crop dev.	Crop dev.	Crop dev.	Crop dev. ,mid-season	Mid-season	Mid-season	Late season		
			Peff.	1	21	46	36	45	48	24	20	0		241
			Water req.	104	48	0	0	0	28	126	194	158		658
13	Drod	1 Oct	Stage	Initial stage	Crop dev.	Crop dev.	Crop dev.	Crop dev.	Crop dev. ,mid-season	Mid-season	Mid-season	Late season		
			Peff.	7	33	39	56	43	59	40	20	0		297
			Water req.	92	34	0	0	0	8	108	199	162		603
14	Shirvan Brojerd	1 Oct	Stage	Initial stage	Crop dev.	Crop dev.	Crop dev.	Crop dev.	Crop dev. ,mid-season	Mid-season	Mid-season	Lateseason		
			Peff.	9	24	49	36	39	44	29	24	0		254
			Water req.	83	41	0	0	0	15	112	163	145		559

Table Apx-2.2. (Continued).

Row	Name	Planting date	Item	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Total (mm)
15	Nahavand	1 Oct	Stage	Initial stage	Crop dev.	Crop dev.	Crop dev.	Crop dev.	Crop dev. ,mid-season	Mid-season	mid-season	Lateseason		
			Peff.	0	24	28	28	18	26	15	20	0		159
			Water req.	97	31	0	0	31	49	148	171	153		680
16	Ilam	1 Oct	Stage	Initial stage	Crop dev.	Crop dev.	Crop dev.	Crop dev.	Crop dev. ,mid-season	Mid-season	Mid-season	Lateseason		
			Peff.	4	58	52	47	55	82	31	16	0		345
			Water req.	132	16	0	0	0	0	147	218	48		561
17	Dehloran	1 Nov	Stage		Initial stage	Crop dev.	Crop dev.	Crop dev.	Crop dev. mid-season	Mid-season	Mid-season	Lateseason		
			Peff.		0	20	18	3	21	4	0			66
			Water req.		113	58	57	130	145	271	33			807
18	Safiabad	21 Nov	Stage			Initial stage	Ini. stage, Crop dev.	Crop dev.	Crop dev.,mid-season	Mid-season	Lateseason			
			Peff.			12	20	23	27	9	3			94
			Water Req.			32	23	31	64	150	185			485
18	Safiabad	21 Nov												
19	Mazo	21 Nov	Stage			Initial stage	Init. stage, crop dev.	Crop dev.	Crop dev., mid-season	Mid-season	Late season			
			Peff.			27	73	69	42	53	16			280
			Water req.			5	0	0	33	71	172			281
20	Hafttape	21 Nov	Stage			Initial stage	Init. stage, crop dev.	Crop dev.	Crop dev., mid-season	Mid-season	Late season			
			Peff.			6	27	17	19	13	0			82
			Water req.			46	15	45	85	166	193			550

Table Apx-2.2. (Continued).

Row	Name	Planting date	Item	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Total (mm)
21	Andimeshk	21 Nov	Stage			Initial stage	Init. stage, crop dev.	Crop dev.	Crop dev., mid-season	Mid-season	Lateseason			
			Peff.			3	29	44	15	21	6			118
			Water req.			49	13	0	88	140	178			468
22	Dezfol	21 Nov	Stage			Initial stage	Init. stage, crop dev.	Crop dev.	Crop dev.,mid-season	Mid-season	Lateseason			
			Peff.			16	49	45	30	24	0			164
			Water req.			24	0	0	57	136	200			417
23	Shosh	21 Nov	Stage			Initial stage	Init. stage, crop dev.	Crop dev.	Crop dev.,mid-season	Mid-season	Late-season			
			Peff.			3	25	31	12	16	4			91
			Water req.			54	24	25	98	160	187			548
24	Shah Abad	21 Nov	Stage			Initial stage	Init. stage, cop dev.	Crop dev.	Crop dev.,mid-season	Mid-season	Lateseason			
			Peff.			8	32	40	12	18	7			117
			Water req.			36	4	2	91	142	173			448
25	Bostan	21 Nov	Stage			Initial stage	Init. stage, crop dev.	Crop dev.	Crop dev.,mid-season	Mid-season	Lateseason			
			Peff.			9	2	12	16	7	0			46
			Water req.			69	70	75	127	224	224			789
26	Sanandaj	22 Sep	Stage	Initial stage	Init. stage, crop dev.	Crop dev	Crop dev.	Crop dev.	Crop dev.,mid-season	Mid-season	Mid-,lateseason	Lateseason	Lateseason	
			Peff.	0	32	29	22	35	32	38	32	2	0	222
			Water req.	143	53	16	9	0	39	102	184	204	14	750

Table Apx-2.3. Annual minimum and suitable areas (km²) for SI of sub-basins of different slopes under normal flow conditions.

Sub-basin	Normal KRB SI: 100 mm in Oct and 150 mm in May							
	Slope from 0 to 5%		Slope from 0 to 8%		Slope from 0 to 12%		Slope from 0 to 20%	
	Annual_min	Suitable	Annual_min	Suitable	Annual_min	Suitable	Annual_min	Suitable
1	7.51	7.51	17.8	17.8	29.07	29.07	45.34	45.34
2	30.47	30.47	48.74	48.74	51.28	66.41	51.28	85.62
3	0.54	10.84	0.54	17.75	0.54	23.74	0.54	29.91
4	0	0	0	0	0	0	0	0
5	20.36	89.88	20.36	119.04	20.36	140.71	20.36	162.92
6	1.07	40.35	1.07	40.8	1.07	41	1.07	41.26
7	30	224.96	30	261.57	30	282.54	30	304.06
8	0.79	0.79	1.34	2.44	1.34	4.87	1.34	9.22
9	7.23	77.1	7.23	108.81	7.23	129.51	7.23	149.05
10	129.14	129.14	137.4	173.97	137.4	211.29	137.4	253.91
11	11.52	12.26	11.52	16.38	11.52	19.4	11.52	23.61
12	0.13	0.13	0.2	0.2	0.33	0.33	0.98	0.98
13	52.5	221.66	52.5	262.72	52.5	295.25	52.5	327.64
14	9.64	23.38	9.64	43.46	9.64	60.36	9.64	82.02
15	19.44	42.52	19.44	63.43	17.42	88.28	6.43	140.27
16	25.98	272.34	25.98	316.17	25.98	355.09	25.98	399.26
17	3.21	37.68	3.21	58.21	3.21	73.69	3.21	91.78
18	0	32.36	0	43.5	0	52.27	0	62.26
19	11.25	24.89	11.25	41.4	11.25	60.61	11.25	90.55
20	19.39	19.39	25.59	25.59	30.31	31.19	30.31	38.28
21	6.16	43.41	6.16	56.56	6.16	66.22	6.16	78.43
22	60.22	60.22	87.35	87.35	117.23	117.23	154.65	154.65
23	41.91	41.91	55.18	65.14	55.18	85.84	55.18	104.57
24	1.61	88.71	1.61	108.86	1.61	121.17	1.61	130.98
25	0.27	34.28	0.27	37.83	0.27	41.74	0.27	48.01
26	0	36.84	0	47.24	0	56.54	0	71.15
27	12.32	27.34	12.32	45.43	12.32	60.67	12.32	79.14
28	18.75	51.13	18.75	59.95	18.75	66.69	18.75	73.88
29	6.96	290.38	6.96	326.94	6.96	350.55	6.96	372.07
30	1.61	32.14	1.61	41.99	1.61	54.33	1.61	74.41
31	98.27	98.27	151.68	151.68	210.18	210.18	139.1	291.98
32	32.41	68.32	32.41	98.49	32.41	111.97	32.41	120.4
33	161.56	161.56	272.78	272.78	393.7	393.7	537.57	537.57
34	0.27	51.02	0.27	104.98	0.27	176.08	0.27	269.07
35	6.17	126.86	5.62	164.5	5.62	193.8	5.62	228.04
36	1.07	8.12	1.07	13.22	1.07	18.42	1.07	24.91
37	11	83.52	4.72	104.27	0	122.19	0	145.28
38	33.87	33.87	46.19	46.19	32.37	57.75	16.1	73.74
39	0.8	0.8	1.83	1.83	3.78	3.78	6.5	6.5
40	16.34	18.09	16.34	30.42	16.34	42.47	16.34	60.34
41	28.52	28.52	63.82	63.82	91.93	108.9	67.76	167.94
42	60	188.23	60	199.79	60	207.36	60	216.53
43	0	19.17	0	22.66	0	25.27	0	28.35
44	1.87	19.8	1.87	25.21	1.87	30.25	1.87	35.86
45	8.29	8.29	8.37	12.36	8.37	15.56	8.37	18.77
46	41.63	41.63	58.22	58.22	74.87	74.87	98.39	98.39
47	65.35	117.11	65.35	217.32	65.35	324.85	65.35	477.21
48	15.27	25.74	15.27	47.29	15.27	67.25	15.27	91.11
49	7.5	14.69	7.5	20.68	7.5	24.02	7.5	26.9
50	102.05	150.94	102.05	221.24	102.05	287.94	102.05	367.32
51	23.93	86.15	23.93	103.11	23.93	114.36	23.93	125.15
52	6.43	6.43	12.05	12.05	18.95	18.95	28.93	29.82
53	6.43	197.87	6.43	270.86	6.43	328.15	6.43	394.3

Table Apx-2.4. Annual minimum and suitable areas (km²) for SI of sub-basins of different slopes under normal flow conditions with EFR.

Sub-basin	Normal conditions with environment flow requirement considerations Normal KRB SI: 100 mm in Oct and 150 mm in May							
	Slope from 0 to 5%		**Slope from 0 to 8%**		**Slope from 0 to 12%**		**Slope from 0 to 20%**	
	Annual_min	**Suitable**	**Annual_min**	**Suitable**	**Annual_min**	**Suitable**	**Annual_min**	**Suitable**
1	7.51	7.51	17.8	17.8	29.07	29.07	43.93	45.34
2	30.47	30.47	29.46	48.74	29.46	66.41	29.46	85.62
3	0	10.84	0	17.75	0	23.74	0	29.91
4	0	0	0	0	0	0	0	0
5	0	89.88	0	119.04	0	140.71	0	162.92
6	0.36	40.35	0.36	40.8	0.36	41	0.36	41.26
7	25.53	224.96	25.53	261.57	25.53	282.54	25.53	304.06
8	0	0.79	0	2.44	0	4.87	0	9.22
9	0	77.1	0	108.81	0	129.51	0	149.05
10	99.37	129.14	99.37	173.97	99.37	211.29	99.37	253.91
11	5.36	12.26	5.36	16.38	5.36	19.4	5.36	23.61
12	0.13	0.13	0.2	0.2	0.33	0.33	0.98	0.98
13	37.5	221.66	37.5	262.72	37.5	295.25	37.5	327.64
14	0	23.38	0	43.46	0	60.36	0	82.02
15	0	42.52	0	63.43	0	88.28	0	140.27
16	9.37	272.34	9.37	316.17	9.37	355.09	9.37	399.26
17	0	37.68	0	58.21	0	73.69	0	91.78
18	0	32.36	0	43.5	0	52.27	0	62.26
19	0	24.89	0	41.4	0	60.61	0	90.55
20	0	19.39	0	25.59	0	31.19	0	38.28
21	0	43.41	0	56.56	0	66.22	0	78.43
22	60.22	60.22	87.35	87.35	117.23	117.23	154.65	154.65
23	16.07	41.91	16.07	65.14	16.07	85.84	16.07	104.57
24	0	88.71	0	108.86	0	121.17	0	130.98
25	0	34.28	0	37.83	0	41.74	0	48.01
26	0	36.84	0	47.24	0	56.54	0	71.15
27	0	27.34	0	45.43	0	60.67	0	79.14
28	16.25	51.13	16.25	59.95	16.25	66.69	16.25	73.88
29	2.68	290.38	2.68	326.94	2.68	350.55	2.68	372.07
30	0	32.14	0	41.99	0	54.33	0	74.41
31	98.27	98.27	151.68	151.68	172.82	210.18	114.46	291.98
32	18.48	68.32	18.48	98.49	18.48	111.97	18.48	120.4
33	161.56	161.56	272.78	272.78	393.7	393.7	537.57	537.57
34	0	51.02	0	104.98	0	176.08	0	269.07
35	0	126.86	0	164.5	0	193.8	0	228.04
36	0	8.12	0	13.22	0	18.42	0	24.91
37	0	83.52	0	104.27	0	122.19	0	145.28
38	33.87	33.87	26.13	46.19	14.86	57.75	0	73.74
39	0.8	0.8	1.83	1.83	3.78	3.78	6.5	6.5
40	11.52	18.09	11.52	30.42	11.52	42.47	11.52	60.34
41	28.52	28.52	37.74	63.82	20.96	108.9	0	167.94
42	9.37	188.23	9.37	199.79	9.37	207.36	9.37	216.53
43	0	19.17	0	22.66	0	25.27	0	28.35
44	1.07	19.8	1.07	25.21	1.07	30.25	1.07	35.86
45	0	8.29	0	12.36	0	15.56	0	18.77
46	41.63	41.63	58.22	58.22	74.87	74.87	95.18	98.39
47	8.04	117.11	8.04	217.32	8.04	324.85	8.04	477.21
48	10.71	25.74	10.71	47.29	10.71	67.25	10.71	91.11
49	2.95	14.69	2.95	20.68	2.95	24.02	2.95	26.9
50	63.21	150.94	63.21	221.24	63.21	287.94	63.21	367.32
51	19.82	86.15	19.82	103.11	19.82	114.36	19.82	125.15
52	6.43	6.43	12.05	12.05	18.95	18.95	21.96	29.82
53	0	197.87	0	270.86	0	328.15	0	394.3

Table Apx-2.5.Annual minimum and suitable areas (km²) for SI of sub-basins of different slopes under drought flow conditions.

Sub-basin	Drought KRB SI: 100 mm in Oct and 150 mm in May							
	Slope from 0 to 5%		Slope from 0 to 8%		Slope from 0 to 12%		Slope from 0 to 20%	
	Annual_min	Suitable	Annual_min	Suitable	Annual_min	Suitable	Annual_min	Suitable
1	2.45	7.51	2.45	17.8	2.45	29.07	2.45	45.34
2	0	30.47	0	48.74	0	66.41	0	85.62
3	0	10.84	0	17.75	0	23.74	0	29.91
4	0	0	0	0	0	0	0	0
5	0	89.88	0	119.04	0	140.71	0	162.92
6	0	40.35	0	40.8	0	41	0	41.26
7	2.23	224.96	2.23	261.57	2.23	282.54	2.23	304.06
8	0	0.79	0	2.44	0	4.87	0	9.22
9	0	77.1	0	108.81	0	129.51	0	149.05
10	88.67	129.14	88.67	173.97	88.67	211.29	88.67	253.91
11	0	12.26	0	16.38	0	19.4	0	23.61
12	0.13	0.13	0.2	0.2	0.33	0.33	0.9	0.98
13	0	221.66	0	262.72	0	295.25	0	327.64
14	0	23.38	0	43.46	0	60.36	0	82.02
15	0	42.52	0	63.43	0	88.28	0	140.27
16	0	272.34	0	316.17	0	355.09	0	399.26
17	0	37.68	0	58.21	0	73.69	0	91.78
18	0	32.36	0	43.5	0	52.27	0	62.26
19	0	24.89	0	41.4	0	60.61	0	90.55
20	0	19.39	0	25.59	0	31.19	0	38.28
21	0	43.41	0	56.56	0	66.22	0	78.43
22	60.22	60.22	87.35	87.35	117.23	117.23	154.65	154.65
23	0	41.91	0	65.14	0	85.84	0	104.57
24	0	88.71	0	108.86	0	121.17	0	130.98
25	0	34.28	0	37.83	0	41.74	0	48.01
26	0	36.84	0	47.24	0	56.54	0	71.15
27	0	27.34	0	45.43	0	60.67	0	79.14
28	0	51.13	0	59.95	0	66.69	0	73.88
29	0	290.38	0	326.94	0	350.55	0	372.07
30	0	32.14	0	41.99	0	54.33	0	74.41
31	98.27	98.27	151.68	151.68	166.33	210.18	166.33	291.98
32	0	68.32	0	98.49	0	111.97	0	120.4
33	161.56	161.56	272.78	272.78	393.7	393.7	537.57	537.57
34	0	51.02	0	104.98	0	176.08	0	269.07
35	0	126.86	0	164.5	0	193.8	0	228.04
36	0	8.12	0	13.22	0	18.42	0	24.91
37	0	83.52	0	104.27	0	122.19	0	145.28
38	0	33.87	0	46.19	0	57.75	0	73.74
39	0	0.8	0	1.83	0	3.78	0	6.5
40	0	18.09	0	30.42	0	42.47	0	60.34
41	0	28.52	0	63.82	0	108.9	0	167.94
42	0	188.23	0	199.79	0	207.36	0	216.53
43	0	19.17	0	22.66	0	25.27	0	28.35
44	0	19.8	0	25.21	0	30.25	0	35.86
45	0	8.29	0	12.36	0	15.56	0	18.77
46	0.77	41.63	0.7	58.22	0.57	74.87	0	98.39
47	0	117.11	0	217.32	0	324.85	0	477.21
48	0	25.74	0	47.29	0	67.25	0	91.11
49	0	14.69	0	20.68	0	24.02	0	26.9
50	0	150.94	0	221.24	0	287.94	0	367.32
51	11.25	86.15	11.25	103.11	11.25	114.36	11.25	125.15
52	6.43	6.43	10.54	12.05	10.54	18.95	10.54	29.82
53	0	197.87	0	270.86	0	328.15	0	394.3

Table Apx-2.6. Annual minimum and suitable areas (km²) for SI of sub-basins of different slopes under drought flow conditions with EFR.

Sub-basin	**Drought with EFR KRB SI: 100 mm in Oct and 150 mm in May**							
	Slope from 0 to 5%		**Slope from 0 to 8%**		**Slope from 0 to 12%**		**Slope from 0 to 20%**	
	Annual_min	**Suitable**	**Annual_min**	**Suitable**	**Annual_min**	**Suitable**	**Annual_min**	**Suitable**
1	0	7.51	0	17.8	0	29.07	0	45.34
2	0	30.47	0	48.74	0	66.41	0	85.62
3	0	10.84	0	17.75	0	23.74	0	29.91
4	0	0	0	0	0	0	0	0
5	0	89.88	0	119.04	0	140.71	0	162.92
6	0	40.35	0	40.8	0	41	0	41.26
7	0	224.96	0	261.57	0	282.54	0	304.06
8	0	0.79	0	2.44	0	4.87	0	9.22
9	0	77.1	0	108.81	0	129.51	0	149.05
10	0	129.14	0	173.97	0	211.29	0	253.91
11	0	12.26	0	16.38	0	19.4	0	23.61
12	0	0.13	0	0.2	0	0.33	0	0.98
13	0	221.66	0	262.72	0	295.25	0	327.64
14	0	23.38	0	43.46	0	60.36	0	82.02
15	0	42.52	0	63.43	0	88.28	0	140.27
16	0	272.34	0	316.17	0	355.09	0	399.26
17	0	37.68	0	58.21	0	73.69	0	91.78
18	0	32.36	0	43.5	0	52.27	0	62.26
19	0	24.89	0	41.4	0	60.61	0	90.55
20	0	19.39	0	25.59	0	31.19	0	38.28
21	0	43.41	0	56.56	0	66.22	0	78.43
22	60.22	60.22	87.35	87.35	117.23	117.23	154.65	154.65
23	0	41.91	0	65.14	0	85.84	0	104.57
24	0	88.71	0	108.86	0	121.17	0	130.98
25	0	34.28	0	37.83	0	41.74	0	48.01
26	0	36.84	0	47.24	0	56.54	0	71.15
27	0	27.34	0	45.43	0	60.67	0	79.14
28	0	51.13	0	59.95	0	66.69	0	73.88
29	0	290.38	0	326.94	0	350.55	0	372.07
30	0	32.14	0	41.99	0	54.33	0	74.41
31	0	98.27	0	151.68	0	210.18	0	291.98
32	0	68.32	0	98.49	0	111.97	0	120.4
33	161.56	161.56	272.78	272.78	393.7	393.7	537.57	537.57
34	0	51.02	0	104.98	0	176.08	0	269.07
35	0	126.86	0	164.5	0	193.8	0	228.04
36	0	8.12	0	13.22	0	18.42	0	24.91
37	0	83.52	0	104.27	0	122.19	0	145.28
38	0	33.87	0	46.19	0	57.75	0	73.74
39	0	0.8	0	1.83	0	3.78	0	6.5
40	0	18.09	0	30.42	0	42.47	0	60.34
41	0	28.52	0	63.82	0	108.9	0	167.94
42	0	188.23	0	199.79	0	207.36	0	216.53
43	0	19.17	0	22.66	0	25.27	0	28.35
44	0	19.8	0	25.21	0	30.25	0	35.86
45	0	8.29	0	12.36	0	15.56	0	18.77
46	0	41.63	0	58.22	0	74.87	0	98.39
47	0	117.11	0	217.32	0	324.85	0	477.21
48	0	25.74	0	47.29	0	67.25	0	91.11
49	0	14.69	0	20.68	0	24.02	0	26.9
50	0	150.94	0	221.24	0	287.94	0	367.32
51	0	86.15	0	103.11	0	114.36	0	125.15
52	0	6.43	0	12.05	0	18.95	0	29.82
53	0	197.87	0	270.86	0	328.15	0	394.3

Table Apx-2.7. Basin totals for SI development for different slopes under normal flow conditions.

Normal KRB flow1: 30 year average flow (missing data filled in) KRB SI1: 100 mm in Oct and 150 mm in May												
Basin totals												
KRB area1: slope from 0 to 5%												
Parameter	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Annual**
Available flow (m^3/s)	56.5	115.4	183.8	194.4	229.5	363	420.7	284.1	111.4	67.3	53.9	53.1	177.36
Outflow after SI water withdrawal (m^3/s)	16.51	106.8	183.8	194.4	229.5	363	407.8	167	111.4	67.3	53.9	53.1	162.26
Irrigation area (km^2)	3336	222.6	0	0	0	0	222.6	3336	0	0	0	0	
Irrigated area (km^2)	1071	222.6	0	0	0	0	222.6	2090	0	0	0	0	
Irrigation vol.(million m^3/year or month)	107.1	22.26	0	0	0	0	33.39	313.5	0	0	0	0	476.29
KRB area1: slope from 0 to 8%													
Parameter	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Annual**
Available flow (m^3/s)	56.5	115.4	183.8	194.4	229.5	363	420.7	284.1	111.4	67.3	53.9	53.1	177.36
Outflow after SI water withdrawal (m^3/s)	10.03	101.4	183.8	194.4	229.5	363	399.8	132.6	111.4	67.3	53.9	53.1	157.68
Irrigation area (km^2)	4440	362	0	0	0	0	362	4440	0	0	0	0	
Irrigated area (km^2)	1245	362	0	0	0	0	362	2705	0	0	0	0	
Irrigation vol.(million m^3/year or month)	124.5	36.2	0	0	0	0	54.29	405.7	0	0	0	0	620.66
KRB area1: slope from 0 to 12%													
Parameter	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Annual**
Available flow (m^3/s)	56.5	115.4	183.8	194.4	229.5	363	420.7	284.1	111.4	67.3	53.9	53.1	177.36
Outflow after SI water withdrawal (m^3/s)	5.92	95.54	183.8	194.4	229.5	363	390.9	105.5	111.4	67.3	53.9	53.1	153.82
Irrigation area (km^2)	5430	514.7	0	0	0	0	514.7	5430	0	0	0	0	
Irrigated area (km^2)	1355	514.7	0	0	0	0	514.7	3189	0	0	0	0	
Irrigation vol.(million m^3/year or month)	135.5	51.47	0	0	0	0	77.21	478.4	0	0	0	0	742.532
KRB area1: slope from 0 to 20%													
Parameter	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Annual**
Available flow (m^3/s)	56.5	115.4	183.8	194.4	229.5	363	420.7	284.1	111.4	67.3	53.9	53.1	177.36
Outflow after SI water withdrawal (m^3/s)	5.8	88.44	183.8	194.4	229.5	363	380.3	82.39	111.4	67.3	53.9	53.1	150.39
Irrigation area (km^2)	6662	698.7	0	0	0	0	698.7	6662	0	0	0	0	
Irrigated area (km^2)	1358	698.7	0	0	0	0	698.7	3602	0	0	0	0	
Irrigation vol.(million m^3/year or month)	135.8	69.87	0	0	0	0	104.8	540.3	0	0	0	0	850.724

Table Apx-2.8. Basin totals for SI development for different slopes under normal flow conditions with EFR.

Normal with EFR
KRB flow1: 30 year average flow (missing data filled in)
KRB SI1: 100 mm in Oct and 150 mm in May

Basin totals

KRB area1: slope from 0 to 5 %

Parameter	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Available flow (m^3/s)	29.85	88.71	157.1	167.8	202.8	336.3	394.1	257.4	84.75	40.6	27.2	26.41	150.69
Outflow after SI water withdrawal (m^3/s)	6.29	80.12	157.1	167.8	202.8	336.3	381.2	143.7	84.75	40.6	27.2	26.41	137.26
Irrigation area (km^2)	3336	222.6	0	0	0	0	222.6	3336	0	0	0	0	
Irrigated area (km^2)	630.9	222.6	0	0	0	0	222.6	2031	0	0	0	0	
Irrigation vol. (million m^3/year or month)	63.09	22.26	0	0	0	0	33.39	304.6	0	0	0	0	423.31
KRB area1: slope 0-8 %													
Parameter	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Annual**
Available flow (m^3/s)	29.85	88.71	157.1	167.8	202.8	336.3	394.1	257.4	84.75	40.6	27.2	26.41	150.69
Outflow after SI water withdrawal (m^3/s)	3.07	74.75	157.1	167.8	202.8	336.3	373.1	112.8	84.75	40.6	27.2	26.41	133.26
Irrigation area (km^2)	4440	362	0	0	0	0	362	4440	0	0	0	0	
Irrigated area (km^2)	717.4	362	0	0	0	0	362	2582	0	0	0	0	
Irrigation vol. (million m^3/year or month)	71.74	36.2	0	0	0	0	54.29	387.3	0	0	0	0	549.537
KRB area1: slope 0-12 %													
Parameter	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Annual**
Available flow (m^3/s)	29.85	88.71	157.1	167.8	202.8	336.3	394.1	257.4	84.75	40.6	27.2	26.41	150.69
Outflow after SI water withdrawal (m^3/s)	2.02	68.85	157.1	167.8	202.8	336.3	364.3	85.86	84.75	40.6	27.2	26.41	129.67
Irrigation area (km^2)	5430	514.7	0	0	0	0	514.7	5430	0	0	0	0	
Irrigated area (km^2)	745.4	514.7	0	0	0	0	514.7	3063	0	0	0	0	
Irrigation vol.(million m^3/year or month)	74.54	51.47	0	0	0	0	77.21	459.5	0	0	0	0	662.73
KRB area1: slope from 0 to 20 %													
Parameter	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Annual**
Available flow (m^3/s)	29.85	88.71	157.1	167.8	202.8	336.3	394.1	257.4	84.75	40.6	27.2	26.41	150.69
Outflow after SI water withdrawal (m^3/s)	2.02	61.75	157.1	167.8	202.8	336.3	353.6	71.62	84.75	40.6	27.2	26.41	127
Irrigation area (km^2)	6662	698.7	0	0	0	0	698.7	6662	0	0	0	0	
Irrigated area (km^2)	745.4	698.7	0	0	0	0	698.7	3318	0	0	0	0	
Irrigation vol.(million m^3/year or month)	74.54	69.87	0	0	0	0	104.8	497.7	0	0	0	0	746.877

Table Apx-2.9. Basin totals for SI development for different slopes under drought conditions.

Drought **KRB flow1: 30 year average flow (missing data filled in)** **KRB SI1: 100 mm in Oct and 150 mm in May**													
Basin totals													
KRB area1: slope from 0 to 5 %													
Parameter	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Annual**
Available flow (m^3/s)	42	67.29	14.94	112	122.7	204.7	224.7	125.6	51.01	46.18	35.24	39.12	90.13
Outflow after SI water withdrawal (m^3/s)	28.34	58.73	14.94	112	122.7	204.7	211.8	112.4	51.01	46.18	35.24	39.12	86.09
Irrigation area (km^2)	3336	222.6	0	0	0	0	222.6	3336	0	0	0	0	
Irrigated area (km^2)	365.8	221.8	0	0	0	0	222.6	234.5	0	0	0	0	
Irrigation vol. (million m^3/year or month)	36.58	22.18	0	0	0	0	33.39	35.18	0	0	0	0	127.326
KRB area1: slope from 0 to 8 %													
Parameter	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Annual**
Available flow (m^3/s)	42	67.29	14.94	112	122.7	204.7	224.7	125.6	51.01	46.18	35.24	39.12	90.13
Outflow after SI water withdrawal (m^3/s)	26.14	53.4	14.94	112	122.7	204.7	203.8	109.2	51.01	46.18	35.24	39.12	84.53
Irrigation area (km^2)	4440	362	0	0	0	0	362	4440	0	0	0	0	
Irrigated area (km^2)	424.9	360.1	0	0	0	0	362	292	0	0	0	0	
Irrigation vol. (million m^3/year or month)	42.49	36.01	0	0	0	0	54.29	43.8	0	0	0	0	176.599
KRB area1: slope from 0 to 12 %													
Parameter	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Annual**
Available flow (m^3/s)	42	67.29	14.94	112	122.7	204.7	224.7	125.6	51.01	46.18	35.24	39.12	90.13
Outflow after SI water withdrawal (m^3/s)	25.46	47.58	14.94	112	122.7	204.7	194.9	106.7	51.01	46.18	35.24	39.12	83.05
Irrigation area (km^2)	5430	514.7	0	0	0	0	514.7	5430	0	0	0	0	
Irrigated area (km^2)	443	510.9	0	0	0	0	514.7	337.5	0	0	0	0	
Irrigation vol. (million m^3/year or month)	44.3	51.09	0	0	0	0	77.21	50.62	0	0	0	0	223.222
KRB area1: slope from 0 to 20 %													
Parameter	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Annual**
Available flow (m^3/s)	42	67.29	14.94	112	122.7	204.7	224.7	125.6	51.01	46.18	35.24	39.12	90.13
Outflow after SI water withdrawal (m^3/s)	25.46	40.58	14.94	112	122.7	204.7	184.3	106.7	51.01	46.18	35.24	39.12	81.6
Irrigation area (km^2)	6662	698.7	0	0	0	0	698.7	6662	0	0	0	0	
Irrigated area (km^2)	443	692.2	0	0	0	0	698.7	337.5	0	0	0	0	
Irrigation vol. (million m^3/year or month)	44.3	69.22	0	0	0	0	104.8	50.62	0	0	0	0	268.952

Table Apx-2.10. Basin totals for SI development for different slopes under drought flow conditions with EFR.

Drought with EFR KRB flow1: 30 year average flow (missing data filled in) KRB SI1: 100 mm in Oct and 150 mm in May													
Basin totals													
KRB area1: slope from 0 to 5 %													
Parameter	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Annual**
Available flow (m³/s)	15.34	40.63	0	85.29	96.01	178.1	198.1	98.91	24.35	19.52	8.58	12.46	64.47
Outflow after SI water withdrawal (m³/s)	15.34	32.07	0	85.29	96.01	178.1	185.2	98.91	24.35	19.52	8.58	12.46	62.71
Irrigation area (km²)	3336	222.6	0	0	0	0	222.6	3336	0	0	0	0	
Irrigated area (km²)	0	221.8	0	0	0	0	222.6	0	0	0	0	0	
Irrigation vol. (million m³/year or month)	0	22.18	0	0	0	0	33.39	0	0	0	0	0	55.565
KRB area1: slope from 0 to 8 %													
Parameter	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Annual**
Available flow (m³/s)	15.34	40.63	0	85.29	96.01	178.1	198.1	98.91	24.35	19.52	8.58	12.46	64.47
Outflow after SI water withdrawal (m³/s)	15.34	26.74	0	85.29	96.01	178.1	177.1	98.91	24.35	19.52	8.58	12.46	61.6
Irrigation area (km²)	4440	362	0	0	0	0	362	4440	0	0	0	0	
Irrigated area (km²)	0	360.1	0	0	0	0	362	0	0	0	0	0	
Irrigation vol. (million m³/year or month)	0	36.01	0	0	0	0	54.29	0	0	0	0	0	90.307
KRB area1: slope from 0 to 12 %													
Parameter	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Annual**
Available flow (m³/s)	15.34	40.63	0	85.29	96.01	178.1	198.1	98.91	24.35	19.52	8.58	12.46	64.47
Outflow after SI water withdrawal (m³/s)	15.34	20.92	0	85.29	96.01	178.1	168.3	98.91	24.35	19.52	8.58	12.46	60.4
Irrigation area (km²)	5430	514.7	0	0	0	0	514.7	5430	0	0	0	0	
Irrigated area (km²)	0	510.9	0	0	0	0	514.7	0	0	0	0	0	
Irrigation vol. (million m³/year or month)	0	51.09	0	0	0	0	77.21	0	0	0	0	0	128.299
KRB area1: slope from 0 to 20 %													
Parameter	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Annual**
Available flow (m³/s)	15.34	40.63	0	85.29	96.01	178.1	198.1	98.91	24.35	19.52	8.58	12.46	64.47
Outflow after SI water withdrawal (m³/s)	15.34	13.92	0	85.29	96.01	178.1	157.6	98.91	24.35	19.52	8.58	12.46	58.95
Irrigation area (km²)	6662	698.7	0	0	0	0	698.7	6662	0	0	0	0	
Irrigated area (km²)	0	692.2	0	0	0	0	698.7	0	0	0	0	0	
Irrigation vol. (million m³/year or month)	0	69.22	0	0	0	0	104.8	0	0	0	0	0	174.03

Table Apx-2.11. Comparison of EFRs with the leftover outflows from sub-basins of different slopes under normal flow conditions (m³/sec)

Slope (%)		From 0 to 5				From 0 to 8				From 0 to 12				From 0 to 20			
SB	**Env.flow**	**Oct**	**Nov**	**Apr**	**May**	**Oct**	**Nov**	**Apr**	**May**	**Oct**	**Nov**	**Apr**	**May**	**Oct**	**Nov**	**Apr**	**May**
1	0.61	2.4	2.92	8.65	6.33	1.63	2.46	8.65	5.33	1.21	2.46	8.65	4.7	0.6	2.46	8.65	3.79
2	6.84	16.9	26.7	113	77.8	1.77	22.5	113	51.5	0	22.5	113	42.6	0	22.5	113	32
3	0.07	0.29	0.47	1.03	0.64	0	0.47	1.03	0	0	0.47	1.03	0	0	0.47	1.03	0
4	0.08	0.16	0.14	1.75	1.64	0.12	0.14	1.75	1.64	0.12	0.14	1.75	1.64	0.12	0.14	1.75	1.64
5	0.61	0.78	1.71	13.4	8.06	0	1.71	13.4	0.48	0	1.71	13.4	0	0	1.71	13.4	0
6	0.26	1.46	1.58	3.06	1.8	0	1.58	3.06	0	0	1.58	3.06	0	0	1.58	3.06	0
7	0.25	1.33	2.08	2.41	1.68	0	1.75	2.41	0	0	1.75	2.41	0	0	1.75	2.41	0
8	0.06	0.05	0.27	1.17	0.47	0	0.27	1.17	0.33	0	0.27	1.17	0.2	0	0.27	1.17	0
9	0.22	0.27	1.38	4.2	2.23	0	1.34	4.2	0	0	1.34	4.2	0	0	1.34	4.2	0
10	1.65	5.56	7.69	23.1	16.5	0	7.69	23.1	5.86	0	7.69	23.1	3.6	0	7.69	23.1	0.98
11	0.23	0.43	0.79	4.53	2.87	0	0.79	4.53	1.95	0	0.79	4.53	1.78	0	0.79	4.53	1.55
12	0.44	1.36	1.49	6.24	6.45	1.35	1.49	6.24	6.44	1.35	1.49	6.24	6.43	1.32	1.49	6.24	6.4
13	0.82	3.42	6.63	8.05	5.22	0	6.63	8.05	0	0	6.63	8.05	0	0	6.63	8.05	0
14	0.44	0.36	1.35	10.5	5.74	0	1.35	10.5	3.31	0	1.35	10.5	2.36	0	1.35	10.5	1.15
15	2.29	2.91	9.25	43.4	24.1	0	9.25	43.4	0	0	9.25	43.4	0	0	9.25	43.4	0
16	0.86	1.36	2.54	16.6	9.05	0	2.54	16.6	0	0	2.54	16.6	0	0	2.54	16.6	0
17	0.22	0.12	0.91	5.37	2.64	0	0.91	5.37	0	0	0.91	5.37	0	0	0.91	5.37	0
18	3.19	4.14	8.81	63.6	35.1	0	8.81	63.6	2.62	0	8.81	63.6	1.51	0	8.81	63.6	0.28
19	0.42	0.65	2.08	6.37	4.79	0	2.08	6.37	1.69	0	2.08	6.37	0.62	0	2.08	6.37	0
20	1.81	2.26	4.18	41.9	27.1	0.18	4.18	41.9	18.3	0	4.18	41.9	17.1	0	4.18	41.9	15.7
21	0.11	0.23	0.57	1.45	0.78	0	0.57	1.45	0	0	0.57	1.45	0	0	0.57	1.45	0
22	23.44	57.3	83.7	404	273	7.91	80.3	396	121	3.79	79.2	394	93.7	3.67	77.7	392	70.6
23	1.81	2.42	4.84	39.1	22.4	0	4.84	39.1	16.3	0	4.84	39.1	14.2	0	4.84	39.1	11.9
24	0.22	0.32	1.02	3.68	1.67	0	1.02	3.68	0	0	1.02	3.68	0	0	1.02	3.68	0
25	0.08	0.01	0.08	1.74	0.69	0	0.08	1.74	0	0	0.08	1.74	0	0	0.08	1.74	0
26	0.14	0.02	0.67	2.84	0.91	0	0.67	2.84	0	0	0.67	2.84	0	0	0.67	2.84	0
27	0.39	0.46	1.22	8.47	4.97	0	1.22	8.47	2.43	0	1.22	8.47	1.57	0	1.22	8.47	0.54
28	0.22	1.11	1.66	2.76	1.74	0	1.58	2.76	0	0	1.58	2.76	0	0	1.58	2.76	0
29	0.14	0.26	0.91	2.08	1.13	0	0.91	2.08	0	0	0.91	2.08	0	0	0.91	2.08	0
30	0.56	0.37	1.96	14.4	4.79	0	1.96	14.4	0	0	1.96	14.4	0	0	1.96	14.4	0
31	15.00	31	62.2	258	148	2.56	57	258	27.7	0.12	57	258	10.7	0	57	258	0
32	0.51	1.21	2.64	9.38	5.13	0	2.64	9.38	0	0	2.64	9.38	0	0	2.64	9.38	0
33	26.66	56.5	115	421	284	10	101	400	133	5.92	95.5	391	106	5.8	88.4	380	82.4
34	0.14	0.01	0.19	4.78	0.45	0	0.19	4.78	0	0	0.19	4.78	0	0	0.19	4.78	0
35	1.09	0.26	1.83	25.8	8.61	0	1.83	25.8	0	0	1.83	25.8	0	0	1.83	25.8	0
36	0.28	0.31	1.34	5.62	2.83	0	1.34	5.62	0	0	1.34	5.62	0	0	1.34	5.62	0
37	5.02	4.8	18.9	100	57.2	0	18.9	100	17.9	0	18.9	100	15.8	0	18.9	100	13.1
38	7.88	19.7	29.1	131	87.1	1.68	26.7	131	55.5	0	26.7	131	45.4	0	26.7	131	33
39	1.43	2.24	7.88	20.1	11.8	2.13	7.81	19.9	11.8	2.13	7.73	19.7	11.8	2.13	7.63	19.6	11.8
40	0.17	0.61	0.7	2.8	2.04	0	0.7	2.8	0.34	0	0.7	2.8	0	0	0.7	2.8	0
41	4.47	8.66	14.1	86.9	50.6	1.68	14.1	86.9	37.7	0	14.1	86.9	32.1	0	14.1	86.9	25.2
42	3.11	4.47	9.17	59.5	35.9	0	8.81	59.5	5.05	0	8.81	59.5	4.44	0	8.81	59.5	3.77
43	0.05	0	0.03	0.58	0.51	0	0.03	0.58	0	0	0.03	0.58	0	0	0.03	0.58	0
44	0.03	0.07	0.04	0.33	0.26	0	0.04	0.33	0	0	0.04	0.33	0	0	0.04	0.33	0
45	0.07	0.36	0.44	0.83	0.53	0	0.44	0.83	0	0	0.44	0.83	0	0	0.44	0.83	0
46	1.17	4.88	6.16	15.9	12.9	2.7	6.16	15.9	9.63	2.07	6.16	15.9	8.69	1.17	6.16	15.9	7.33
47	10.86	13.2	36.3	213	121	0	36.3	213	30.4	0	36.3	213	20.8	0	36.3	213	8.27
48	0.18	0.57	0.98	2.22	1.07	0	0.98	2.22	0	0	0.98	2.22	0	0	0.98	2.22	0
49	0.16	0.28	0.44	2.98	2.89	0	0.44	2.98	1.73	0	0.44	2.98	1.54	0	0.44	2.98	1.38
50	13.32	21	57.2	237	137	0	54.1	237	27.4	0	54.1	237	14.1	0	54.1	237	0
51	0.23	1.33	1.61	1.73	1.34	0	1.52	1.73	0	0	1.52	1.73	0	0	1.52	1.73	0
52	0.26	1.08	1.49	3.38	2.58	0.63	1.41	3.38	1.91	0.37	1.41	3.38	1.52	0	1.41	3.38	0.91
53	0.39	0.25	0.81	8.22	8.27	0	0.81	8.22	0	0	0.81	8.22	0	0	0.81	8.22	0

Table Apx-2.12. Stream flow reductions into the Karkheh Dam compared to the available flows from sub-basins of different slopes under normal flow conditions.

Normal **KRB flow1: 30year average flow (missing data filled in)** **KRB SI1: 100 mm in Oct and 150 mm in May**												
Basin totals												
KRB area1: slope from 0 to 5 %												
Parameter	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Annual**
Available flow (m^3/s)	56.5	115.4	183.8	194.4	229.5	363	420.7	284.1	111.4	67.3	53.9	53.1	177.36
Outflow after SI water withdrawal (m^3/s)	16.51	106.8	183.8	194.4	229.5	363	407.8	167	111.4	67.3	53.9	53.1	162.26
Irrigated area (km^2)	1071	222.6	0	0	0	0	222.6	2090	0	0	0	0	
Decreasing stream flow (%)	-70.8	-7.4					-3.1	-41.2					-8.5
KRB area1: slope from 0 to 8 %													
Parameter	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Annual**
Available flow (m^3/s)	56.5	115.4	183.8	194.4	229.5	363	420.7	284.1	111.4	67.3	53.9	53.1	177.36
Outflow after SI water withdrawal (m^3/s)	10.03	101.4	183.8	194.4	229.5	363	399.8	132.6	111.4	67.3	53.9	53.1	157.68
Irrigated area (km^2)	1245	362	0	0	0	0	362	2705	0	0	0	0	
Decreasing stream flow (%)	-82.2	-12.1					-5.0	-53.3					-11.1
KRB area1: slope from 0 to 12 %													
Parameter	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Annual**
Available flow (m^3/s)	56.5	115.4	183.8	194.4	229.5	363	420.7	284.1	111.4	67.3	53.9	53.1	177.36
Outflow after SI water withdrawal (m^3/s)	5.92	95.54	183.8	194.4	229.5	363	390.9	105.5	111.4	67.3	53.9	53.1	153.82
Irrigated area (km^2)	1355	514.7	0	0	0	0	514.7	3189	0	0	0	0	
Decreasing stream flow (%)	-89.5	-17.2					-7.1	-62.9					-13.3
KRB area1: slope from 0 to 20 %													
Parameter	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Annual**
Available flow (m^3/s)	56.5	115.4	183.8	194.4	229.5	363	420.7	284.1	111.4	67.3	53.9	53.1	177.36
Outflow after SI water withdrawal (m^3/s)	5.8	88.44	183.8	194.4	229.5	363	380.3	82.39	111.4	67.3	53.9	53.1	150.39
Irrigated area (km^2)	1358	698.7	0	0	0	0	698.7	3602	0	0	0	0	
Decreasing stream flow (%)	-89.7	-23.4					-9.6	-71.0					-15.2

Table Apx-2.13. Stream flow reductions into the Karkheh Dam compared to the available flows from sub-basins of different slopes under normal flow conditions with environmental flow.

Normal _Environment **KRB flow1: 30year average flow (missing data filled in)** **KRB SI1: 100 mm in Oct and 150 mm in May**												
Basin totals												
KRB area1: slope from 0 to 5%												
Parameter	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Annual**
Available flow (m^3/s)	29.85	88.71	157.1	167.8	202.8	336.3	394.1	257.4	84.75	40.6	27.2	26.41	150.69
Outflow after SI water withdrawal (m^3/s)	6.29	80.12	157.1	167.8	202.8	336.3	381.2	143.7	84.75	40.6	27.2	26.41	137.26
Irrigated area (km^2)	630.9	222.6					222.6	2031					
Decreasing stream flow (%)	-78.9	-9.7					-3.3	-44.2					-8.9
KRB area1: slope from 0 to 8%													
Parameter	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Annual**
Available flow (m^3/s)	29.85	88.71	157.1	167.8	202.8	336.3	394.1	257.4	84.75	40.6	27.2	26.41	150.69
Outflow after SI water withdrawal (m^3/s)	3.07	74.75	157.1	167.8	202.8	336.3	373.1	112.8	84.75	40.6	27.2	26.41	133.26
Irrigated area (km^2)	717.4	362					362	2582					
Decreasing stream flow (%)	-89.7	-15.7					-5.3	-56.2					-11.6
KRB area1: slope from 0 to 12%													
Parameter	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Annual**
Available flow (m^3/s)	29.85	88.71	157.1	167.8	202.8	336.3	394.1	257.4	84.75	40.6	27.2	26.41	150.69
Outflow after SI water withdrawal (m^3/s)	2.02	68.85	157.1	167.8	202.8	336.3	364.3	85.86	84.75	40.6	27.2	26.41	129.67
Irrigated area (km^2)	745.4	514.7					514.7	3063					
Decreasing stream flow (%)	-93.2	-22.4					-7.6	-66.6					-13.9
KRB area1: slope from 0 to 20%													
Parameter	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Annual**
Available flow (m^3/s)	29.85	88.71	157.1	167.8	202.8	336.3	394.1	257.4	84.75	40.6	27.2	26.41	150.69
Outflow after SI water withdrawal (m^3/s)	2.02	61.75	157.1	167.8	202.8	336.3	353.6	71.62	84.75	40.6	27.2	26.41	127
Irrigated area (km^2)	745.4	698.7					698.7	3318					
Decreasing stream flow (%)	-93.2	-30.4					-10.3	-72.2					-15.7

Table Apx-2.14. Stream flow reductions into the Karkheh Dam compared to the available flows from sub-basins of different slopes under drought conditions.

Drought **KRB flow1: 30year average flow (missing data filled in)** **KRB SI1: 100 mm in Oct and 150 mm in May**												
Basin totals												
KRB area1: slope from 0 to 5%												
Parameter	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Annual**
Available flow (m^3/s)	42	67.29	14.94	112	122.7	204.7	224.7	125.6	51.01	46.18	35.24	39.12	90.13
Outflow after SI water withdrawal (m^3/s)	28.34	58.73	14.94	112	122.7	204.7	211.8	112.4	51.01	46.18	35.24	39.12	86.09
Irrigated area (km^2)	365.8	221.8					222.6	234.5					
Decreasing stream flow (%)	-32.5	-12.7					-5.7	-10.5					-4.5
KRB area1: slope from 0 to 8%													
Parameter	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Annual**
Available flow (m^3/s)	42	67.29	14.94	112	122.7	204.7	224.7	125.6	51.01	46.18	35.24	39.12	90.13
Outflow after SI water withdrawal (m^3/s)	26.14	53.4	14.94	112	122.7	204.7	203.8	109.2	51.01	46.18	35.24	39.12	84.53
Irrigated area (km^2)	424.9	360.1					362	292					
Decreasing stream flow (%)	-37.8	-20.6					-9.3	-13.0					-6.2
KRB area1: slope from 0 to 12%													
Parameter	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Annual**
Available flow (m^3/s)	42	67.29	14.94	112	122.7	204.7	224.7	125.6	51.01	46.18	35.24	39.12	90.13
Outflow after SI water withdrawal (m^3/s)	25.46	47.58	14.94	112	122.7	204.7	194.9	106.7	51.01	46.18	35.24	39.12	83.05
Irrigated area (km^2)	443	510.9					514.7	337.5					
Decreasing stream flow (%)	-39.4	-29.3					-13.3	-15.1					-7.9
KRB area1: slope from 0 to 20%													
Parameter	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Annual**
Available flow (m^3/s)	42	67.29	14.94	112	122.7	204.7	224.7	125.6	51.01	46.18	35.24	39.12	90.13
Outflow after SI water withdrawal (m^3/s)	25.46	40.58	14.94	112	122.7	204.7	184.3	106.7	51.01	46.18	35.24	39.12	81.6
Irrigated area (km^2)	443	692.2					698.7	337.5					
Decreasing stream flow (%)	-39.4	-39.7					-18.0	-15.1					-9.5

Table Apx-2.15. Stream flow reductions into the Karkheh Dam compared to the available flows from sub-basins of different slopes under drought conditions with environmental flow.

Drought with EFR **KRB flow1: 30year average flow (missing data filled in)** **KRB SI1: 100 mm in Oct and 150 mm in May**												
Basin totals												
KRB area1: slope from 0 to 5%												
Parameter	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Annual**
Available flow (m^3/s)	15.34	40.63	0	85.29	96.01	178.1	198.1	98.91	24.35	19.52	8.58	12.46	64.47
Outflow after SI water withdrawal (m^3/s)	15.34	32.07	0	85.29	96.01	178.1	185.2	98.91	24.35	19.52	8.58	12.46	62.71
Irrigated area (km^2)	0	221.8	0	0	0	0	222.6	0	0	0	0	0	
Decreasing stream flow (%)	0.0	-21.1					-6.5	0.0					-2.7
KRB area1: slope from 0 to 8%													
Parameter	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Annual**
Available flow (m^3/s)	15.34	40.63	0	85.29	96.01	178.1	198.1	98.91	24.35	19.52	8.58	12.46	64.47
Outflow after SI water withdrawal (m^3/s)	15.34	26.74	0	85.29	96.01	178.1	177.1	98.91	24.35	19.52	8.58	12.46	61.6
Irrigated area (km^2)	0	360.1	0	0	0	0	362	0	0	0	0	0	
Decreasing stream flow (%)	0.0	-34.2					-10.6	0.0					-4.5
KRB area1: slope from 0 to 12%													
Parameter	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Annual**
Available flow (m^3/s)	15.34	40.63	0	85.29	96.01	178.1	198.1	98.91	24.35	19.52	8.58	12.46	64.47
Outflow after SI water withdrawal (m^3/s)	15.34	20.92	0	85.29	96.01	178.1	168.3	98.91	24.35	19.52	8.58	12.46	60.4
Irrigated area (km^2)	0	510.9	0	0	0	0	514.7	0	0	0	0	0	
Decreasing stream flow (%)	0.0	-48.5					-15.0	0.0					-6.3
KRB area1: slope from 0 to 20%													
Parameter	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Annual**
Available flow (m^3/s)	15.34	40.63	0	85.29	96.01	178.1	198.1	98.91	24.35	19.52	8.58	12.46	64.47
Outflow after SI water withdrawal (m^3/s)	15.34	13.92	0	85.29	96.01	178.1	157.6	98.91	24.35	19.52	8.58	12.46	58.95
Irrigated area (km^2)	0	692.2	0	0	0	0	698.7	0	0	0	0	0	
Decreasing stream flow (%)	0.0	-65.7					-20.4	0.0					-8.6

Allocation program and sample input and output data:

```
program si5
c --  Compute supplemental irrigation areas in Upper KRB sub basins
c --  for different land suitability, irrigation and flow scenarios
c --  Adriana Bruggeman, ICARDA and Behzad Hessari , AERI
c --  11 Sept 2008
c
c --  Input files (note: all monthly data start in October!)
c --  flow.csv     monthly flow of each sub basin (m³/s)
c --  area.csv     irrigation area (potential) for each sub basin (km²)
c --  irri.csv     monthly irrigation requirements for each sub basin (mm)
c --  route.csv    routing scheme for sub basins
c
c --  Output files
c --  flowx.csv    monthly outflow after irrigation abstraction for each sub basin
c --  areaw.csv    monthly irrigated area for each sub basin
c --  subbasin.csv monthly flows and areas by sub basin
c --  basin.csv    monthly and annual outflows, areas, and irrigation volumes for basin
c
c --  nb           = number of sub basins
c --  nm           = number of months (12)
c
c --  nds          = number of seconds per day
c --  ndm (nm)       = number of days per month
c
c --  nbup (nb)     = number of sub basins upstream
c --  ibdown (nb)   = id of downstream basin for routing outflow
c
c --  flo (nb,nm)   = available flow of sub basin for each month [m³/s]
c --  flon (nb,nm)  = net available flow of sub basin for each month [m³/mo]
c --                (flow generated in sub basin = flow minus inflow of upstream sub basins)
c --  flox (nb,nm)  = leftover outflow of each sub basin for each month [m³/mo]
c --  floa (nb,nm)  = actual available flow of sub basin for each month [m³/mo]
c --                (net flow plus any leftover outflow from upstream sub basins)
c
c --  flob (nm)     = monthly flow out of basin [m³/mo]
c --  floxb (nm)    = monthly leftover flow out of basin [m³/mo]
c --  floby         = annual flow out of basin [m³/yr]
c --  floxby        = annual leftover flow out of basin [m³/yr]
c
c --  area (nb)     = available irrigation area for each sub basin [km²]
c --  areai (nb,nm) = requested irrigation area for each sub basin and month [km²]
c --  areaw (nb,nm) = actually irrigated area for each sub basin and month [km²]
c
c --  areaib (nm)   = requested irrigation area for complete basin per month [km²]
c --  areawb (nm)   = actually irrigated area for complete basin per month [km²]
c --  areaiby       = requested irrigation area for complete basin and year [km²]
c --  areawby       = actually irrigated area for complete basin and year [km²]
c
```

```
c --  wir (nb,nm)    = monthly irrigation requirement for each sub basin [mm]
c
c --  volirb (nm)    = monthly irrigation water volume of complete basin [m³/mo]
c --  volirby        = annual irrigation water volume for complete basin [m³/yr]
c
c ------------------------------------------------------------------
c
      parameter (nfi=4,nm=12,nb=53)
      integer ndm (nm),nbup(nb),ibdown(nb),nbupchk(nb)
      real*8 flo (nb,nm),flon(nb,nm),floa(nb,nm),flox(nb,nm)
      real*8 flob (nm),floxb(nm),floby,floxby
      real*8 area (nb),areai(nb,nm),areaw(nb,nm),wir(nb,nm)
         real*8 areaib (nm),areawb(nm),volirb(nm)
         real*8 areaiby,areawby,volirby
      character*120 head(nfi)
c --  days per month (starting in October!)
      data ndm/31,30,31,31,28,31,30,31,30,31,31,30/
c
      nsd=86400
      ndy=365
c
c ------------------------------------------------------------------
         write(6,101)
c
c --  open input files
      nfin=4
      open(unit=11,file='area.csv',status='old')
      open(unit=12,file='flow.csv',status='old')
      open(unit=13,file='irri.csv',status='old')
      open(unit=14,file='route.csv',status='old')
c
c --  read input file header (first line only)
      do 10 i=1,nfin
         ifl=10+i
      read(ifl,210)head(i)
10    read(ifl,*)
c
c --  read input data
      do 11 i=1,nb
11    read(11,*) ib,area(i)
c
      do 12 i=1,nb
12       read(12,*) ib, (flo(i,j),j=1,nm)
c
      do 13 i=1,nb
13       read(13,*) ib, (wir(i,j),j=1,nm)
c
      do 14 i=1,nb
14       read(14,*)ib,nbup(i), ibdown(i)
c
```

```
c --  close input files
      do 15 i=1,nfin
         ifl=10+i
15    close(ifl)
c
c --  define outlet of basin = ibdown() of most downstream basin
      iout=nb+1
c
c -----------------------------------------------------------------
c --  check routing
      do 60 i=1,nb
60       nbupchk(i)=0
c
      do 61 iu=1,nb
          nup=iu-1
c --    find subbasin with nup subbasins upstream
        do 62 i=1,nb
          if (nbup(i).eq.nup.and.ibdown(i).lt.iout) then
c --    set nr of upstream basins for downstream basin ii
            ii=ibdown(i)
            nbupchk(ii)=nbupchk(ii)+nbup(i)+1
          endif
62      continue
61    continue
c
      ier=0
      open(unit=60,file='error.txt',status='unknown')
      do 63 i=1,nb
          if ((nbupchk(i)-nbup(i)).ne.0) then
         ierr=1
            write(6,601)i,nbup(i),nbupchk(i)
            write(60,601)i,nbup(i),nbupchk(i)
        endif
63    continue
      close(60)
c
      if (ierr.eq.1) stop
c
601   format(' error in file route.csv !!',/,' subbasin: ',
     $i2,' - nr of upstream subbasins: ',i2,' or ',i2,' ?',/)
c
c -----------------------------------------------------------------
c --  open output files
      nfo=4
      open(unit=21,file='areaw.csv',status='unknown')
      open(unit=22,file='flowx.csv',status='unknown')
      open(unit=23,file='subbasin.csv',status='unknown')
      open(unit=24,file='basin.csv',status='unknown')
c     open(unit=24,file='basin.csv',access='append',status='unknown')
c
```

```
c --  write output file headers (flow, area, irrigation, months)
      do 56 i=1,nfo
        ifl=20+i
        write(ifl,210)head(1)
        write(ifl,210)head(2)
        write(ifl,210)head(3)
        if (i.eq.1) then
              write(ifl,211)
        else if (i.eq.2) then
              write(ifl,212)
        else if (i.eq.3) then
              write(ifl,213)
            else
              write(ifl,214)
            endif
56    continue
c
c -------------------------------------------------------------------
c --  initialize basin totals (sums)
          floby=0.
          floxby=0.
          areab=0.
      areaiby=0.
      areawby=0.
      volirby=0.
      do 57 j=1,nm
          flob(j)=0.
          floxb(j)=0.
          areaib(j)=0.
          areawb(j)=0.
57        volirb(j)=0.
c
c --  convert flow [m³/s] to [m³/mo], starting in October
c --  initialize net available flow per subbasin [m³/mo] and irrigation area
      do 16 i=1,nb
          do 16 j=1,nm
            flo(i,j)=flo(i,j)*nsd*ndm(j)
        flon(i,j)=flo(i,j)
        areai(i,j)=0.
            if (wir(i,j).gt.0.0) areai(i,j)=area(i)
16    continue
c
c -------------------------------------------------------------------
c --  compute net available flow = flow generated in subbasin (outflow minus incoming
flow from upstream subbasins)
c --  minus downstream allocations [m³/mo]
c --  start from downstream to keep downstream allocations or losses
      do 17 iu=nb,1,-1
            nup=iu-1
c --    find basin that has nup subbasins upstream
```

```
    do 18 i=1,nb
     if (nbup(i).eq.nup) then
c --    find all upstream subbasins k that flow in to subbasin i and substract upstream
inflow
      do 70 j=1,nm
       floups=0.
       do 71 k=1,nb
             if (ibdown(k).eq.i) then
         floups=floups+flo(k,j)
           flon(i,j)=flon(i,j)-flo(k,j)
             endif
71      continue
c --  downstream outflow is less than inflow from upstream subbasins
c --  make a relative adjustment to the upstream subbasins
       if (flon(i,j).lt.0.0) then
        reduc=-flon(i,j)/floups
          flon(i,j)=0.0
        do 72 k=1,nb
              if (ibdown(k).eq.i) then
            flon(k,j)=flon(k,j)-flo(k,j)*reduc
              endif
72       continue
       endif
70      continue
     endif
18   continue
17  continue
c
c --  sum of net available flows of all subbasins should be equal to outflow from most
downstream subbasin
c     do 81 j=1,nm
c      summi=0.
c     do 82 i=1,nb
c82     summi=summi+flon(i,j)
c      write(*,*)j,summi
c81   continue
c
c --  initialize actual available flow = net flow [m3/mo]
   do 20 i=1,nb
   do 20 j=1,nm
20  floa(i,j)=flon(i,j)
c
c --  compute irrigated area (km2) and leftover outflow (m3/mo) for all months
c --  add leftover outflow to downstream subbasin = actual available flow
c --  first for all subbasins with 0 upstream subbasins (nup=0),
c --  next for all subbasins with 1 upstream subbasin,.. upto 52 upstream subbasins
   do 21 iu=1,nb
      nup=iu-1
    do 22 i=1,nb
     if (nbup(i).eq.nup) then
```

```
        do 23 j=1,nm
       wneed=1000.*area(i)*wir(i,j)
       if (wneed.le.0.00) then
        flox(i,j)=floa(i,j)
        areaw(i,j)=0.
       else if (wneed.le.floa(i,j)) then
        flox(i,j)=floa(i,j)-wneed
             areaw(i,j)=area(i)
       else
          flox(i,j)=0.
          areaw(i,j)=0.001*floa(i,j)/wir(i,j)
         endif
c --  add leftover outflow to downstream subbasin
         ii=ibdown(i)
       if (ii.le.nb) then
                floa(ii,j)=floa(ii,j)+flox(i,j)
         endif
23     continue
       endif
22   continue
21  continue
c
c -------------------------------------------------------------------
c --  compute annual totals (sums)
c --  write annual and monthly original, net, and leftover outflow for each subbasin (m^3/s)
c --  write annual and monthly irrigation need (mm)
c --  write annual and monthly irrigation area and irrigated area for each subbasin (km^2)
   big=99999999.
   do 30 i=1,nb
    sum1=0.
    sum2=0.
    sum3=0.
    sum4=0.
    sum5=0.
      sum6=big
    do 31 j=1,nm
     sum1=sum1+flo(i,j)
     sum2=sum2+floa(i,j)
     sum3=sum3+flox(i,j)
     flo(i,j)=flo(i,j)/(nsd*ndm(j))
     floa(i,j)=floa(i,j)/(nsd*ndm(j))
     flox(i,j)=flox(i,j)/(nsd*ndm(j))
     sum4=sum4+wir(i,j)
     sum5=sum5+areai(i,j)
     if (wir(i,j).gt.0.00)sum6=min(sum6,areaw(i,j))
31   continue
c
    if (sum6.ge.(big-0.1))sum6=0.
    sum1=sum1/(nsd*ndy)
    sum2=sum2/(nsd*ndy)
```

```
      sum3=sum3/(nsd*ndy)
c
      write(23,301)i,(flo(i,j),j=1,nm),sum1
      write(23,302)i,(floa(i,j),j=1,nm),sum2
         write(23,303)i,(flox(i,j),j=1,nm),sum3
c --   write flows at outlet to basin file
      if (ibdown(i).eq.iout) then
        write(24,401)(flo(i,j),j=1,nm),sum1
           write(24,403)(flox(i,j),j=1,nm),sum3
      endif
c
         write(23,304)i,(wir(i,j),j=1,nm),sum4
         write(23,305)i,(areai(i,j),j=1,nm),sum5
         write(23,306)i,(areaw(i,j),j=1,nm),sum6
c
         write(21,221)i,(areaw(i,j),j=1,nm),sum6,area(i)
         write(22,221)i,(flox(i,j),j=1,nm),sum3,sum1
c
30    continue
c
c ---------------------------------------------------------------------
c --  sum monthly irrigation area and irrigated area for basin (km^2)(m^3)
c --  sum monthly total volume irrigation water for basin (m^3)
     do 41 i=1,nb
     do 41 j=1,nm
        areaib(j)=areaib(j)+areai(i,j)
        areawb(j)=areawb(j)+areaw(i,j)
41    volirb(j)=volirb(j)+areaw(i,j)*wir(i,j)*1000.
c
c --  compute annual totals for the above
     do 46 j=1,nm
46    volirby=volirby+volirb(j)
c
c --  write monthly and annual basin totals
44    continue
        write(24,405)(areaib(j),j=1,nm)
        write(24,406)(areawb(j),j=1,nm)
        write(24,407)((volirb(j)/1000000.),j=1,nm),(volirby/1000000.)
c
     do 45 i=1,nfo
        ifil=20+i
45    close(ifil)
c
        write(6,105)
c
c ---------------------------------------------------------------------
101   format(/,' This program computes supplementary ',
    $'irrigation scenarios for KRB.',/,' It requires 4 input files: ',
    $'area.csv, flow.csv, irri.csv, route.csv',/)
105   format(/,' Analysis completed!',//,' Results are in files: ',
```

```
     $'areaw.csv, flowx.csv, subbasin.csv, basin.csv',/)
c
210   format(a120)
211   format('irrigated area (km²)',/,'subbasin,oct,nov,dec,',
     $'jan,feb,mar,apr,may,jun,jul,aug,sep,annual_min,suitable')
212   format('outflow after irrigation (/s)',/,'subbasin,oct,nov,',
     $'dec,jan,feb,mar,apr,may,jun,jul,aug,sep m³,annual,annual_before')
213   format('subbasin data',/,'parameter,subbasin,oct,nov,dec,',
     $'jan,feb,mar,apr,may,jun,jul,aug,sep,annual')
214   format('basin totals',/,'parameter,oct,nov,dec,jan,feb,',
     $'mar,apr,may,jun,jul,aug,sep,annual')
c
221   format(i2,14(',',f10.2))
c
301   format('available flow (m³/s),',i2,13(',',f10.2))
302   format('actual av.flow (m³/s),',i2,13(',',f10.2))
303   format('outflow after (m³/s),',i2,13(',',f10.2))
304   format('irrigation need (mm),',i2,13(',',f8.1))
305   format('irrigation area (km²),',i2,13(',',f10.2))
306   format('irrigated area (km²),',i2,13(',',f10.2))
c
401   format('available flow (m³/s)',13(',',f10.2))
403   format('outflow after (m³/s)',13(',',f10.2))
405   format('irrigation area (km²)',12(',',f10.2))
406   format('irrigated area (km²)',12(',',f10.2))
407   format('irrigation vol.(10^6 m³/yr or mo))',13(',',f12.3))
c
      stop
      end
c
```

Sample Input files: Route.csv

KRB sub-basin routing		
Ib	**Nbup**	**Ibdown**
1	0	38
2	7	38
3	0	26
4	0	17
5	2	15
6	2	13
7	0	38
8	0	35
9	0	36
10	1	2
11	0	10
12	0	46
13	3	50
14	0	23
15	9	37
16	4	42
17	1	15
18	9	47
19	1	15
20	4	37
21	0	19
22	50	33
23	1	41
24	1	16
25	0	28
26	1	5
27	0	20
28	1	6
29	0	24
30	2	20
31	38	22
32	0	47
33	52	54
34	0	53
35	1	42
36	1	30
37	16	47
38	10	22
39	0	33
40	0	47
41	4	2
42	8	18
43	0	16
44	0	16
45	0	37
46	1	41
47	29	50
48	0	50
49	0	42
50	35	31
51	0	31
52	0	31
53	1	15

Input: Area.csv

KRB area1: slope 0-5	
Ib	**Area_km^2**
1	7.51
2	30.47
3	10.84
4	0
5	89.88
6	40.35
7	224.96
8	0.79
9	77.1
10	129.14
11	12.26
12	0.13
13	221.66
14	23.38
15	42.52
16	272.34
17	37.68
18	32.36
19	24.89
20	19.39
21	43.41
22	60.22
23	41.91
24	88.71
25	34.28
26	36.84
27	27.34
28	51.13
29	290.38
30	32.14
31	98.27
32	68.32
33	161.56
34	51.02
35	126.86
36	8.12
37	83.52
38	33.87
39	0.8
40	18.09
41	28.52
42	188.23
43	19.17
44	19.8
45	8.29
46	41.63
47	117.11
48	25.74
49	14.69
50	150.94
51	86.15
52	6.43
53	197.87

Input: Flow.csv

KRB flow1: 30-year average flow (missing data filled in)

Ib	Oct_m^3/s	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1	2.4	2.92	5.34	3.54	4.9	7.11	8.65	6.33	2.54	1.97	1.53	1.71
2	16.88	26.66	42.9	43.98	56.59	91.67	113.36	77.77	29.89	17.9	14.37	15.02
3	0.29	0.47	0.51	0.56	0.62	0.88	1.03	0.64	0.35	0.22	0.19	0.2
4	0.16	0.14	0.24	0.21	0.3	0.67	1.75	1.64	0.57	0.17	0.09	0.15
5	0.78	1.71	3.54	3.49	4.34	9.63	13.38	8.06	2.16	0.91	0.54	0.2
6	1.46	1.58	2.23	1.79	2.06	4.95	3.06	1.8	0.41	0.43	0.42	0.49
7	1.33	2.08	2.79	1.88	2	2.4	2.41	1.68	0.94	0.85	0.87	0.95
8	0.05	0.27	0.32	0.34	0.78	1.27	1.17	0.47	0.15	0.06	0.02	0.08
9	0.27	1.38	1.6	1.59	1.83	3.28	4.2	2.23	0.43	0.16	0.13	0.16
10	5.56	7.69	10.67	10.57	13.23	19.58	23.05	16.52	9.11	6.43	4.68	4.96
11	0.43	0.79	1.29	1.28	2.24	3.3	4.53	2.87	0.64	0.32	0.24	0.43
12	1.36	1.49	2.2	1.87	1.93	3.84	6.24	6.45	3.72	2.63	1.84	1.67
13	3.42	6.63	9.47	5.48	7.12	9.46	8.05	5.22	3.86	2.43	2.1	2.53
14	0.36	1.35	2.64	2.28	2.93	6.34	10.47	5.74	1.45	0.55	0.34	0.54
15	2.91	9.25	16.88	17.89	21.94	32.44	43.35	24.12	6.02	3.03	2.19	3.06
16	1.36	2.54	4.37	4.75	8.07	13.87	16.6	9.05	3.47	2	1.38	1.49
17	0.12	0.91	1.46	1.71	2.05	2.69	5.37	2.64	0.37	0.06	0.06	0.09
18	4.14	8.81	17.54	19.07	30.24	48.65	63.57	35.06	13.3	6.1	3.95	4.93
19	0.65	2.08	3.74	3.79	3.83	5.13	6.37	4.79	1.41	0.49	0.47	0.53
20	2.26	4.18	10.24	8.96	11.31	27.94	41.86	27.07	6.64	2.19	1.3	0.71
21	0.23	0.57	1.01	0.86	1.08	1.44	1.45	0.78	0.32	0.25	0.2	0.25
22	57.3	83.7	151	144	184.1	311	403.5	273.1	109.9	67	49.4	41.1
23	2.42	4.84	8.73	9.73	14.03	28.19	39.07	22.36	6.38	3.36	2.48	2.82
24	0.32	1.02	2.14	1.77	2.42	3.75	3.68	1.67	0.48	0.25	0.14	0.19
25	0.01	0.08	0.23	0.44	0.77	2.01	1.74	0.69	0.12	0	0	0
26	0.02	0.67	1.61	1.48	1.4	1.67	2.84	0.91	0.24	0.21	0.1	0.26
27	0.46	1.22	2.33	2.23	3.31	6.03	8.47	4.97	1.23	0.21	0.17	0.26
28	1.11	1.66	1.41	1.49	1.89	2.65	2.76	1.74	0.73	0.62	0.57	0.99
29	0.26	0.91	1.14	1.06	1.29	2.24	2.08	1.13	0.4	0.24	0.2	0.23
30	0.37	1.96	3.66	3.92	4.68	9.82	14.44	4.79	0.65	0.16	0.09	0.07
31	31	62.2	107.3	109.7	131.7	199.6	258.4	147.6	58.7	35.6	28.5	29.5
32	1.21	2.64	3.53	3.38	4.16	7.19	9.38	5.13	1.61	0.88	1.08	1
33	56.5	115.4	183.8	194.4	229.5	363	420.7	284.1	111.4	67.3	53.9	53.1
34	0.01	0.19	0.55	0.85	1.77	2.02	4.78	0.45	0.09	0.03	0.01	0.41
35	0.26	1.83	6.12	7.54	12.6	20.85	25.76	8.61	1.78	0.43	0.16	1.65
36	0.31	1.34	1.96	1.99	2.6	4.3	5.62	2.83	0.71	0.3	0.21	0.36
37	4.8	18.9	36.8	36	46.7	74.1	100.2	57.2	14.2	4.2	2.8	5.4
38	19.7	29.1	52.9	50	66.8	106.5	131.2	87.1	32.8	21.8	15.5	16.9
39	2.24	7.88	9.63	10.98	12.46	20.98	20.1	11.79	6.89	5.67	3.21	2.45
40	0.61	0.7	1.04	1.25	1.45	2.22	2.8	2.04	0.64	0.43	0.26	0.32
41	8.66	14.07	26.05	30.25	38.99	61.53	86.93	50.61	15.99	10.23	7.26	7.06
42	4.47	9.17	17.15	18.82	29.13	47.1	59.48	35.87	12.79	5.92	3.92	5.22
43	0	0.03	0.25	0.59	0.82	0.71	0.58	0.51	0.36	0.15	0.04	0.02
44	0.07	0.04	0.25	0.53	0.45	0.41	0.33	0.26	0.12	0.06	0.06	0.09
45	0.36	0.44	0.5	0.42	0.43	0.71	0.83	0.53	0.45	0.44	0.41	0.38
46	4.88	6.16	7.9	7.73	8.47	11.43	15.88	12.9	5.82	4.35	3.91	4.3
47	13.2	36.3	68.7	74.8	102.2	164.3	213.1	121.1	36.3	14.8	9.4	14.4
48	0.57	0.98	1.76	1.62	2.28	2.59	2.22	1.07	0.36	0.24	0.13	0.21
49	0.28	0.44	0.63	0.6	0.73	1.78	2.98	2.89	1.68	0.62	0.25	0.16
50	21	57.2	97.8	95.5	134.5	187.6	236.7	136.8	44.3	19.4	14.3	20.3
51	1.33	1.61	1.98	2.21	1.68	1.81	1.73	1.34	1.11	1.1	1.07	1.19
52	1.08	1.49	1.69	1.93	2.01	2.15	3.38	2.58	1.44	1.09	0.95	0.72
53	0.25	0.81	2	2.12	3.23	4.93	8.22	8.27	1.01	0.2	0.26	0.18

Input: irri.csv

KRB irrigation1: 100 mm in Oct and 150 mm in May												
Ib	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
1	100	0	0	0	0	0	0	150	0	0	0	0
2	100	0	0	0	0	0	0	150	0	0	0	0
3	100	0	0	0	0	0	0	150	0	0	0	0
4	100	0	0	0	0	0	0	150	0	0	0	0
5	100	0	0	0	0	0	0	150	0	0	0	0
6	100	0	0	0	0	0	0	150	0	0	0	0
7	100	0	0	0	0	0	0	150	0	0	0	0
8	100	0	0	0	0	0	0	150	0	0	0	0
9	100	0	0	0	0	0	0	150	0	0	0	0
10	100	0	0	0	0	0	0	150	0	0	0	0
11	100	0	0	0	0	0	0	150	0	0	0	0
12	100	0	0	0	0	0	0	150	0	0	0	0
13	100	0	0	0	0	0	0	150	0	0	0	0
14	100	0	0	0	0	0	0	150	0	0	0	0
15	100	0	0	0	0	0	0	150	0	0	0	0
16	100	0	0	0	0	0	0	150	0	0	0	0
17	100	0	0	0	0	0	0	150	0	0	0	0
18	100	0	0	0	0	0	0	150	0	0	0	0
19	100	0	0	0	0	0	0	150	0	0	0	0
20	100	0	0	0	0	0	0	150	0	0	0	0
21	100	0	0	0	0	0	0	150	0	0	0	0
22	0	100	0	0	0	0	150	0	0	0	0	0
23	100	0	0	0	0	0	0	150	0	0	0	0
24	100	0	0	0	0	0	0	150	0	0	0	0
25	100	0	0	0	0	0	0	150	0	0	0	0
26	100	0	0	0	0	0	0	150	0	0	0	0
27	100	0	0	0	0	0	0	150	0	0	0	0
28	100	0	0	0	0	0	0	150	0	0	0	0
29	100	0	0	0	0	0	0	150	0	0	0	0
30	100	0	0	0	0	0	0	150	0	0	0	0
31	100	0	0	0	0	0	0	150	0	0	0	0
32	100	0	0	0	0	0	0	150	0	0	0	0
33	0	100	0	0	0	0	150	0	0	0	0	0
34	100	0	0	0	0	0	0	150	0	0	0	0
35	100	0	0	0	0	0	0	150	0	0	0	0
36	100	0	0	0	0	0	0	150	0	0	0	0
37	100	0	0	0	0	0	0	150	0	0	0	0
38	100	0	0	0	0	0	0	150	0	0	0	0
39	0	100	0	0	0	0	150	0	0	0	0	0
40	100	0	0	0	0	0	0	150	0	0	0	0
41	100	0	0	0	0	0	0	150	0	0	0	0
42	100	0	0	0	0	0	0	150	0	0	0	0
43	100	0	0	0	0	0	0	150	0	0	0	0
44	100	0	0	0	0	0	0	150	0	0	0	0
45	100	0	0	0	0	0	0	150	0	0	0	0
46	100	0	0	0	0	0	0	150	0	0	0	0
47	100	0	0	0	0	0	0	150	0	0	0	0
48	100	0	0	0	0	0	0	150	0	0	0	0
49	100	0	0	0	0	0	0	150	0	0	0	0
50	100	0	0	0	0	0	0	150	0	0	0	0
51	100	0	0	0	0	0	0	150	0	0	0	0
52	100	0	0	0	0	0	0	150	0	0	0	0
53	100	0	0	0	0	0	0	150	0	0	0	0

Sample Output files: Output: areaw.csv

KRB area1: slope 0-5%														
KRB flow1: 30-year average flow (missing data filled in);KRB irrigation1: 100 mm in Oct and 150 mm in May														
Irrigated area (km^2)														
Sub-basin	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Annual_Min**	**Suitable**
1	7.51	0	0	0	0	0	0	7.51	0	0	0	0	7.51	7.51
2	30.47	0	0	0	0	0	0	30.47	0	0	0	0	30.47	30.47
3	0.54	0	0	0	0	0	0	10.84	0	0	0	0	0.54	10.84
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	20.36	0	0	0	0	0	0	89.88	0	0	0	0	20.36	89.88
6	9.37	0	0	0	0	0	0	1.07	0	0	0	0	1.07	40.35
7	34.05	0	0	0	0	0	0	30	0	0	0	0	30	225
8	0.79	0	0	0	0	0	0	0.79	0	0	0	0	0.79	0.79
9	7.23	0	0	0	0	0	0	39.82	0	0	0	0	7.23	77.1
10	129.1	0	0	0	0	0	0	129.1	0	0	0	0	129.1	129.1
11	11.52	0	0	0	0	0	0	12.26	0	0	0	0	11.52	12.26
12	0.13	0	0	0	0	0	0	0.13	0	0	0	0	0.13	0.13
13	52.5	0	0	0	0	0	0	61.07	0	0	0	0	52.5	221.7
14	9.64	0	0	0	0	0	0	23.38	0	0	0	0	9.64	23.38
15	19.44	0	0	0	0	0	0	42.52	0	0	0	0	19.44	42.52
16	25.98	0	0	0	0	0	0	118	0	0	0	0	25.98	272.3
17	3.21	0	0	0	0	0	0	37.68	0	0	0	0	3.21	37.68
18	0	0	0	0	0	0	0	32.36	0	0	0	0	0	32.36
19	11.25	0	0	0	0	0	0	24.89	0	0	0	0	11.25	24.89
20	19.39	0	0	0	0	0	0	19.39	0	0	0	0	19.39	19.39
21	6.16	0	0	0	0	0	0	13.93	0	0	0	0	6.16	43.41
22	0	60.22	0	0	0	0	60.22	0	0	0	0	0	60.22	60.22
23	41.91	0	0	0	0	0	0	41.91	0	0	0	0	41.91	41.91
24	1.61	0	0	0	0	0	0	9.64	0	0	0	0	1.61	88.71
25	0.27	0	0	0	0	0	0	12.32	0	0	0	0	0.27	34.28
26	0	0	0	0	0	0	0	5.41	0	0	0	0	0	36.84
27	12.32	0	0	0	0	0	0	27.34	0	0	0	0	12.32	27.34
28	29.46	0	0	0	0	0	0	18.75	0	0	0	0	18.75	51.13
29	6.96	0	0	0	0	0	0	20.18	0	0	0	0	6.96	290.4
30	1.61	0	0	0	0	0	0	32.14	0	0	0	0	1.61	32.14
31	98.27	0	0	0	0	0	0	98.27	0	0	0	0	98.27	98.27
32	32.41	0	0	0	0	0	0	68.32	0	0	0	0	32.41	68.32
33	0	161.6	0	0	0	0	161.6	0	0	0	0	0	161.6	161.6
34	0.27	0	0	0	0	0	0	8.04	0	0	0	0	0.27	51.02
35	6.17	0	0	0	0	0	0	126.9	0	0	0	0	6.17	126.9
36	1.07	0	0	0	0	0	0	8.12	0	0	0	0	1.07	8.12
37	11	0	0	0	0	0	0	83.52	0	0	0	0	11	83.52
38	33.87	0	0	0	0	0	0	33.87	0	0	0	0	33.87	33.87
39	0	0.8	0	0	0	0	0.8	0	0	0	0	0	0.8	0.8
40	16.34	0	0	0	0	0	0	18.09	0	0	0	0	16.34	18.09
41	28.52	0	0	0	0	0	0	28.52	0	0	0	0	28.52	28.52
42	60	0	0	0	0	0	0	188.2	0	0	0	0	60	188.2
43	0	0	0	0	0	0	0	9.11	0	0	0	0	0	19.17
44	1.87	0	0	0	0	0	0	4.64	0	0	0	0	1.87	19.8
45	8.29	0	0	0	0	0	0	8.29	0	0	0	0	8.29	8.29
46	41.63	0	0	0	0	0	0	41.63	0	0	0	0	41.63	41.63
47	65.35	0	0	0	0	0	0	117.1	0	0	0	0	65.35	117.1
48	15.27	0	0	0	0	0	0	19.11	0	0	0	0	15.27	25.74
49	7.5	0	0	0	0	0	0	14.69	0	0	0	0	7.5	14.69
50	102.1	0	0	0	0	0	0	150.9	0	0	0	0	102.1	150.9
51	35.62	0	0	0	0	0	0	23.93	0	0	0	0	23.93	86.15
52	6.43	0	0	0	0	0	0	6.43	0	0	0	0	6.43	6.43
53	6.43	0	0	0	0	0	0	139.6	0	0	0	0	6.43	197.9

Output: flowx.csv

KRB area1: slope 0-5%													
KRB flow1: 30-year average flow (missing data filled in);KRB irrigation1: 100 mm in Oct and 150 mm in May													
Outflow after irrigation (m^3/s)													
Sub-basin	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual	Annual_Before
1	2.01	2.46	5.22	3.23	4.78	07.11	8.65	5.91	2.5	1.97	1.41	1.45	3.89	4.07
2	5.2	22.5	41.9	40.1	55.2	91.7	113	60.6	29.4	17.9	13.3	12.7	41.9	45.5
3	0	0.47	0.51	0.56	0.62	0.88	1.03	0.03	0.24	0.21	0.1	0.2	0.4	0.5
4	0.12	0.14	0.24	0.21	0.3	0.67	1.75	1.64	0.37	0.06	0.06	0.09	0.47	0.51
5	0	1.71	3.54	3.49	4.34	9.63	13.4	2.12	2.16	0.91	0.54	0.2	3.49	4.06
6	0	1.58	2.23	1.79	2.06	4.95	3.06	0	0.41	0.43	0.42	0.49	1.45	1.72
7	0	1.75	2.73	1.72	1.95	2.4	2.41	0	0.92	0.85	0.8	0.8	1.36	1.68
8	0.02	0.27	0.32	0.34	0.78	1.27	1.17	0.43	0.15	0.06	0.02	0.08	0.41	0.41
9	0	1.34	1.6	1.59	1.83	3.28	4.2	0	0.43	0.16	0.09	0.07	1.21	1.43
10	0.31	7.69	10.7	10.4	13.2	19.6	23.1	8.6	9.11	6.43	4.68	4.96	9.85	11
11	0	0.79	1.29	1.28	2.24	3.3	4.53	2.18	0.64	0.32	0.24	0.43	1.43	1.52
12	1.36	1.49	2.2	1.87	1.93	3.84	6.24	6.44	3.72	2.63	1.84	1.67	2.94	2.94
13	0	6.63	9.47	5.48	7.12	9.46	8.05	0	3.86	2.43	2.1	2.53	4.74	5.47
14	0	1.35	2.64	2.28	2.93	6.34	10.5	4.43	1.45	0.55	0.34	0.54	2.77	2.91
15	0	9.25	16.9	17.9	21.9	32.4	43.4	3.24	6.02	2.25	1.57	3.06	13.1	15.2
16	0	2.54	4.37	4.75	8.07	13.9	16.6	0	3.47	2	1.38	1.49	4.84	5.72
17	0	0.91	1.46	1.71	2.05	2.69	5.37	0.53	0.37	0.06	0.06	0.09	1.26	1.45
18	0	8.81	17.5	19.1	30.2	48.7	63.6	5.68	13.3	6.1	3.95	4.93	18.3	21.2
19	0	2.08	3.74	3.79	3.83	5.13	6.37	2.62	1.41	0.49	0.47	0.53	2.53	2.77
20	0.41	4.18	10.2	8.96	11.3	27.9	41.9	20	6.64	1.63	0.93	0.71	11.2	12.1
21	0	0.57	1.01	0.86	1.08	1.44	1.45	0	0.32	0.25	0.2	0.25	0.62	0.7
22	14.4	81.4	151	144	184	311	397	155	105	62.1	49.4	41.1	141	156
23	0.5	4.84	8.73	9.73	14	28.2	39.1	18.7	6.38	3.36	2.48	2.8	11.5	12
24	0	1.02	2.14	1.77	2.42	3.75	3.68	0	0.48	0.25	0.14	0.19	1.31	1.48
25	0	0.08	0.23	0.44	0.77	2.01	1.74	0	0.12	0	0	0	0.45	0.51
26	0	0.67	1.61	1.48	1.4	1.67	2.84	0	0.24	0.21	0.1	0.2	0.86	0.95
27	0	1.22	2.33	2.23	3.31	6.03	8.47	3.44	1.23	0.21	0.17	0.26	2.4	2.57
28	0	1.58	1.41	1.49	1.89	2.65	2.76	0	0.41	0.43	0.42	0.49	1.12	1.46
29	0	0.91	1.14	1.06	1.29	2.24	2.08	0	0.4	0.24	0.14	0.19	0.8	0.93
30	0	1.96	3.66	3.92	4.68	9.82	14.4	0.31	0.65	0.16	0.09	0.07	3.29	3.7
31	4.76	57	101	98.9	122	200	258	51.8	58.7	35.6	28.5	26.1	86.5	99.7
32	0	2.64	3.53	3.38	4.16	7.19	9.38	1.3	1.61	0.88	1.08	1	3	3.42
33	16.5	107	184	194	230	363	408	167	111	67.3	53.9	53.1	162	177
34	0	0.19	0.55	0.85	1.77	2.02	4.78	0	0.09	0.03	0.01	0.18	0.86	0.92
35	0	1.83	6.12	7.54	12.6	20.9	25.8	1.46	1.78	0.43	0.16	1.65	6.62	7.25
36	0	1.34	1.96	1.99	2.6	4.3	5.62	0.15	0.65	0.16	0.09	0.07	1.56	1.87
37	0	18.9	36.8	36	46.7	74.1	100	24.1	14.2	4.2	2.8	5.4	30.1	33.3
38	5.95	26.7	49.9	45.1	62	107	131	65.9	32.8	21.8	15.5	15	48	52.4
39	2.13	7.85	9.63	11	12.5	21	19.9	11.8	6.57	5.25	3.21	2.45	9.41	9.5
40	0	0.7	1.04	1.25	1.45	2.22	2.8	1.03	0.64	0.43	0.26	0.32	1.01	1.14
41	4.11	14.1	26.1	29.7	39	61.5	86.9	43	16	10.2	7.26	7.06	28.6	29.7
42	0	8.81	17.2	18.8	29.1	47.1	59.5	7.5	12.8	5.92	3.92	4.93	17.8	20.7
43	0	0.03	0.25	0.59	0.82	0.71	0.58	0	0.36	0.15	0.04	0.02	0.29	0.34
44	0	0.04	0.25	0.53	0.45	0.41	0.33	0	0.12	0.06	0.06	0.09	0.19	0.22
45	0	0.44	0.5	0.42	0.43	0.71	0.83	0.07	0.45	0.33	0.29	0.38	0.4	0.49
46	3.32	6.16	7.9	7.73	8.47	11.4	15.9	10.6	5.82	4.35	3.91	4.26	7.47	7.8
47	0	36.3	68.7	74.8	102	164	213	47.2	36.3	14.8	9.4	14.4	64.7	72.1
48	0	0.98	1.76	1.62	2.28	2.59	2.22	0	0.36	0.24	0.13	0.21	1.02	1.16
49	0	0.44	0.63	0.6	0.73	1.78	2.98	2.07	1.68	0.62	0.25	0.16	0.99	1.09
50	0	54.1	97.5	94.8	119	188	237	48.2	44.3	19.4	14.3	20.3	77.6	88.4
51	0	1.52	1.97	2.19	1.48	1.81	1.73	0	1.11	1.1	1.07	1.19	1.26	1.51
52	0.84	1.41	1.68	1.92	1.78	2.15	3.38	2.22	1.44	1.09	0.95	0.72	1.63	1.71
53	0	0.81	2	2.12	3.23	4.93	8.22	0	1.01	0.2	0.26	0.18	1.9	2.62

Output: Subbasin.csv

KRB area1: slope 0-5%
KRB flow1: 30-year average flow (missing data filled in)
KRB irrigation1: 100 mm in Oct and 150 mm in May

Sub-basin data

Parameter	Sub-basin	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
available flow (m^3/s)	1	2.4	2.92	5.34	3.54	4.9	7.11	8.65	6.33	2.54	1.97	1.53	1.71	4.07
actual av.flow (m^3/s)	1	2.29	2.46	5.22	3.23	4.78	7.11	8.65	6.33	2.5	1.97	1.41	1.45	3.95
outflow after (m^3/s)	1	2.01	2.46	5.22	3.23	4.78	7.11	8.65	5.91	2.5	1.97	1.41	1.45	3.89
irrigation need (mm)	1	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	1	7.51	0	0	0	0	0	0	7.51	0	0	0	0	15.02
irrigated area (km^2)	1	7.51	0	0	0	0	0	0	7.51	0	0	0	0	7.51
available flow (m^3/s)	2	16.88	26.66	42.9	43.98	56.59	91.67	113.4	77.77	29.89	17.9	14.37	15.02	45.48
actual av.flow (m^3/s)	2	6.33	22.46	41.92	40.14	55.22	91.67	113.4	62.26	29.38	17.9	13.28	12.72	42.09
outflow after (m^3/s)	2	5.2	22.46	41.92	40.14	55.22	91.67	113.4	60.55	29.38	17.9	13.28	12.72	41.85
irrigation need (mm)	2	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	2	30.47	0	0	0	0	0	0	30.47	0	0	0	0	60.94
irrigated area (km^2)	2	30.47	0	0	0	0	0	0	30.47	0	0	0	0	30.47
available flow (m^3/s)	3	0.29	0.47	0.51	0.56	0.62	0.88	1.03	0.64	0.35	0.22	0.19	0.2	0.5
actual av.flow (m^3/s)	3	0.02	0.47	0.51	0.56	0.62	0.88	1.03	0.64	0.24	0.21	0.1	0.2	0.46
outflow after (m^3/s)	3	0	0.47	0.51	0.56	0.62	0.88	1.03	0.03	0.24	0.21	0.1	0.2	0.4
irrigation need (mm)	3	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	3	10.84	0	0	0	0	0	0	10.84	0	0	0	0	21.68
irrigated area (km^2)	3	0.54	0	0	0	0	0	0	10.84	0	0	0	0	0.54
available flow (m^3/s)	4	0.16	0.14	0.24	0.21	0.3	0.67	1.75	1.64	0.57	0.17	0.09	0.15	0.51
actual av.flow (m^3/s)	4	0.12	0.14	0.24	0.21	0.3	0.67	1.75	1.64	0.37	0.06	0.06	0.09	0.47
outflow after (m^3/s)	4	0.12	0.14	0.24	0.21	0.3	0.67	1.75	1.64	0.37	0.06	0.06	0.09	0.47
irrigation need (mm)	4	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	4	0	0	0	0	0	0	0	0	0	0	0	0	0
irrigated area (km^2)	4	0	0	0	0	0	0	0	0	0	0	0	0	0
available flow (m^3/s)	5	0.78	1.71	3.54	3.49	4.34	9.63	13.38	8.06	2.16	0.91	0.54	0.2	4.06
actual av.flow (m^3/s)	5	0.76	1.71	3.54	3.49	4.34	9.63	13.38	7.15	2.16	0.91	0.54	0.2	3.98
outflow after (m^3/s)	5	0	1.71	3.54	3.49	4.34	9.63	13.38	2.12	2.16	0.91	0.54	0.2	3.49
irrigation need (mm)	5	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	5	89.88	0	0	0	0	0	0	89.88	0	0	0	0	179.8
irrigated area (km^2)	5	20.36	0	0	0	0	0	0	89.88	0	0	0	0	20.36
available flow (m^3/s)	6	1.46	1.58	2.23	1.79	2.06	4.95	3.06	1.8	0.41	0.43	0.42	0.49	1.72
actual av.flow (m^3/s)	6	0.35	1.58	2.23	1.79	2.06	4.95	3.06	0.06	0.41	0.43	0.42	0.49	1.48
outflow after (m^3/s)	6	0	1.58	2.23	1.79	2.06	4.95	3.06	0	0.41	0.43	0.42	0.49	1.45
irrigation need (mm)	6	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	6	40.35	0	0	0	0	0	0	40.35	0	0	0	0	80.7
irrigated area (km^2)	6	9.37	0	0	0	0	0	0	1.07	0	0	0	0	1.07

Output: Subbasin.csv (continued).

KRB area1: slope 0-5%
KRB flow1: 30-year average flow (missing data filled in)
KRB irrigation1: 100 mm in Oct and 150 mm in May

Sub-basin data

Parameter	**Sub-basin**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Annual**
vailable flow (m^3/s)	7	1.33	2.08	2.79	1.88	2	2.4	2.41	1.68	0.94	0.85	0.87	0.95	1.68
actual av.flow (m^3/s)	7	1.27	1.75	2.73	1.72	1.95	2.4	2.41	1.68	0.92	0.85	0.8	0.8	1.61
outflow after (m^3/s)	7	0	1.75	2.73	1.72	1.95	2.4	2.41	0	0.92	0.85	0.8	0.8	1.36
irrigation need (mm)	7	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	7	225	0	0	0	0	0	0	225	0	0	0	0	449.9
irrigated area (km^2)	7	34.05	0	0	0	0	0	0	30	0	0	0	0	30
available flow (m^3/s)	8	0.05	0.27	0.32	0.34	0.78	1.27	1.17	0.47	0.15	0.06	0.02	0.08	0.41
actual av.flow (m^3/s)	8	0.05	0.27	0.32	0.34	0.78	1.27	1.17	0.47	0.15	0.06	0.02	0.08	0.41
outflow after (m^3/s)	8	0.02	0.27	0.32	0.34	0.78	1.27	1.17	0.43	0.15	0.06	0.02	0.08	0.41
irrigation need (mm)	8	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	8	0.79	0	0	0	0	0	0	0.79	0	0	0	0	1.58
irrigated area (km^2)	8	0.79	0	0	0	0	0	0	0.79	0	0	0	0	0.79
available flow (m^3/s)	9	0.27	1.38	1.6	1.59	1.83	3.28	4.2	2.23	0.43	0.16	0.13	0.16	1.43
actual av.flow (m^3/s)	9	0.27	1.34	1.6	1.59	1.83	3.28	4.2	2.23	0.43	0.16	0.09	0.07	1.42
outflow after (m^3/s)	9	0	1.34	1.6	1.59	1.83	3.28	4.2	0	0.43	0.16	0.09	0.07	1.21
irrigation need (mm)	9	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	9	77.1	0	0	0	0	0	0	77.1	0	0	0	0	154.2
irrigated area (km^2)	9	7.23	0	0	0	0	0	0	39.82	0	0	0	0	7.23
available flow (m^3/s)	10	5.56	7.69	10.67	10.57	13.23	19.58	23.05	16.52	9.11	6.43	4.68	4.96	10.98
actual av.flow (m^3/s)	10	5.13	7.69	10.67	10.39	13.23	19.58	23.05	15.83	9.11	6.43	4.68	4.96	10.87
outflow after (m^3/s)	10	0.31	7.69	10.67	10.39	13.23	19.58	23.05	8.6	9.11	6.43	4.68	4.96	9.85
irrigation need (mm)	10	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	10	129.1	0	0	0	0	0	0	129.1	0	0	0	0	258.3
irrigated area (km^2)	10	129.1	0	0	0	0	0	0	129.1	0	0	0	0	129.1
available flow (m^3/s)	11	0.43	0.79	1.29	1.28	2.24	3.3	4.53	2.87	0.64	0.32	0.24	0.43	1.52
actual av.flow (m^3/s)	11	0.43	0.79	1.29	1.28	2.24	3.3	4.53	2.87	0.64	0.32	0.24	0.43	1.52
outflow after (m^3/s)	11	0	0.79	1.29	1.28	2.24	3.3	4.53	2.18	0.64	0.32	0.24	0.43	1.43
irrigation need (mm)	11	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	11	12.26	0	0	0	0	0	0	12.26	0	0	0	0	24.52
irrigated area (km^2)	11	11.52	0	0	0	0	0	0	12.26	0	0	0	0	11.52
available flow (m^3/s)	12	1.36	1.49	2.2	1.87	1.93	3.84	6.24	6.45	3.72	2.63	1.84	1.67	2.94
actual av.flow (m^3/s)	12	1.36	1.49	2.2	1.87	1.93	3.84	6.24	6.45	3.72	2.63	1.84	1.67	2.94
outflow after (m^3/s)	12	1.36	1.49	2.2	1.87	1.93	3.84	6.24	6.44	3.72	2.63	1.84	1.67	2.94
irrigation need (mm)	12	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	12	0.13	0	0	0	0	0	0	0.13	0	0	0	0	0.26
irrigated area (km^2)	12	0.13	0	0	0	0	0	0	0.13	0	0	0	0	0.13
available flow (m^3/s)	13	3.42	6.63	9.47	5.48	7.12	9.46	8.05	5.22	3.86	2.43	2.1	2.53	5.47

Output: Subbasin.csv (continued).

KRB area1: slope 0-5%
KRB flow1: 30-year average flow (missing data filled in)
KRB irrigation1: 100 mm in Oct and 150 mm in May

Sub-basin data

Parameter	Sub-basin	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
actual av.flow (m³/s)	13	1.96	6.63	9.47	5.48	7.12	9.46	8.05	3.42	3.86	2.43	2.1	2.53	5.19
outflow after (m³/s)	13	0	6.63	9.47	5.48	7.12	9.46	8.05	0	3.86	2.43	2.1	2.53	4.74
irrigation need (mm)	13	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km²)	13	221.7	0	0	0	0	0	0	221.7	0	0	0	0	443.3
irrigated area (km²)	13	52.5	0	0	0	0	0	0	61.07	0	0	0	0	52.5
available flow (m³/s)	14	0.36	1.35	2.64	2.28	2.93	6.34	10.47	5.74	1.45	0.55	0.34	0.54	2.91
actual av.flow (m³/s)	14	0.36	1.35	2.64	2.28	2.93	6.34	10.47	5.74	1.45	0.55	0.34	0.54	2.91
outflow after (m³/s)	14	0	1.35	2.64	2.28	2.93	6.34	10.47	4.43	1.45	0.55	0.34	0.54	2.77
irrigation need (mm)	14	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km²)	14	23.38	0	0	0	0	0	0	23.38	0	0	0	0	46.76
irrigated area (km²)	14	9.64	0	0	0	0	0	0	23.38	0	0	0	0	9.64
available flow (m³/s)	15	2.91	9.25	16.88	17.89	21.94	32.44	43.35	24.12	6.02	3.03	2.19	3.06	15.2
actual av.flow (m³/s)	15	0.73	9.25	16.88	17.89	21.94	32.44	43.35	5.62	6.02	2.25	1.57	3.06	13.32
outflow after (m³/s)	15	0	9.25	16.88	17.89	21.94	32.44	43.35	3.24	6.02	2.25	1.57	3.06	13.06
irrigation need (mm)	15	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km²)	15	42.52	0	0	0	0	0	0	42.52	0	0	0	0	85.04
irrigated area (km²)	15	19.44	0	0	0	0	0	0	42.52	0	0	0	0	19.44
available flow (m³/s)	16	1.36	2.54	4.37	4.75	8.07	13.87	16.6	9.05	3.47	2	1.38	1.49	5.72
actual av.flow (m³/s)	16	0.97	2.54	4.37	4.75	8.07	13.87	16.6	6.61	3.47	2	1.38	1.49	5.48
outflow after (m³/s)	16	0	2.54	4.37	4.75	8.07	13.87	16.6	0	3.47	2	1.38	1.49	4.84
irrigation need (mm)	16	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km²)	16	272.3	0	0	0	0	0	0	272.3	0	0	0	0	544.7
irrigated area (km²)	16	25.98	0	0	0	0	0	0	118	0	0	0	0	25.98
available flow (m³/s)	17	0.12	0.91	1.46	1.71	2.05	2.69	5.37	2.64	0.37	0.06	0.06	0.09	1.45
actual av.flow (m³/s)	17	0.12	0.91	1.46	1.71	2.05	2.69	5.37	2.64	0.37	0.06	0.06	0.09	1.45
outflow after (m³/s)	17	0	0.91	1.46	1.71	2.05	2.69	5.37	0.53	0.37	0.06	0.06	0.09	1.26
irrigation need (mm)	17	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km²)	17	37.68	0	0	0	0	0	0	37.68	0	0	0	0	75.36
irrigated area (km²)	17	3.21	0	0	0	0	0	0	37.68	0	0	0	0	3.21
available flow (m³/s)	18	4.14	8.81	17.54	19.07	30.24	48.65	63.57	35.06	13.3	6.1	3.95	4.93	21.19
actual av.flow (m³/s)	18	0	8.81	17.54	19.07	30.24	48.65	63.57	7.5	13.3	6.1	3.95	4.93	18.5
outflow after (m³/s)	18	0	8.81	17.54	19.07	30.24	48.65	63.57	5.68	13.3	6.1	3.95	4.93	18.34
irrigation need (mm)	18	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km²)	18	32.36	0	0	0	0	0	0	32.36	0	0	0	0	64.72
irrigated area (km²)	18	0	0	0	0	0	0	0	32.36	0	0	0	0	0
available flow (m³/s)	19	0.65	2.08	3.74	3.79	3.83	5.13	6.37	4.79	1.41	0.49	0.47	0.53	2.77
actual av.flow (m³/s)	19	0.42	2.08	3.74	3.79	3.83	5.13	6.37	4.01	1.41	0.49	0.47	0.53	2.68

Output: Subbasin.csv (continued).

KRB area1: slope 0-5%
KRB flow1: 30-year average flow (missing data filled in)
KRB irrigation1: 100 mm in Oct and 150 mm in May

Sub-basin data

Parameter	**Sub-basin**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Annual**
outflow after (m^3/s)	19	0	2.08	3.74	3.79	3.83	5.13	6.37	2.62	1.41	0.49	0.47	0.53	2.53
irrigation need (mm)	19	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	19	24.89	0	0	0	0	0	0	24.89	0	0	0	0	49.78
irrigated area (km^2)	19	11.25	0	0	0	0	0	0	24.89	0	0	0	0	11.25
available flow (m^3/s)	20	2.26	4.18	10.24	8.96	11.31	27.94	41.86	27.07	6.64	2.19	1.3	0.71	12.05
actual av.flow (m^3/s)	20	1.13	4.18	10.24	8.96	11.31	27.94	41.86	21.05	6.64	1.63	0.93	0.71	11.36
outflow after (m^3/s)	20	0.41	4.18	10.24	8.96	11.31	27.94	41.86	19.97	6.64	1.63	0.93	0.71	11.21
irrigation need (mm)	20	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	20	19.39	0	0	0	0	0	0	19.39	0	0	0	0	38.78
irrigated area (km^2)	20	19.39	0	0	0	0	0	0	19.39	0	0	0	0	19.39
available flow (m^3/s)	21	0.23	0.57	1.01	0.86	1.08	1.44	1.45	0.78	0.32	0.25	0.2	0.25	0.7
actual av.flow (m^3/s)	21	0.23	0.57	1.01	0.86	1.08	1.44	1.45	0.78	0.32	0.25	0.2	0.25	0.7
outflow after (m^3/s)	21	0	0.57	1.01	0.86	1.08	1.44	1.45	0	0.32	0.25	0.2	0.25	0.62
irrigation need (mm)	21	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	21	43.41	0	0	0	0	0	0	43.41	0	0	0	0	86.82
irrigated area (km^2)	21	6.16	0	0	0	0	0	0	13.93	0	0	0	0	6.16
available flow (m^3/s)	22	57.3	83.7	151	144	184.1	311	403.5	273.1	109.9	67	49.4	41.1	156
actual av.flow (m^3/s)	22	14.38	83.7	151	144	184.1	311	400.7	155.3	104.8	62.05	49.4	41.1	141.3
outflow after (m^3/s)	22	14.38	81.38	151	144	184.1	311	397.3	155.3	104.8	62.05	49.4	41.1	140.8
irrigation need (mm)	22	0	100	0	0	0	0	150	0	0	0	0	0	250
irrigation area (km^2)	22	0	60.22	0	0	0	0	60.22	0	0	0	0	0	120.4
irrigated area (km^2)	22	0	60.22	0	0	0	0	60.22	0	0	0	0	0	60.22
available flow (m^3/s)	23	2.42	4.84	8.73	9.73	14.03	28.19	39.07	22.36	6.38	3.36	2.48	2.82	12
actual av.flow (m^3/s)	23	2.06	4.84	8.73	9.73	14.03	28.19	39.07	21.05	6.38	3.36	2.48	2.8	11.86
outflow after (m^3/s)	23	0.5	4.84	8.73	9.73	14.03	28.19	39.07	18.7	6.38	3.36	2.48	2.8	11.53
irrigation need (mm)	23	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	23	41.91	0	0	0	0	0	0	41.91	0	0	0	0	83.82
irrigated area (km^2)	23	41.91	0	0	0	0	0	0	41.91	0	0	0	0	41.91
available flow (m^3/s)	24	0.32	1.02	2.14	1.77	2.42	3.75	3.68	1.67	0.48	0.25	0.14	0.19	1.48
actual av.flow (m^3/s)	24	0.06	1.02	2.14	1.77	2.42	3.75	3.68	0.54	0.48	0.25	0.14	0.19	1.36
outflow after (m^3/s)	24	0	1.02	2.14	1.77	2.42	3.75	3.68	0	0.48	0.25	0.14	0.19	1.31
irrigation need (mm)	24	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	24	88.71	0	0	0	0	0	0	88.71	0	0	0	0	177.4
irrigated area (km^2)	24	1.61	0	0	0	0	0	0	9.64	0	0	0	0	1.61
available flow (m^3/s)	25	0.01	0.08	0.23	0.44	0.77	2.01	1.74	0.69	0.12	0	0	0	0.51
actual av.flow (m^3/s)	25	0.01	0.08	0.23	0.44	0.77	2.01	1.74	0.69	0.12	0	0	0	0.51
outflow after (m^3/s)	25	0	0.08	0.23	0.44	0.77	2.01	1.74	0	0.12	0	0	0	0.45

Output: Subbasin.csv (continued).

KRB area1: slope 0-5%
KRB flow1: 30-year average flow (missing data filled in)
KRB irrigation1: 100 mm in Oct and 150 mm in May

Sub-basin data

Parameter	**Sub-basin**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Annual**
irrigation need (mm)	25	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	25	34.28	0	0	0	0	0	0	34.28	0	0	0	0	68.56
irrigated area (km^2)	25	0.27	0	0	0	0	0	0	12.32	0	0	0	0	0.27
available flow (m^3/s)	26	0.02	0.67	1.61	1.48	1.4	1.67	2.84	0.91	0.24	0.21	0.1	0.26	0.95
actual av.flow (m^3/s)	26	0	0.67	1.61	1.48	1.4	1.67	2.84	0.3	0.24	0.21	0.1	0.2	0.89
outflow after (m^3/s)	26	0	0.67	1.61	1.48	1.4	1.67	2.84	0	0.24	0.21	0.1	0.2	0.86
irrigation need (mm)	26	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	26	36.84	0	0	0	0	0	0	36.84	0	0	0	0	73.68
irrigated area (km^2)	26	0	0	0	0	0	0	0	5.41	0	0	0	0	0
available flow (m^3/s)	27	0.46	1.22	2.33	2.23	3.31	6.03	8.47	4.97	1.23	0.21	0.17	0.26	2.57
actual av.flow (m^3/s)	27	0.46	1.22	2.33	2.23	3.31	6.03	8.47	4.97	1.23	0.21	0.17	0.26	2.57
outflow after (m^3/s)	27	0	1.22	2.33	2.23	3.31	6.03	8.47	3.44	1.23	0.21	0.17	0.26	2.4
irrigation need (mm)	27	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	27	27.34	0	0	0	0	0	0	27.34	0	0	0	0	54.68
irrigated area (km^2)	27	12.32	0	0	0	0	0	0	27.34	0	0	0	0	12.32
available flow (m^3/s)	28	1.11	1.66	1.41	1.49	1.89	2.65	2.76	1.74	0.73	0.62	0.57	0.99	1.46
actual av.flow (m^3/s)	28	1.1	1.58	1.41	1.49	1.89	2.65	2.76	1.05	0.41	0.43	0.42	0.49	1.3
outflow after (m^3/s)	28	0	1.58	1.41	1.49	1.89	2.65	2.76	0	0.41	0.43	0.42	0.49	1.12
irrigation need (mm)	28	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	28	51.13	0	0	0	0	0	0	51.13	0	0	0	0	102.3
irrigated area (km^2)	28	29.46	0	0	0	0	0	0	18.75	0	0	0	0	18.75
available flow (m^3/s)	29	0.26	0.91	1.14	1.06	1.29	2.24	2.08	1.13	0.4	0.24	0.2	0.23	0.93
actual av.flow (m^3/s)	29	0.26	0.91	1.14	1.06	1.29	2.24	2.08	1.13	0.4	0.24	0.14	0.19	0.92
outflow after (m^3/s)	29	0	0.91	1.14	1.06	1.29	2.24	2.08	0	0.4	0.24	0.14	0.19	0.8
irrigation need (mm)	29	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	29	290.4	0	0	0	0	0	0	290.4	0	0	0	0	580.8
irrigated area (km^2)	29	6.96	0	0	0	0	0	0	20.18	0	0	0	0	6.96
available flow (m^3/s)	30	0.37	1.96	3.66	3.92	4.68	9.82	14.44	4.79	0.65	0.16	0.09	0.07	3.7
actual av.flow (m^3/s)	30	0.06	1.96	3.66	3.92	4.68	9.82	14.44	2.11	0.65	0.16	0.09	0.07	3.45
outflow after (m^3/s)	30	0	1.96	3.66	3.92	4.68	9.82	14.44	0.31	0.65	0.16	0.09	0.07	3.29
irrigation need (mm)	30	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	30	32.14	0	0	0	0	0	0	32.14	0	0	0	0	64.28
irrigated area (km^2)	30	1.61	0	0	0	0	0	0	32.14	0	0	0	0	1.61
available flow (m^3/s)	31	31	62.2	107.3	109.7	131.7	199.6	258.4	147.6	58.7	35.6	28.5	29.5	99.7
actual av.flow (m^3/s)	31	8.43	57.02	101.1	98.92	122.2	199.6	258.4	57.26	58.7	35.6	28.5	26.13	87.23
outflow after (m^3/s)	31	4.76	57.02	101.1	98.92	122.2	199.6	258.4	51.76	58.7	35.6	28.5	26.13	86.46
irrigation need (mm)	31	100	0	0	0	0	0	0	150	0	0	0	0	250

Output: Subbasin.csv (continued).

KRB area1: slope 0-5%
KRB flow1: 30-year average flow (missing data filled in)
KRB irrigation1: 100 mm in Oct and 150 mm in May

Sub-basin data

Parameter	Sub-basin	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
irrigation area (km^2)	31	98.27	0	0	0	0	0	0	98.27	0	0	0	0	196.5
irrigated area (km^2)	31	98.27	0	0	0	0	0	0	98.27	0	0	0	0	98.27
available flow (m^3/s)	32	1.21	2.64	3.53	3.38	4.16	7.19	9.38	5.13	1.61	0.88	1.08	1	3.42
actual av.flow (m^3/s)	32	1.21	2.64	3.53	3.38	4.16	7.19	9.38	5.13	1.61	0.88	1.08	1	3.42
outflow after (m^3/s)	32	0	2.64	3.53	3.38	4.16	7.19	9.38	1.3	1.61	0.88	1.08	1	3
irrigation need (mm)	32	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	32	68.32	0	0	0	0	0	0	68.32	0	0	0	0	136.6
irrigated area (km^2)	32	32.41	0	0	0	0	0	0	68.32	0	0	0	0	32.41
available flow (m^3/s)	33	56.5	115.4	183.8	194.4	229.5	363	420.7	284.1	111.4	67.3	53.9	53.1	177.4
actual av.flow (m^3/s)	33	16.51	113.1	183.8	194.4	229.5	363	417.2	167	111.4	67.3	53.9	53.1	163.5
outflow after (m^3/s)	33	16.51	106.8	183.8	194.4	229.5	363	407.8	167	111.4	67.3	53.9	53.1	162.3
irrigation need (mm)	33	0	100	0	0	0	0	150	0	0	0	0	0	250
irrigation area (km^2)	33	0	161.6	0	0	0	0	161.6	0	0	0	0	0	323.1
irrigated area (km^2)	33	0	161.6	0	0	0	0	161.6	0	0	0	0	0	161.6
available flow (m^3/s)	34	0.01	0.19	0.55	0.85	1.77	2.02	4.78	0.45	0.09	0.03	0.01	0.41	0.92
actual av.flow (m^3/s)	34	0.01	0.19	0.55	0.85	1.77	2.02	4.78	0.45	0.09	0.03	0.01	0.18	0.9
outflow after (m^3/s)	34	0	0.19	0.55	0.85	1.77	2.02	4.78	0	0.09	0.03	0.01	0.18	0.86
irrigation need (mm)	34	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	34	51.02	0	0	0	0	0	0	51.02	0	0	0	0	102
irrigated area (km^2)	34	0.27	0	0	0	0	0	0	8.04	0	0	0	0	0.27
available flow (m^3/s)	35	0.26	1.83	6.12	7.54	12.6	20.85	25.76	8.61	1.78	0.43	0.16	1.65	7.25
actual av.flow (m^3/s)	35	0.23	1.83	6.12	7.54	12.6	20.85	25.76	8.57	1.78	0.43	0.16	1.65	7.24
outflow after (m^3/s)	35	0	1.83	6.12	7.54	12.6	20.85	25.76	1.46	1.78	0.43	0.16	1.65	6.62
irrigation need (mm)	35	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	35	126.9	0	0	0	0	0	0	126.9	0	0	0	0	253.7
irrigated area (km^2)	35	6.17	0	0	0	0	0	0	126.9	0	0	0	0	6.17
available flow (m^3/s)	36	0.31	1.34	1.96	1.99	2.6	4.3	5.62	2.83	0.71	0.3	0.21	0.36	1.87
actual av.flow (m^3/s)	36	0.04	1.34	1.96	1.99	2.6	4.3	5.62	0.6	0.65	0.16	0.09	0.07	1.61
outflow after (m^3/s)	36	0	1.34	1.96	1.99	2.6	4.3	5.62	0.15	0.65	0.16	0.09	0.07	1.56
irrigation need (mm)	36	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	36	8.12	0	0	0	0	0	0	8.12	0	0	0	0	16.24
irrigated area (km^2)	36	1.07	0	0	0	0	0	0	8.12	0	0	0	0	1.07
available flow (m^3/s)	37	4.8	18.9	36.8	36	46.7	74.1	100.2	57.2	14.2	4.2	2.8	5.4	33.32
actual av.flow (m^3/s)	37	0.41	18.9	36.8	36	46.7	74.1	100.2	28.75	14.2	4.2	2.8	5.4	30.53
outflow after (m^3/s)	37	0	18.9	36.8	36	46.7	74.1	100.2	24.08	14.2	4.2	2.8	5.4	30.1
irrigation need (mm)	37	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	37	83.52	0	0	0	0	0	0	83.52	0	0	0	0	167

Output: Subbasin.csv (continued).

KRB area1: slope 0-5%
KRB flow1: 30-year average flow (missing data filled in)
KRB irrigation1: 100 mm in Oct and 150 mm in May

Sub-basin data

Parameter	Sub-basin	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
irrigated area (km^2)	37	11	0	0	0	0	0	0	83.52	0	0	0	0	11
available flow (m^3/s)	38	19.7	29.1	52.9	50	66.8	106.5	131.2	87.1	32.8	21.8	15.5	16.9	52.41
actual av.flow (m^3/s)	38	7.21	26.68	49.86	45.08	61.95	106.5	131.2	67.78	32.8	21.8	15.5	14.97	48.3
outflow after (m^3/s)	38	5.95	26.68	49.86	45.08	61.95	106.5	131.2	65.88	32.8	21.8	15.5	14.97	48.03
irrigation need (mm)	38	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	38	33.87	0	0	0	0	0	0	33.87	0	0	0	0	67.74
irrigated area (km^2)	38	33.87	0	0	0	0	0	0	33.87	0	0	0	0	33.87
available flow (m^3/s)	39	2.24	7.88	9.63	10.98	12.46	20.98	20.1	11.79	6.89	5.67	3.21	2.45	9.5
actual av.flow (m^3/s)	39	2.13	7.88	9.63	10.98	12.46	20.98	19.96	11.76	6.57	5.25	3.21	2.45	9.42
outflow after (m^3/s)	39	2.13	7.85	9.63	10.98	12.46	20.98	19.92	11.76	6.57	5.25	3.21	2.45	9.41
irrigation need (mm)	39	0	100	0	0	0	0	150	0	0	0	0	0	250
irrigation area (km^2)	39	0	0.8	0	0	0	0	0.8	0	0	0	0	0	1.6
irrigated area (km^2)	39	0	0.8	0	0	0	0	0.8	0	0	0	0	0	0.8
available flow (m^3/s)	40	0.61	0.7	1.04	1.25	1.45	2.22	2.8	2.04	0.64	0.43	0.26	0.32	1.14
actual av.flow (m^3/s)	40	0.61	0.7	1.04	1.25	1.45	2.22	2.8	2.04	0.64	0.43	0.26	0.32	1.14
outflow after (m^3/s)	40	0	0.7	1.04	1.25	1.45	2.22	2.8	1.03	0.64	0.43	0.26	0.32	1.01
irrigation need (mm)	40	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	40	18.09	0	0	0	0	0	0	18.09	0	0	0	0	36.18
irrigated area (km^2)	40	16.34	0	0	0	0	0	0	18.09	0	0	0	0	16.34
available flow (m^3/s)	41	8.66	14.07	26.05	30.25	38.99	61.53	86.93	50.61	15.99	10.23	7.26	7.06	29.71
actual av.flow (m^3/s)	41	5.18	14.07	26.05	29.74	38.99	61.53	86.93	44.61	15.99	10.23	7.26	7.06	28.87
outflow after (m^3/s)	41	4.11	14.07	26.05	29.74	38.99	61.53	86.93	43.02	15.99	10.23	7.26	7.06	28.64
irrigation need (mm)	41	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	41	28.52	0	0	0	0	0	0	28.52	0	0	0	0	57.04
irrigated area (km^2)	41	28.52	0	0	0	0	0	0	28.52	0	0	0	0	28.52
available flow (m^3/s)	42	4.47	9.17	17.15	18.82	29.13	47.1	59.48	35.87	12.79	5.92	3.92	5.22	20.67
actual av.flow (m^3/s)	42	2.24	8.81	17.15	18.82	29.13	47.1	59.48	18.04	12.79	5.92	3.92	4.93	18.92
outflow after (m^3/s)	42	0	8.81	17.15	18.82	29.13	47.1	59.48	7.5	12.79	5.92	3.92	4.93	17.83
irrigation need (mm)	42	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	42	188.2	0	0	0	0	0	0	188.2	0	0	0	0	376.5
irrigated area (km^2)	42	60	0	0	0	0	0	0	188.2	0	0	0	0	60
available flow (m^3/s)	43	0	0.03	0.25	0.59	0.82	0.71	0.58	0.51	0.36	0.15	0.04	0.02	0.34
actual av.flow (m^3/s)	43	0	0.03	0.25	0.59	0.82	0.71	0.58	0.51	0.36	0.15	0.04	0.02	0.34
outflow after (m^3/s)	43	0	0.03	0.25	0.59	0.82	0.71	0.58	0	0.36	0.15	0.04	0.02	0.29
irrigation need (mm)	43	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	43	19.17	0	0	0	0	0	0	19.17	0	0	0	0	38.34
irrigated area (km^2)	43	0	0	0	0	0	0	0	9.11	0	0	0	0	0

Output: Subbasin.csv (continued).

KRB area1: slope 0-5%
KRB flow1: 30-year average flow (missing data filled in)
KRB irrigation1: 100 mm in Oct and 150 mm in May

Sub-basin data

Parameter	**Sub-basin**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Annual**
available flow (m^3/s)	44	0.07	0.04	0.25	0.53	0.45	0.41	0.33	0.26	0.12	0.06	0.06	0.09	0.22
actual av.flow (m^3/s)	44	0.07	0.04	0.25	0.53	0.45	0.41	0.33	0.26	0.12	0.06	0.06	0.09	0.22
outflow after (m^3/s)	44	0	0.04	0.25	0.53	0.45	0.41	0.33	0	0.12	0.06	0.06	0.09	0.19
irrigation need (mm)	44	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	44	19.8	0	0	0	0	0	0	19.8	0	0	0	0	39.6
irrigated area (km^2)	44	1.87	0	0	0	0	0	0	4.64	0	0	0	0	1.87
available flow (m^3/s)	45	0.36	0.44	0.5	0.42	0.43	0.71	0.83	0.53	0.45	0.44	0.41	0.38	0.49
actual av.flow (m^3/s)	45	0.31	0.44	0.5	0.42	0.43	0.71	0.83	0.53	0.45	0.33	0.29	0.38	0.47
outflow after (m^3/s)	45	0	0.44	0.5	0.42	0.43	0.71	0.83	0.07	0.45	0.33	0.29	0.38	0.4
irrigation need (mm)	45	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	45	8.29	0	0	0	0	0	0	8.29	0	0	0	0	16.58
irrigated area (km^2)	45	8.29	0	0	0	0	0	0	8.29	0	0	0	0	8.29
available flow (m^3/s)	46	4.88	6.16	7.9	7.73	8.47	11.43	15.88	12.9	5.82	4.35	3.91	4.3	7.8
actual av.flow (m^3/s)	46	4.88	6.16	7.9	7.73	8.47	11.43	15.88	12.89	5.82	4.35	3.91	4.26	7.8
outflow after (m^3/s)	46	3.32	6.16	7.9	7.73	8.47	11.43	15.88	10.56	5.82	4.35	3.91	4.26	7.47
irrigation need (mm)	46	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	46	41.63	0	0	0	0	0	0	41.63	0	0	0	0	83.26
irrigated area (km^2)	46	41.63	0	0	0	0	0	0	41.63	0	0	0	0	41.63
available flow (m^3/s)	47	13.2	36.3	68.7	74.8	102.2	164.3	213.1	121.1	36.3	14.8	9.4	14.4	72.11
actual av.flow (m^3/s)	47	2.44	36.3	68.7	74.8	102.2	164.3	213.1	53.76	36.3	14.8	9.4	14.4	65.48
outflow after (m^3/s)	47	0	36.3	68.7	74.8	102.2	164.3	213.1	47.2	36.3	14.8	9.4	14.4	64.71
irrigation need (mm)	47	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	47	117.1	0	0	0	0	0	0	117.1	0	0	0	0	234.2
irrigated area (km^2)	47	65.35	0	0	0	0	0	0	117.1	0	0	0	0	65.35
available flow (m^3/s)	48	0.57	0.98	1.76	1.62	2.28	2.59	2.22	1.07	0.36	0.24	0.13	0.21	1.16
actual av.flow (m^3/s)	48	0.57	0.98	1.76	1.62	2.28	2.59	2.22	1.07	0.36	0.24	0.13	0.21	1.16
outflow after (m^3/s)	48	0	0.98	1.76	1.62	2.28	2.59	2.22	0	0.36	0.24	0.13	0.21	1.02
irrigation need (mm)	48	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	48	25.74	0	0	0	0	0	0	25.74	0	0	0	0	51.48
irrigated area (km^2)	48	15.27	0	0	0	0	0	0	19.11	0	0	0	0	15.27
available flow (m^3/s)	49	0.28	0.44	0.63	0.6	0.73	1.78	2.98	2.89	1.68	0.62	0.25	0.16	1.09
actual av.flow (m^3/s)	49	0.28	0.44	0.63	0.6	0.73	1.78	2.98	2.89	1.68	0.62	0.25	0.16	1.09
outflow after (m^3/s)	49	0	0.44	0.63	0.6	0.73	1.78	2.98	2.07	1.68	0.62	0.25	0.16	0.99
irrigation need (mm)	49	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	49	14.69	0	0	0	0	0	0	14.69	0	0	0	0	29.38
irrigated area (km^2)	49	7.5	0	0	0	0	0	0	14.69	0	0	0	0	7.5
available flow (m^3/s)	50	21	57.2	97.8	95.5	134.5	187.6	236.7	136.8	44.3	19.4	14.3	20.3	88.4

Output: Subbasin.csv (continued).

KRB area1: slope 0-5%
KRB flow1: 30-year average flow (missing data filled in)
KRB irrigation1: 100 mm in Oct and 150 mm in May

Sub-basin data

Parameter	Sub-basin	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
actual av.flow (m^3/s)	50	3.81	54.09	97.48	94.81	118.9	187.6	236.7	56.61	44.3	19.4	14.3	20.3	78.59
outflow after (m^3/s)	50	0	54.09	97.48	94.81	118.9	187.6	236.7	48.16	44.3	19.4	14.3	20.3	77.55
irrigation need (mm)	50	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	50	150.9	0	0	0	0	0	0	150.9	0	0	0	0	301.9
irrigated area (km^2)	50	102.1	0	0	0	0	0	0	150.9	0	0	0	0	102.1
available flow (m^3/s)	51	1.33	1.61	1.98	2.21	1.68	1.81	1.73	1.34	1.11	1.1	1.07	1.19	1.51
actual av.flow (m^3/s)	51	1.33	1.52	1.97	2.19	1.48	1.81	1.73	1.34	1.11	1.1	1.07	1.19	1.49
outflow after (m^3/s)	51	0	1.52	1.97	2.19	1.48	1.81	1.73	0	1.11	1.1	1.07	1.19	1.26
irrigation need (mm)	51	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	51	86.15	0	0	0	0	0	0	86.15	0	0	0	0	172.3
irrigated area (km^2)	51	35.62	0	0	0	0	0	0	23.93	0	0	0	0	23.93
available flow (m^3/s)	52	1.08	1.49	1.69	1.93	2.01	2.15	3.38	2.58	1.44	1.09	0.95	0.72	1.71
actual av.flow (m^3/s)	52	1.08	1.41	1.68	1.92	1.78	2.15	3.38	2.58	1.44	1.09	0.95	0.72	1.68
outflow after (m^3/s)	52	0.84	1.41	1.68	1.92	1.78	2.15	3.38	2.22	1.44	1.09	0.95	0.72	1.63
irrigation need (mm)	52	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	52	6.43	0	0	0	0	0	0	6.43	0	0	0	0	12.86
irrigated area (km^2)	52	6.43	0	0	0	0	0	0	6.43	0	0	0	0	6.43
available flow (m^3/s)	53	0.25	0.81	2	2.12	3.23	4.93	8.22	8.27	1.01	0.2	0.26	0.18	2.62
actual av.flow (m^3/s)	53	0.24	0.81	2	2.12	3.23	4.93	8.22	7.82	1.01	0.2	0.26	0.18	2.58
outflow after (m^3/s)	53	0	0.81	2	2.12	3.23	4.93	8.22	0	1.01	0.2	0.26	0.18	1.9
irrigation need (mm)	53	100	0	0	0	0	0	0	150	0	0	0	0	250
irrigation area (km^2)	53	197.9	0	0	0	0	0	0	197.9	0	0	0	0	395.7
irrigated area (km^2)	53	6.43	0	0	0	0	0	0	139.6	0	0	0	0	6.43

Output: Basin.csv.

KRB area1: slope 0-5%
KRB flow1: 30-year average flow (missing data filled in)
KRB irrigation1: 100 mm in Oct and 150 mm in May

Basin totals

Parameter	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
available flow (m^3/s)	56.5	115.4	183.8	194.4	229.5	363	420.7	284.1	111.4	67.3	53.9	53.1	177.36
outflow after (m^3/s)	16.51	106.81	183.8	194.4	229.5	363	407.82	167.04	111.4	67.3	53.9	53.1	162.26
irrigation area (km^2)	3336.4	222.58	0	0	0	0	222.58	3336.4	0	0	0	0	
irrigated area (km^2)	1071.2	222.58	0	0	0	0	222.58	2090.2	0	0	0	0	
irrigation vol.(million m^3/year or month)	107.12	22.258	0	0	0	0	33.387	313.53	0	0	0	0	476.29

CGIAR Challenge Program on
WATER & FOOD

Benchmark river basins

The CP Water & Food is a research, extension and capacity building program aims at increasing the productivity of water used for agriculture. The CP Water & Food is managed by an 18-member consortium, composed of five CGIAR/Future Harvest Centres, six National Agricultural Research and Extension Systems (NARES) institutions, four Advanced Research Institutes (ARIs) and three international NGOs. The project is implemented at nine river basins (shown above) across the developing world. The Karkheh River Basin (KRB) in western Iran is one of the selected basins. The program's interlocking goals are to allow more food to be produced with the same amount of water that is used in agriculture today, as populations expand over the coming twenty years. And, do this in a way that decreases malnourishment and rural poverty, improves people's health and maintains environmental sustainability.

Improving On-farm Agricultural Water Productivity in the Karkheh River Basin Project (CPWF PN 8)

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