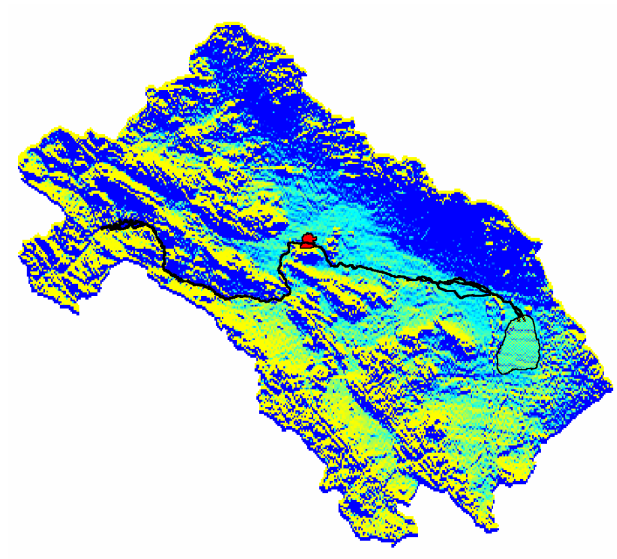
Sustainable Irrigation and Water Management in the Zayandeh Rud Basin, Iran

Water Resources Development and Water Utilization in the Zayandeh Rud basin, Iran

H. Murray-Rust, H.R. Salemi and P.Droogers,



Research Report No. 14

Iranian **A**gricultural **E**ngineering **R**esearch **I**nstitute
Esfahan **A**gricultural **R**esearch **C**enter
International **W**ater **M**anagement **I**nstitute

IAERI EARC IWMI

Murray-Rust, H., H.R. Salemi and P. Droogers 2002. Water Resources Development and Water Utilization in the Zayandeh Rud basin, Iran. IAERI-IWMI Research Reports 14
.
Keywords: Water resources development, basin, supply and demand, drought, water scarcity, water allocation

H. Murray Rust, International Water Management Institute
H.R. Salemi, Esfahan Agricultural Research Center
Peter Droogers, International Water Management Institute

The IAERI-EARC-IWMI collaborative project is a multi-year program of research, training and information dissemination fully funded by the Government of the Islamic Republic of Iran that commenced in 1998. The main purpose of the project is to foster integrated approaches to managing water resources at basin, irrigation system and farm levels, and thereby contribute to promoting and sustaining agriculture in the country. The project is currently using the Zayendeh Rud basin in Esfahan province as a pilot study site. This research report series is intended as a means of sharing the results and findings of the project with a view to obtaining critical feedback and suggestions that will lead to strengthening the project outputs. Comments should be addressed to:

Iranian Agricultural Engineering Research Institute (IAERI)
PO Box 31585-845, Karaj, Iran.
Phone: +98-261-241116, fax: +98-261-226277
e-mail: maryam.sal@neda.net
Esfahan Agricultural Research Center (EARC)
PO Box 81785-19, Esfahan, Iran
Phone: +98-31-757201-2, fax: +98-31-759007
e-mail: agresor@cc.iut.ac.ir

International Water Management Institute (IWMI)
PO Box 2075, Colombo, Sri Lanka
Phone: +94-1-867404, fax +94-1-866854
e-mail: iwmi@cgiar.org

Water Resources Development and Water Utilization in the Zayandeh Rud basin, Iran

Hammond Murray-Rust[1], H.R. Salemi and P. Droogers

Abstract

Analysis of water supplies and demand over the past 50 years in the Zayandeh Rud basin indicate that despite large investments in water resources development the basin remains just as vulnerable to drought as it always has been. During the period of analysis two transbasin diversions and a storage reservoir have been constructed which have more or less doubled the annual supply to water to the basin. But with each water resource development extractive capacity for irrigation, urban and industrial use has increased by the same amount, so that all new water is allocated as soon as it is available. The most recent developments, since 1980, have actually increased vulnerability to drought because extractive capacity is greater than average flow into the basin. Whenever demand exceeds supply all water is extracted from the basin and the tail end dries up. During the past 50 years flows into the salt pan at the downstream end of the basin have been negligible for more than half the time. Prospects for the future are bleak because once the current phase of water resources development is completed no further water supplies are likely, but demand continues to rise at a steady rate. Ultimately agriculture will have to concede water to urban, industrial and environmental demands.

1. Water Resources Development in the basin context

In every river basin there is a sequential development of water resources that should ideally keep pace with demand or attempt to anticipate future demand. In many cases the initial developments are relatively small scale, meeting local needs, and are often constructed by communities rather than central government. This is the phase of acquisition defined by Molden (2001) where the level is water resources development is only a small fraction of potentially available water.

[1] Murray-Rust and Droogers: Principal Researchers, IWMI, P.O. Box 2075, Colombo;
Salemi: Researcher, Esfahan Agricultural Research Center, Esfahan, Iran

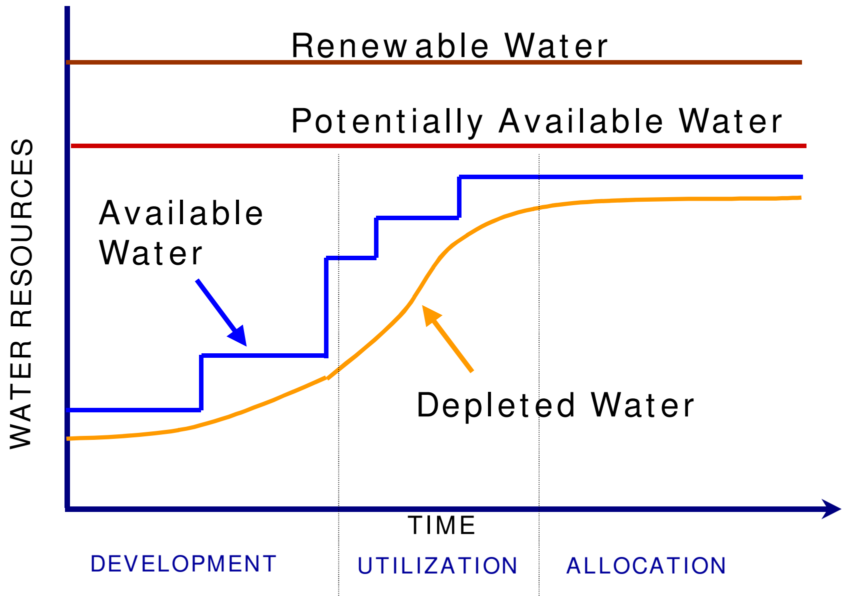


Figure 1: Phases in overall basin development

The second stage of development is one that occurs when it is no longer possible for communities acting in isolation to construct new water acquisition infrastructure. The responsibility for water resources development passes to government agencies, and over time the concern changes more from water acquisition to management of water. While resources are not in particularly short supply, it gradually becomes necessary to focus on management to ensure that as the supply:demand ratio becomes smaller, water is used as effectively as possible.

The final phase of basin development occurs when supply: demand ratio approaches parity, and the basin starts to close. At this point the main concern with basin management is allocation between sectors and for improving water productivity within each sector within the total amount allocated. In this phase there is almost no spare water available.

Ideally this should be a smooth progression. However, examination of the development of water resources in the Zayandeh Rud basin in central Iran show that the sequence of development can be much more complex.

2. Water Resources Development in the Zayandeh Rud basin

The Zayandeh Rud, "the river that renews itself", has been the basis for a long and diverse culture based around the city of Esfahan. Fed primarily by snowmelt in the Zagros mountains, the river runs eastwards into increasingly arid areas, finally culminating in the Gavkhouni swamp 150 km east of Esfahan city. Geologically the Zayandeh Rud basin is always a closed basin as the swamp is an inland salt pan, but functionally as long as water flows into the swamp we can treat the basin as an open basin. A more detailed desription of the hydrology of the basin is provided by Murray-Rust et al. (2000).

a) Phase I: Water resources development before 1953

Until 1953 water resources development were confined primarily to small diversion structures that provided irrigation water to riverine irrigation systems in the central part of the valley. Irrigation was primarily confined to the spring and early summer when snowmelt provided sufficient discharge, but was of minimal importance in full summer and autumn. Cropping patterns reflected water availability, with wheat, barley and fruit trees being the main crops grown.

The importance of these small scale diversions should not be underemphasized. Climatic conditions in the main part of the basin do not permit significant crop growth without irrigation: annual rainfall is between 100 and 150 mm, falling mostly in winter months when it is cold, and summers are hot (35C) and very dry. Yet in 1500 Esfahan was one of the ten largest cities in the world and supported a thriving economy. All of this is attributable to the small-scale diversion systems along the river.

By the Second World War, however, the water resources were clearly becoming under pressure. There is no reliable information about discharges along the river in this period, but subsequent events indicate that water resources were indeed scarce. Based on analyses presented later, the average annual yield of the Zayandeh Rud is approximately 800 MCM.

b) Phase II: First Transbasin Diversion

The first major water resources development was completed in 1952 when a tunnel was constructed from the Kurang river west of the Zayandeh Rud watershed into the Zayendeh Rud itself. This tunnel has a capacity of approximately 337 MCM per year, or about 40% of the normal annual yield of the Zayandeh Rud itself.

The Kurang River is fed through karstic springs and snowmelt and eventually flows into the Persian Gulf. It is therefore a suitable option to divert flows into the arid interior of the country to supplement eastward flowing rivers. However, it also has significant seasonal variations and thus cannot provide full discharge through the tunnel in the water-short summer season. Much of the additional water is therefore available in winter and spring when the Zayandeh Rud itself has relatively favorable water conditions.

c) Phase III: Chadegan Reservoir

In some years there is significant snowfall in the Zagros mountains that results in serious spring flooding. To minimize flooding hazards along the Zayandeh Rud the government decided to construct a multipurpose flood control-hydropower-irrigation reservoir at Chadegan at the point where the Zagros mountains meet the plains. The dam was completed in 1972.

The reservoir itself has only a modest storage capacity (1500 MCM) which is less than twice the annual inflow. While this provides only a modest capacity to store water from one year to the next, it is sufficient to capture most of the spring floodwater and release it more gradually throughout the summer. This has permitted expansion of summer cropping to include rice and maize as important crops.

The reservoir by itself does not really allow an increase in annual volumes released into the basin, but it is able to store flows from the Kurang diversion when demand for water in the basin is low.

d) Phase IV: Second Transbasin Diversion

By the early 1980's it was clear that demand for water was again exceeding available supplies and a second transbasin diversion was completed from the Kurang river in 1985. This second tunnel is smaller than the original, with an annual yield of about 250 MCM.

e) Phase V: Future Developments

At present the basin is still in Phase IV of development but two new developments are underway and will be completed before 2010.

A third tunnel from the Kurang river is under construction. When completed it will provide an additional 280 MCM per year. This means that the three diversion tunnels will provide as much water as the natural flow of the Zayandeh Rud itself.

In addition there are numerous springs and local water sources that can be tapped from the limstone foothills of the Zagros mountains. It is estimated that the total yield of these springs and local sources will be approximately 150 MCM.

In summary, therefore, we can see a gradual increase in available water resources in the basin over the past 50 years, as shown in Figure 2.

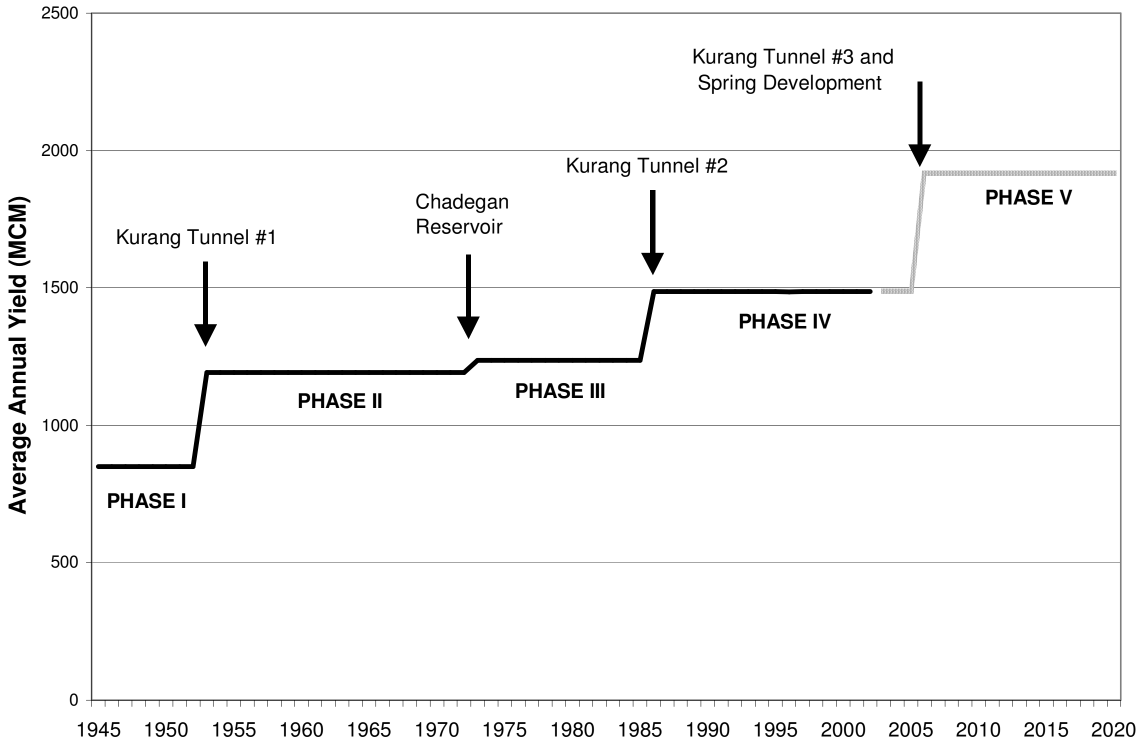


Figure 2: Water Resources Development in Zayandeh Rud basin 1945-2020

The overall result of these developments is that average annual yield, equivalaent to available water reosurces, has risen from about 850 MCM to 1487 MCM at present and will eventually reach 1917 MCM by the year 2010. Through a sequence of planned developments total water available has more than doubled.

However, to put these developments into perspective it now becomes necessary to look at actual water utilization over the same period.

3. Water Utilization in Zayandeh Rud basin, 1949-2000

Data are available for several key locations that allow us to assess overall water utilization at basin level. The most important pieces of information are discharges at Pol-e-Kaleh in the upstream reach of the Zayandeh Rud between Chadegan reservoir and the first diversions, and at Varzaneh which is the final gauging station before Gavkhouni Swamp. The difference between these two stations tells us the total water extraction along the Zayandeh Rud because to all intents and purposes there is no local inflow between these two points. The Pol-e-Kaleh data set starts in 1949, the Varzaneh one in 1952.

In addition there are annual totals for releases from Chadegan from 1972 onwards, and precipitation data for Kurang from 1966.

The river gauging stations are based on monthly observations of flow. This creates a problem in that flood peaks are sometimes missed. After 1972 this is not a serious problem because all flows are regulated and there is little day-to-day fluctuation in water levels. However, for the period 1949-1972 the monthly discharges recorded at Pol-e-Kaleh are almost certainly an underestimate of total discharge.

Figure 3 presents the entire data sets for Pol-e-Kaleh and Varzaneh. These present a comprehensive picture of the relative balance between supply and demand during each phase of development of the basin water resources.

Throughout the last 50 years there is considerable variation in annual flows at Pol-e-Kaleh, both before and after reservoir construction. These fluctuations are almost entirely related to variations in rainfall (see Section 4 below) and illustrate that average water availability estimates are of little utility for actual management purposes. It is instructive to examine conditions in each of the main phases of basin development. There are insufficient data available to make any assessment of conditions before the construction of the Kurang Tunnel #1.

a) Phase II: 1953-1971

In Phase II (1953-1971) there were only two years when water availability exceeded the planned level of supply (although as noted above the water availability figures before the construction of Chadega reservoir may miss some high flow conditions). Immediately after the construction of Kurang Tunnel #1 water supply exceeded demand, and there were good flows recorded at Varzaneh. This means that all demands for water were fully met, or more precisely, that water diversion strcutures took as much as they could but there was still water left over.

From 1955 onwards, however, discharges at Pol-e-Kaleh began to fall while abstractions remained more or less constant. By 1960 all water was used up before Varzaneh and apart from floods in 1967-68 and 1968-69 total annual discharges were less that 40 MCM, or an annual average discharge at Varzaneh of less than 1.25 m3/sec (most of which comes in the winter months).

It appears that during this phase the extractive capacity was in the order of 750 MCM between Pol-e-Kaleh and Varzaneh: when flows exceed this amount, water reaches Varzaneh, but when flows are less than 750 MCM flows into Gavkhouni Swamp were negligible.

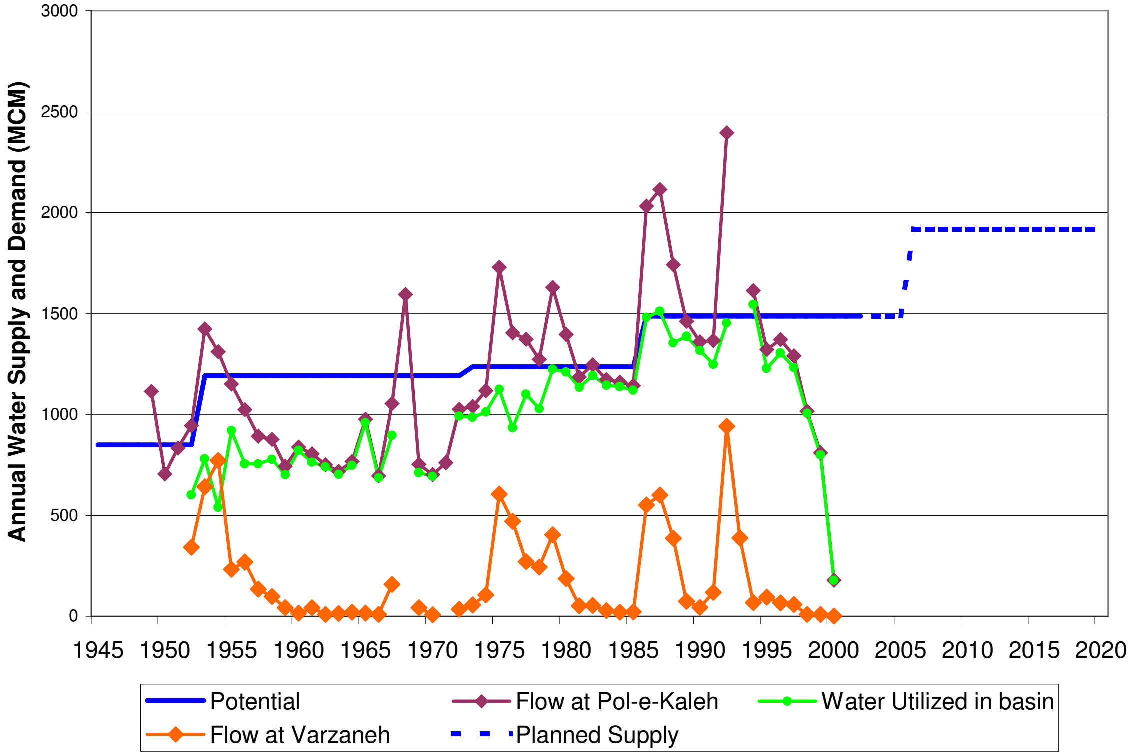


Figure 3: Annual water Availability and Utilization, Zayandeh Rud, 1945-2020

b) Phase II: 1972-1985

The construction of Chadegan by 1972 did not significantly increase overall water availability, but it did enable storage of flood waters for releases later in the year. There was parallel upgrading of major irrigation systems at Nekouabad and Abshah at this time, which increased the irrigated area and allowed more water to be abstracted for irrigation.

Opening of the reservoir coincided with an increase in irrigation abstractions so that although flows increased somewhat no water reached Varzaneh. It was not until improved inflow into the reservoir in 1975-76 that water supply conditions exceeded demand, and from 1976 to 1982 there was sufficient water not only to meet demand but also to have substantial flows into Gavkhouni Swamp.

After 1982, however, a decrease in rainfall and continued high levels of abstractions meant that the Zayandeh Rud dried up again in 1982 and remained dry for the next five years.

With the increase in water resources infrastructure the extractive capacity rose to about 1000 MCM.

c) Phase IV: 1986-2001

The current phase of basin development was marked by the opening of Kurang Tunnel #2 in 1986. Rainfall was plentiful in the next couple of years and water abstractions immediately rose to about 1500 MCM per year. There was still sufficient excess that flows to Varzaneh increased to over 550 MCM for two consecutive years.

Within three years of the opening of the second tunnel, however, water supplies dropped below 1500 MCM and immediately Varzaneh water supplies dried up again. For three years very little water reached the Gavkouni Swamp. Floods in 1992-93 and 1993-94 gave two years of good flows at Varzaneh, and water abstractions rose to over 1500MCM for the first time.

At this point in time catastrophe struck the Zayandeh Rud basin. Rainfall at Kurang fell to historic lows for six of the next seven years, water supplies fell below 1300 MCM for the next three years, and from 1998-2001 water supplies more or less disappeared. Irrigation was curtailed in the summer of 2000 and no surface water was delivered in 2001. All surface water was reserved for urban and domestic uses, and any irrigation relied solely on groundwater extraction.

4. The importance of precipitation for the Zayandeh Rud

The Zayandeh Rud is highly dependent on annual snowfall in the Zagros Mountains, and this situation has not changed despite the construction of two tunnels at Kurang, plus a third one to be completed.

Because the reservoir has an annual storage capacity less than annual demand there is little or no carry over capacity from year to year, and indeed for flood control purposes it is desirable the reservoir be well below full supply level before spring snowmelt occurs.

Analysis of rainfall patterns at Kurang from 1966-67 until 2000-01 show that there is high annual variability in precipitation and this is directly related to water availability at Pol-e-Kaleh (Figure 4). Before the construction of Kurang Tunnel # 2 the relationship between Kurang precipitation and flow at Pol-e-Kaleh was quite clear, despite the presence of Chadegan reservoir. After construction of the tunnel actual inflows at Pol-e-Kaleh have increased by about 200 MCM per year over earlier data, and there is some evidence that in dry years (1996-1998) significantly more water was made available than would have been the case had Kurang Tunnel #2 not been constrcuted. Nevertheless, Figure 4 indicates that despite the presence of a reservoir and the construction of an additional transbasin diversion, flows in the Zayandeh Rud are very dependent on having good rainfall. The tunnel construction is not a drought protection measure but tends instead to augment the normal discharge pattern experienced under uncontrolled conditions.

This relationship suggests that the basin remains highly vulnerable to changes in precipitation, and that when shortfalls are experienced the tail end of the basin will suffer major water shortages.

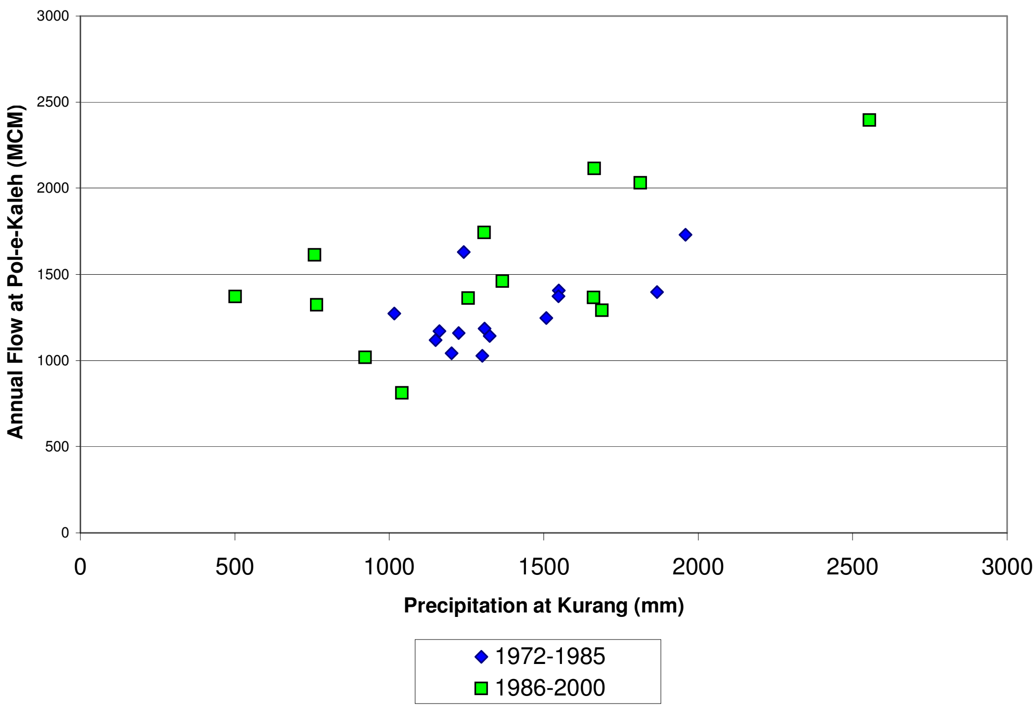


Figure 4: Relationship between precipitation at Kurang and Flow at Pol-e-Kaleh

Figure 4 suggests that since the construction of Kurang tunnel #2 flows at Pol-e-Kaleh are higher than they would have been had the tunnels not been constructed. This is as would be expected, but it also shows that flows through the tunnel are susceptible to shortfalls in rainfall and do not mitigate drought years to any significant extent..

5. Basin Vulnerability

The stages of basin development shown in Figure 1 imply that there could be a relatively smooth transition between the Development, Utilization and Allocation stages of basin development. The experience of the Zayandeh Rud shows a much less encouraging picture.

Each phase of development of water resources within the Zayandeh Rud basin led to an increase in potentially available water, but each increase in supply was matched almost immediately be increases in demand. This can best be illustrated by looking at the flows at Varzaneh which effectively gauge the vulnerability of the basin to shortfalls in irrigation supplies.

Data from Phases II, II and IV in Figure 5 show the relationship between flows at Pol-e-Kaleh and Varzaneh.

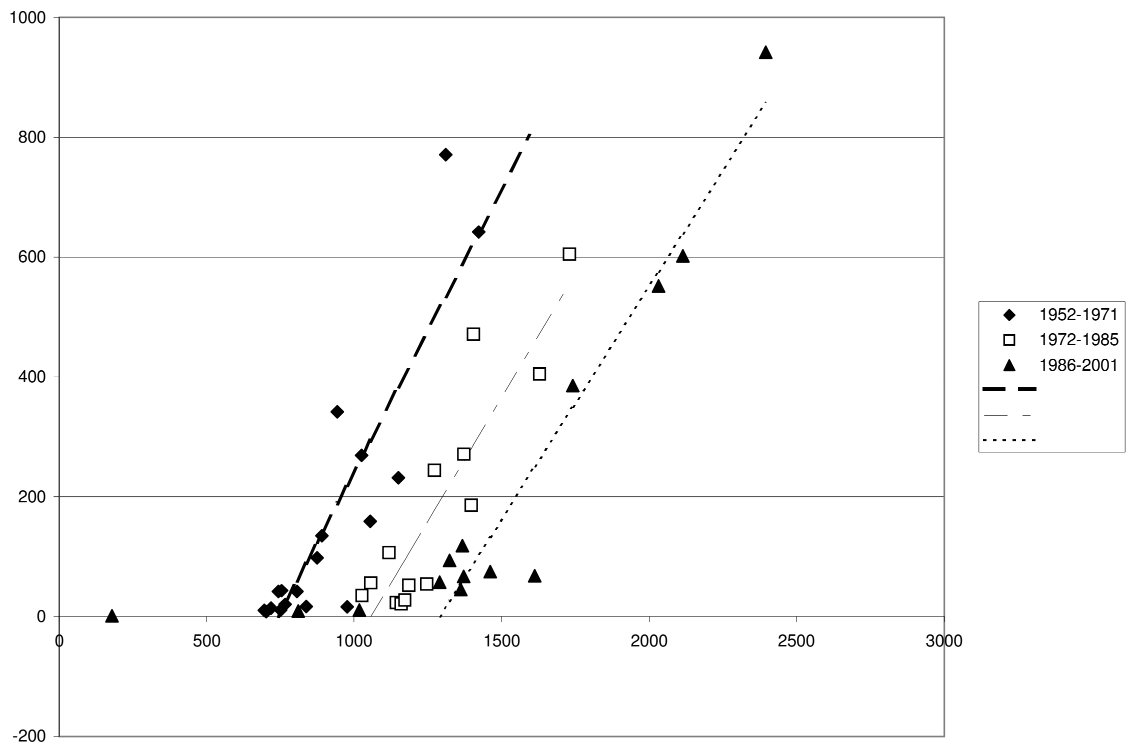


Figure 5: Relationship between flows at Pol-e-Kaleh and Varzaneh, 1952-2001

Between 1952 and 1971 significant flows were only recorded at Varzaneh when flows at Pol-e-Kaleh exceeded 700-750 MCM. We can therefore conclude this is the extractive capacity of all users between the two points, and that if flows at Pol-e-Kaleh exceeded 750 MCM virtually all the water reached Varzaneh.

The construction of the reservoir at Chadegan and the associated irrigation infrastrcuture by 1972 meant that extractive capacities increased to approximately 1000 MCM. This appears to have occured more or less within one year because there is no overlap between the data before and after 1972. In other words, the threshold value for flows at Pol-e-Kaleh to reach Varzaneh appear to be at 1050 MCM per year.

Exactly the same pattern occurred in 1986 with the construction of the second tunnel at Kurang. The threshold value now rises to approximately 1300 MCM, almost exactly the annual capacity of the tunnel. Again, data from 1986 onwards do not overlap with data from before 1986.

From this we can conclude that there is an almost immediate matching of supply and demand as soon as new supplies become available. Irrespective of the improvement in water resources availability at basin level, the basin remains just as vulnerable to water deficits as before.

We can see this from several periods in the data set. In 1970-71, beofre the construction of Chadegan reservoir, flows at Pol-e-Kaleh were 702 MCM, 94% of extractive capacity but Varzaneh received only 8 MCM during the year. In 1983-85, after construction of Chadegan reservoir, flows at Pol-e-Kaleh were close to 1150 MCM for two years (93% of demand) yet Varzaneh received less that 25 MCM in both years. In 1990-92, following the construction of Kurang Tunnel #2, supplies were between 1360 and 1460 MCM (92-98% of demand) yet Varzaneh received less than 60 MCM. To put these figures into context, the minimum desirable environmental flow into Gavkhouni Swamp is estimated to be 70 MCM, and should not just be a brief flood in the winter but a more continuous flow.

This suggests that there is no basin level integrated management that allocates shortages equally between different users, or even within a particular water use. The implication of this is that the basin will remain vulnerable whenever supplies are less than demand, and shortfalls in supply that are less than 10% of the potential lead to significant stress on downstream areas.

6. Prospects for the Future

The data presented here paint a rather gloomy picture for the Zayandeh Rud basin. The situation is being actively addressed by planners and managers, and several studies of basin water reosources are available in Farsi. The most important of these are Momtazpur (1996), Yekom Consulting (1998) and Zahabsanei (2000).

Over the past 50 years a series of water resource developments have doubled potentially available water for the basin, and yet there has been a series of water crises than have occurred fairly quickly after each new water source has been tapped.

In part this reflects the increasing demand for water that is difficult to meet. As soon as more water is made available it is fully allocated so that there is never any reserve to mitigate the impacts of below-average rainfall. As soon as winter precipitation in the mountains falls below average, the water supply situation in the following summer is highly vulnerable.

Analysis of probabilities of flows at Pol-e-Kaleh illustrate the extent of this lack of reserve to cope with contingencies. The planned demand appears to reflect almost exactly average flows, i.e. they will be exceeded one year in two. This trend has continued since the construction of the first tunnel at Kurang where planned flows are more or less at the 50% probability level (Figure 6). This means that every other year, on average, will be below the planned demand and flows will not reach Varzaneh.

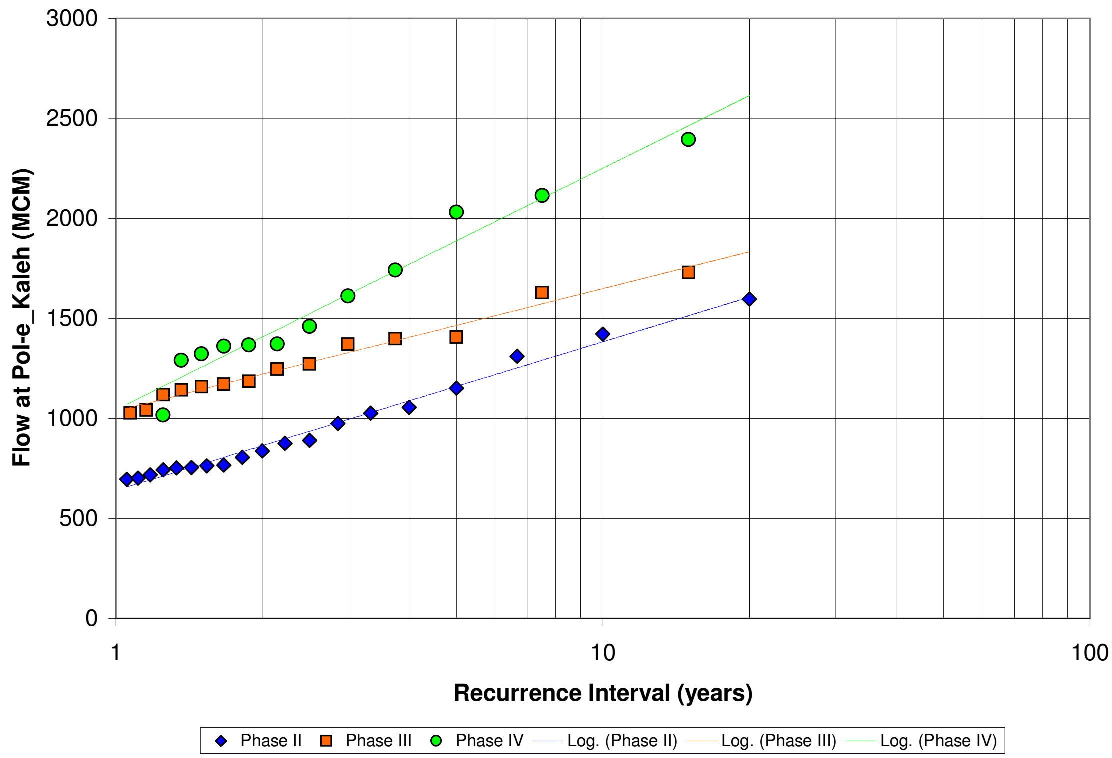


Figure 8: Recurrence intervals of flows at Pol-e-Kaleh in each phase of basin development

If we take a somewhat more pessimistic view and see how often flows fall below 90% of the planned amount, we find that this occurred once every 3.5 years in Phase II, once every 7.0 years in Phase III, and once every 2.8 years in Phase IV. In other words, the basin has become more vulnerable to drought in the past 15 years because the extractive capacity is actually above the average flow condition at Pol-e-Kaleh.

The development of additional water supplies currently underway, both at Kurang and through tapping of local springs and other water sources, will almost certainly not solve the problems. The hydrology of the mountains is dependent on winter precipitation, and discharges in the Kurang river drop in drought periods in exactly the same manner as discharges in the Zayandeh Rud catchment itself. A deficit in runoff within the catchment is more or less matched by similar deficits in the Kurang river. The same is true for local springs. By 2010 all likely sources of water will have been tapped and there will be no more additional water available.

To compound matters further, groundwater resources are under just as much threat as surface water resources. As is common in drought periods, groundwater use in the Zayandeh Rud basin increased greatly from 1999 onwards. Indeed, no irrigation by surface water took place in 2001. Groundwater levels in Borkhar have dropped by 15 meters in 10 years, and it is difficult to see how the aquifer can recover in the near future because rainfall is only 100 mm per year.

Worse, two new irrigation systems have been developed in recent years: Mahyar and Borkhar. These systems are intended to provide supplementary irrigation to areas traditionally dependent on groundwater, so that in dry years irrigation water can be used to protect the aquifer. In reality, absolutely the opposite is likely to happen: the prospect of surface supplies will encourage farmers to expand their irrigation so that when surface supplies are in deficit they will pump even more groundwater and accelerate the decline in groundwater levels.

With increasing population growth in Esfahan, with a large industrial base whose growth is only nominally capped, transbasin diversions to Yazd and Kashan, and efforts to maintain a minimum annual flow into Gavkhouni Swamp of 70 MCM, means that demand for water continues to grow. The only sector that could use less water is agriculture but to do this requires concerted action by basin level planners and the irrigation managers of the different systems so that issues to systems better reflect the share of water for the agricultural sector.

8. Conclusions

The Zayandeh Rud provides an excellent example of how a chronically water-short basin has tried to match supply and demand over the past fifty years. As potential demand grows, new water supplies have been developed, primarily by transbasin diversion, so that total water avaialbility is now double that of the natural flow of the river.

Despite these increases in supply, demand rises almost immediately after commissioning of the new systems, so that for most of the past 50 years the basin remains under stress. The basin became completely closed in 1960, and has only discharged water into the salt pan at the lower end when rainfall is significantly above average.

We can therefore redraw Figure 1 to better reflect the conditions in Zayandeh Rud (Figure 9). Demand frequently exceeds available supply, a situation that is possible due to groundwater mining, and we believe that at present groundwater is being mined at an unprecedented rate due to the current dry conditions.

It would be naïve to think that demand should be curtailed to provide a cushion in times of drought, but responses to shortfalls in supply appear to be ad-hoc and uncoordinated. Irrigation systems, particularly head end ones, extract their design discharges irrespective of basin level water conditions, and there seems little early-warning mechanism that will reduce water to different sectors in water-short years. The need for a more integrated approach to basin management is required, as well as a set of longer term plans for reallocation of water among sectors to cope with the anticipate water deficits that will arrive in or around 2010.

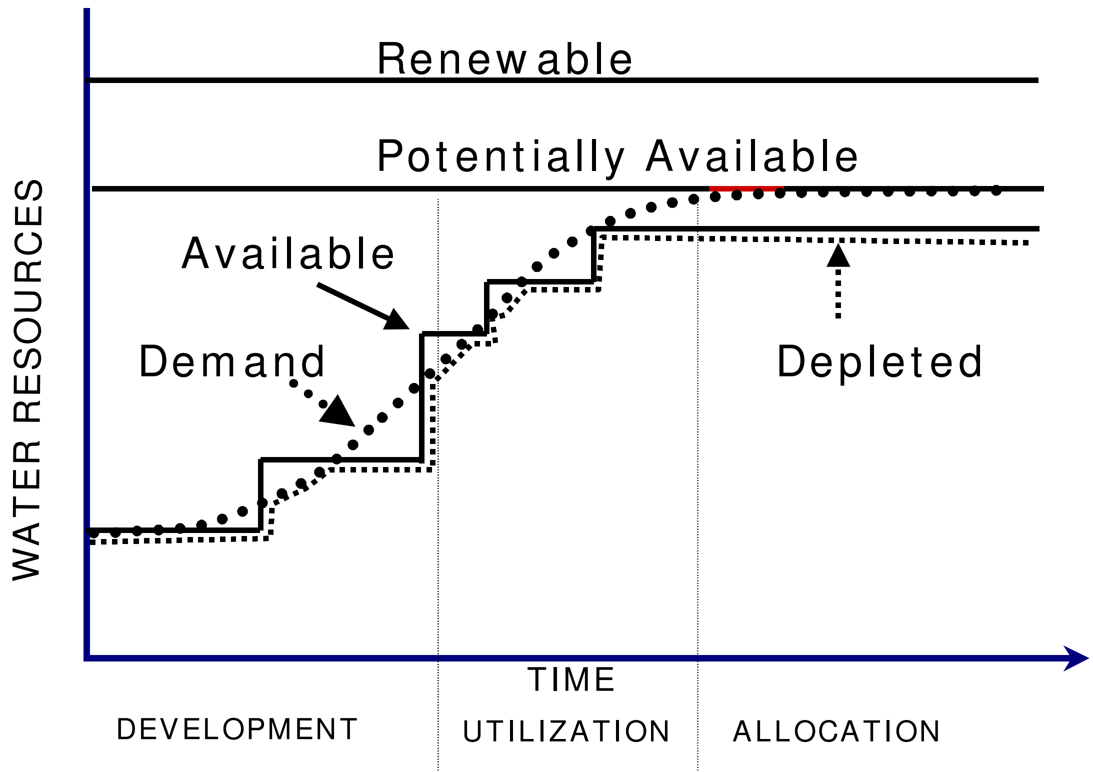


Figure 9: Basin development stages under water scare conditions

Acknowledgements

We are deeply indebted to Engineer Lotfollah Ziaie of Zayandab Consult, Ghloamhosein Heydarpur and Mehdi Eslami from Esfahan Regional Water Authority who provided us with much of the data used in this paper. Additional thanks go to the Esfahan staff of the Ministry of Energy, the Department of Environment and the Master Plan Organization. Finaincing of the Iran-IWMI Collaborative Research Project is provided by the Government of the Islamic Republic of Iran through the Agricultural Research, Extension and Education Organization of the Ministry of Jehad-e-Agriculture.

References

Molden, D. (2001) Stages of basin development and implications for water management. in Proceedings of the Workshop on Institutional Support Systems for Transferred Irrigation systems, Loshop Dam, September 2000. IWMI

Momtazpur, M. (1996) An explanation of characteristics of the Zayandeh Rud basin and revision of water resources for optimal use of water. Proceedings of the Esfahan Conference on Water Resources Management. (in Farsi)

Murray-Rust, H., H. Sally, H.R. Salemi and A. Mamanpoush. (2000) An overview of the hydrology of the Zayandeh Rud basin. Iran-IWMI Collaborative Research Project, Research Paper 3.

Zahabsanei, A. (2000) Investigation of data summary of water situation in the Zayandeh Rud. Esfahan Regional Water Authority (in Farsi)

Yekom Consulting (1998). Supplemtary studies of surface water resources within the Zayandeh Rud basin. Department of Budget and Planning, ministry of Agriculture, Esfahan (in Farsi).

The following reports have been published in the IAERI-IWMI Research Report series.

1. **Water Management for Sustainable Irrigated Agriculture in the Zayandeh Rud Basin, Esfahan Province, Iran.** (2000) H.R. Salemi, A. Mamanpoush, M. Miranzadeh, M. Akbari, M. Torabi, N. Toomanian, H. Murray-Rust, P. Droogers, H. Sally, A. Gieske.
2. **Exploring field scale salinity using simulation modeling, example for Rudasht area, Esfahan Province, Iran.** (2000) P. Droogers, M. Akbari, M. Torabi, E. Pazira.
3. **An overview of the hydrology of the Zayandeh Rud Basin.** (2000) H. Murray-Rust, H. Sally, H.R. Salemi, A. Mamanpoush.
4. **Groundwater chemistry of the Lenjanat District, Esfahan Province, Iran.** (2000) A. Gieske, M. Miranzadeh, A. Mamanpoush.
5. **Exploring basin scale salinity problems using a simplified water accounting model: the example of Zayandeh Rud Basin, Iran.** (2000) P. Droogers, H.R. Salemi, A. Mamanpoush.
6. **Sustainable irrigation and water management in the Zayandeh Rud Basin. Proceedings of Workshop in Esfahan, Iran, 19-21 November 2000.** (2001) Anonymous.
7. **Assessment of irrigation performance using NOAA satellite imagery.** (2001) P. Droogers, P., W.G.M. Bastiaanssen, A. Gieske, N. Toomanian, M. Akbari.
8. **Water supply and demand in four major irrigation systems in the Zayandeh Rud Basin, Iran.** (2001) H. Sally, H. Murray-Rust, A.R. Mamanpoush, M. Akbari.
9. **Spatial analysis of groundwater trends: example for Zayandeh Rud Basin, Iran.** (2001) P. Droogers, M. Miranzadeh.
10. **Irrigated area by NOAA-Landsat upscaling techniques: Zayandeh Rud Basin, Iran.** (2002) A. Gieske, N. Toomanian, M. Akbari.
11. **Crop and land cover classification by LANDSAT 7 ETM (July 2000) for the Zayandeh Rud basin.** (2002). A.Gieske, A.R. Mamanpoush, M. Akbari, M. Miranzadeh.
12. **Field scale scenarios for water and salinity management by simulation modeling.** (2002) P. Droogers and M. Torabi.
13. **Water Supply and Demand Forecasting for the Zayandeh Rud.** (2002). H.R. Salemi and H. Murray-Rust.
14. **Water Resources Development and Water Utilization in the Zayandeh Rud Basin, Iran.** (2002). H. Murray-Rust, H.R. Salemi and P. Droogers.
15. **Groundwater resources modeling of the Lenjanat aquifer system.** (2002). A. Gieske and M. Miranzadeh.