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

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Abstract
Zayandeh Rud is the most important river in Isfahan Province in central Iran. For many centuries it has provided the basis for a rich and prosperous region based around the ancient city of Isfahan.

Analysis of water supplies and demand over the past 50 years in the Zayandeh Rud basin indicates 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 trans-basin diversions and a storage reservoir have been constructed which have more or less doubled the annual supply of 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.

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. 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 2020. This article attempts to arises some issues related to water supply and demand in the Zayandeh Rud basin and to provide the current situation and scope of future water scarcity as an early warning to the management authorities of water resources in the basin.

Keywords: Consumption, Demand, Supply, Water resources, Water short basin, Zayandeh Rud Basin

Introduction
The Zayandeh Rud river flows out of the Zagros Mountain range into the arid inland basin of central Iran (Fig.1). The Zayandeh Rud is chronically water short, and has been for the past 50 years. During the second half of the 20th century the age-long balance between economic growth and the water resources available to support that growth has dramatically changed. Expansion of the irrigated area through major investments in modern irrigation systems, the establishment of large scale industries which require significant volumes of water, and the continuing rapid growth of Isfahan with a current population over 2 million people has all depended on the fragile water resources of the Zayandeh Rud basin.
Since 1950 a series of measures have been taken to increase natural water sources, both through trans-basin diversions and reservoir construction, but by 2000 it is clear that demand has continued to grow faster than it is possible to develop water resources. As a result there is increased pressure on both water and soil resources, tail end areas showing the greatest stress with reduced water availability, deteriorating ground water quality, increased soil salinity and declining agricultural production and little water now reaches the Gavkhouni swamp at the tail end of the river (Fig. 3).

Salemi et al. (2000), Sally et al. (2001), Murray Rust et al. (2000), Salemi and Murray Rust (2002) studied different water resources and water management issues of the Zayandeh Rud basin.

There are serious concerns that it will be extremely difficult, if not impossible, to meet expected demands for water over the next 20 years, and this has grave implications for economic growth in the basin, particularly for agriculture that remains the main user of water. The objective of this paper is to discuss water resources development and utilization status in current situation and to take some lessons from the past and to provide forecasting and early warnings about water deficit in the basin in future.

Materials and Methods

In every river basin there is a sequential development of water resources that should ideally keep peace with demand or attempt to anticipate future demand (Fig. 2). 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 D. Molden (Molden, 2001) where the level of water resources development is only a small fraction of potentially available water.

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 (Fig. 2). 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 (Fig. 2).

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

Data are available for analysis of water utilization in the basin for several key locations. It allows us to assess overall water utilization at basin level. The most important pieces of information are discharges at Pol-e-Kalleh river gauging station the upstream reach of the Zayandeh Rud between Chadegan reservoir and the first diversions, and at Varzaneh which is the final river gauging station before Gavkhouni Swamp (Fig. 3). The difference between these two stations tells us the total water extraction along the Zayandeh Rud because there is not any local inflow between these two points. The Pol-e-Kalleh data set starts in 1949, and the Varzaneh one in 1952. In addition there are annual totals for releases from Chadegan from 1972 onwards, and
precipitation data for Kuhrang from 1966. The entire data sets for Pol-e-Kalleh and Varzaneh river gauging stations are presented in Fig. (4).

In this paper the attempt is to explain the water resources development and utilization phases of the Zayandeh Rud basin.

Results and Discussions

1. Water Resources Development in the Zayandeh Rud basin

The Zayandeh Rud, has been the basis for a long and diverse culture based around the city of Isfahan. 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 Isfahan city (Fig 3). 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 description of the hydrology of the basin is provided by Murray-Rust et al. (2000). The development phases of basin are as follow:

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.

b) Phase II: First Trans-basin Diversion

The first major water resources development was completed in 1952 when a tunnel was constructed from the Kuhrang 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 Kuhrang 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 (Fig. 3). 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 Kuhrang diversion when demand for water in the basin is low.

d) Phase IV: Second Trans-basin Diversion

By the early 1980’s it was clear that demand for water was again exceeding available supplies and a second trans-basin diversion was completed from the Kuhrang river in 1985. This second tunnel is smaller than the initial one, 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 Kuhrang 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 limestone 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 Fig. (5).

The overall result of these developments is that average annual yield, equivalent to available water resources, 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.


Figure 4 presents 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-Kalleh, both before and after reservoir construction. These fluctuations are almost entirely related to variations in rainfall 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 Kuhrang Tunnel #1 (Phase I). Therefore, the phases for water utilization are identified from phase II as below:

a) Phase II: 1953-1971

In Phase II (1953-1971) there were only two years when water availability exceeded the planned level of supply. Immediately after the construction of Kuhrang 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 structures took as much as they could but there was still water left over. From 1955 onwards, however, discharges at Pol-e-Kalleh 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 than 40 MCM, or an annual average discharge at Varzaneh of less than 1.25 m$^3$/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-Kalleh and Varzaneh, when flows exceed this amount, water reaches Varzaneh, but when flows are less than 750 MCM flows into Gavkhouni Swamp were negligible.

b) Phase III: 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 Abshar 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 Kuhrang 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 Gavkhouni Swamp. Floods in 1992-93 and 1993-94 gave two years of good flows at Varzaneh, and water abstractions rose to over 1500 MCM for the first time.

At this point in time catastrophe struck the Zayandeh Rud basin. Rainfall at Kuhrang 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.

The stages of basin development shown in Fig. (2) 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 by increases in demand. The implication of this is that the basin will remain vulnerable whenever supplies are less than demand.
Conclusions

The Zayandeh Rud basin 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 availability 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 Fig. (2) to better reflect the conditions in Zayandeh Rud (Fig. 6). 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 naive 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 2020.

References


Fig. (1) The Zayandeh Rud basin, Iran
Fig. (2) Phases in overall basin development
Fig. (3) The main regulators in the Zayandeh Rud basin
Fig. (4) Annual water Availability and Utilization, Zayandeh Rud, 1945-2020
Fig. (5) Water resources development in Zayandeh Rud basin 1945-2020
Fig. (6) Basin development stages under water scare conditions