Flood water spreading and spate irrigation in Iran

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Overview Paper Spate Irrigation

Spate Irrigation Network

ABSTRACT

Floodwater harvesting for spate irrigation and the artificial recharge of groundwater has been practiced in Iran from time immemorial. In fact, this practice, and its offshoot, the qanat, have sustained our civilization for millennia. Small amount and erratic distribution of rainfall in deserts make the flood, contrary to an old adage, a blessing in disguise and not a curse. Thousands of hectares of spate-irrigated farm fields in the Iranian deserts is a solid proof that spate irrigation, particularly for the artificial recharge of groundwater, is the most appropriate water-resource technology for our environment. Spate irrigation is technically practicable, environmentally sound, financially viable and socially acceptable technology. The area covered by the spate-irrigated system in the Land of Iran is estimated at 800,000 ha. The recent prolonged drought has persuaded the Government to plan construction of 1.5 million ha of such systems countrywide. This activity is supported by the ongoing studies at 38 research stations. The benefit: cost ratio of one such project on the Gareh Bygone Plain in southern Iran has been 20:1 without considering the intangible benefits. Inclusion of some of the environmental benefits in the analyses increases this ratio to 90:1. Creation of employment opportunities through implementation of spate-irrigation projects stems the cityward migration tide.

1. Introduction

Iran is the land of floods, droughts and *qanats*, the underground galleries that collect and deliver water in deserts underlain by the coarse-grained Quaternary deposits. The mean annual precipitation (MAP) of 870,000 km^2 of mountainous regions and 773,000 km^2 of plains of Iran is estimated at 356 and 115 mm, respectively (Anon., 1984). Thus, the MAP of the entire land of Iran is about 243 mm, which is about 1/3 that of the planet Earth.

Prolonged and cyclic meteorological droughts have been impacting our country for millennia. Occurrence of flood-producing downpours in this mountainous country interrupts the rainless periods and cause untold mortalities and enormous financial damages; thus, we usually have a famine-flooding cycle.

It is postulated that the serendipitous discovery of abundant green grass on floodplains oriented the Arians (meaning nomads) to choose the debris cones and coarse alluvial fans for living. This enabled them not only to benefit from the permanent and temporary springs, which issued from the apices of the cones, but also spread the nutrient rich floodwaters on their permeable land, irrigating crops and building soils, while simultaneously recharging the underlying aquifers. Digging through the seepage face and arriving at saturated strata was the turning point in the Iranian civilization, which is, in actuality, the *qanat* civilization; the most appropriate technology that has endured the Iranians for thousand of years. It is therefore obvious that the spate irrigation-assisted artificial recharge of groundwater has been the bulwark of our civilization (Kowsar, 1991, 1999).

As groundwater supplies about 60 % of our needs, over-exploitation of this resource has made us face a hydrological drought since 1945, when at first cable tools, then rotary drilling machines and powerful pumps arrived in Iran. It is believed that more than 2/3 of the *qanats* have dried up. We do hope that application of spate irrigation on a very large extent will rejuvenate the dry *qanats*.

2. Concepts

1. While the mean annual rainfall in drylands is very low, its variability is very high (erratic in distribution and frequency; an 11 year sampling of Shiraz rainfall is presented in Table 1 as evidence). Thus, the chance of receiving the desired rainfall at the expected time is meager, indeed. Therefore, water is the most precious commodity and flood is its largest supplier in drylands. Although floodwater is a renewable capital, its use must be optimized.
2. Available water capacity (AWC) is the most important direct driver of ecological sustainability in drylands. Soil *texture* and *depth* are the two major determinants of AWC.
3. Water, an erosion agent, may become a land renovator and soil builder by transporting to and depositing nutritious sediment on the

slightly-sloping, drastically disturbed lands, thus improving their texture and increasing their depth; *therefore, enhancing their AWC.*

4. High evaporation rate from surface waters, rapid siltation, flooding of productive lands, dwellings and important archeological sites, forced migration of the inhabitants of the inundated area and construction sites, threat to biodiversity, reservoir leakage, earthquakes and other related environmental hazards, and the very high costs and relatively long time needed for their construction, make large dams the most *inappropriate technology* in drylands. Furthermore, such schemes do not benefit inhabitants of the runoff-producing headwater catchments. They not only lose most of the water that Nature bestows upon them, but also the surface soil, the life-giving substance that nothing can replace; therefore,
5. Turbid floodwater should be harnessed to build soil and produce virtual water through spate irrigation, and/or it should be stored in aquifers by employing the artificial recharge of groundwater (ARG) methods and used commensurate with needs. These shall also mitigate flooding hazards too (Kowsar, 2006).

Table 1. Shiraz annual rainfall for the 1963 - 1973 period

Year	Rainfall, mm
1963	223.0
1964	251.0
1965	397.0
1966	96.3
1967	395.1
1968	294.8
1969	388.6
1970	143.2
1971	207.0
1972	499.3
1973	183.4

3. Potential for spate irrigation

Quaternary deposits cover 639,241 km^2, or 39.7 % of the area of the I.R.Iran. Of the studied area by the GIS technology and field surveys, 149,000 km^2 are *highly suitable*, 62,700 km^2 are *suitable*, and 110,300 km^2 are *relatively suitable* for the ARG through SI. Floodwater diversion is very easy and inexpensive in the *highly suitable areas*; the need for construction of a conveyance canal longer than 1 km puts the sites in the *suitable* category; some social limitations make the coarse alluvium covered land *relatively suitable*. Considering that the mean annually wasted floodwater in this country is 61.97 km^3, I have officially suggested that 42 km^3 of this water be spread on 140,000 km^2 of the most suitable coarse-gained alluvium (3000m^{3}ha^{-1}yr^{-1}). This would provide about 4 million direct employment opportunities and more than twice of that if the added value of the products is considered.

Needless to say, we waste more than the reported 61.97 km^3 every year. Therefore, we may harvest upwards of 100 km^3 in the wet years. Should we recharge our aquifers to the level of about 60 years ago, when the first deep well was bored, we can face up to a 40 year drought at the present rate of pumping from our underground water sources.

4. Technology

Traditional Spate Irrigated Systems

Spate irrigation (SI) is defined as supplying floodwater from ephemeral streams to farm fields prepared by damming the streams with brushwood, check dams made of dry masonry (*darband*), dry masonry and/or earth embankment: *khooshãb* in northern Baluchestan, SE Iran, and *bandsar* in Khorasan, NE Iran; and diverting flood from ephemeral streams and spreading the water on the relatively level land: *degar* in southern Baluchestan; *pal* and *bandsãr* in Khorasan; *rooben bastan*, which consists of *ta, gotak, taghal* and *gaband* in the Izadkhast Plain, Darab, SE Iran; *goorehband* in Sistan, eastern Iran, and *korband* (silt retainer)in southern Fars, southern Iran, the Persian Gulf coast and the Qeshm Island. Please note that the *khooshãb*, which is also constructed adjacent to a wadi, is also called: *hooshãb, hooshãf, zamin* (land), *zaminan* (lands) and *ãsman zamin* (sky land) in northern Baluchestan; those of *degãr* are *zamin* and *ãsman zamin* in southern Baluchestan. The other name of *darband* is *bãgh* (orchard or grove) in northern Baluchestan. *Lavar* (silt bringer) is the name given to a spate-irrigated farm field in Dorz-Sãyehbãn area in SE Fars. Moreover, the upstream spate-irrigated fields in Mazaijohn, south of the Izadkhast Plain, Darab, are called *bonakhoo*, and those on the downstream end are called *shatmãl* (sheet irrigation). "Sheet irrigation" is called *takhtãbi* in Khorasan.

There are two major types of SI farms in Khorasan: "*bandsãr*" (ã is pronounced as the "a" in America) and "*pal*". A series of earth banks or stone walls across low slope valley bottoms make the first kind. "*Band*" in Farsi means a short dam, and "*sãr*" connotes a group of objects in one place. These fields are actually terraces, 100 m^2 to 25 ha in extent, built on slopes ranging 1.5 - 4.4 %. Floodwater is directed towards the top terrace, or may be apportioned through side channels to the individual terraces. Vegetated or stone-and- mortar drops drain the surplus water from the surface of each field. The lower bank is sometimes up to 3.5 m high. A "*pal*" is a two-or three-sided basin that receives water from the upstream side that is devoid of a bank. Surplus water flows from the upper end and around the side banks to the lower "*pal*". Tractor-mounted dozers are used now for construction of these "*pals*". "*Bandsãrs*" are usually planted to wheat, chick peas, watermelon, and saffron; and less frequently, to cotton, sugar beet, barberry, pistachio and grapes. "*Pals*" are usually planted to watermelon for seeds, which are eaten roasted.

A complete lack of easily accessible groundwater in Dashtyari and other plains of Baluchestan, where the MAP is less than 100 mm, and soils are silty to silty clay, has made the inhabitants, mostly Baluchi nomads, depend on floodwater harvesting for survival. Therefore, they have devised different schemes suitable for their habitat. Construction of a short earth bank across a draw is the easiest way to impound water for domestic use. This 300 - 400 m^3 reservoir is called "*hootak*". Sometimes the capacity of this pond is increased by construction of a short bank, not more than 1.0 m high, around it. The "*hootak*" may receive floodwater through a man-made waterway, too. The number and the total extent of the "*hootaks*" are not known.

Wheat, barley, maze, vetch, and indigenous woody bushes are grown in "*degãr*", a 1.0 - 25.0 ha relatively flat area surrounded by a 1.0 - 1.5 m earth bank. Floodwater is conveyed by an up to 1 km inundation canal to a "*degãr*". This canal may supply more than one "*degãr*" depending on its capacity. Some "*degãrs*" are 2.5 km long. These 2 systems do not have outlets to drain the surcharge. Water level in the wadi is less than that of the surrounding earth banks; therefore, the banks are not breached. As the water infiltrates into the soil and the land becomes trafficable, farmers plow the land on the contour with draft animals and sow wheat or the seeds of other adapted crops. In the meantime, they drink from the remaining water in the depressions behind the banks. As long as they have to wait for the water to recharge the soil profile they have to plant on contour strips; therefore, the corrugations made by plowing hold the scant rainfall and help the grain grow. As soon as the nomads finish the water supply they have to move to another water hole. The approximate extent of these spate-irrigated farms in southern Baluchestan is 40,000 ha.

"*Darband*" is a 2.0 - 4.5 m high and 2.0 - 25.0 m long, stone wall (dry masonry) built across narrow mountain valleys in northern Baluchestan. Each one has a spillway whose dimensions depend on the flow rate of the wadi it has dammed, 1.0 - 15.0 m long, 1.0-1.5 m high. Deposition of sediment behind the dam provides a 0.2 - 0.5 ha farm field in which date palms are grown.

A more advanced (maybe the best on the technical aspects) system is "*khooshãb*", a runoff farm constructed in the riparian regions of northern Baluchestan. "*Khooshãbs*" are constructed on the ephemeral riverbanks. Strong stone walls (dry masonry), up to 10 m in height, are made parallel to the riverbank and also perpendicular to it. The two walls, which usually meet at a right angle, are backed by filters that range from coarse gravel adjacent to the wall to silty clay on the inside. The area behind the walls, sometimes up to 2.5 ha in extent, is filled up with the suspended load carried in floodwaters. Drainage takes place through weep holes installed about 3 m from the top of the wall. Some "*khooshãbs*" are equipped with a drain pipe installed at their lowest point. A slab of stone connected to a rope covers the entrance of the pipe. Removal of this cover facilitates the drainage of extra water from the field. Surplus floodwater is discharged through a spillway installed in the wall. These human-made fields are planted to wheat, maze, vetch, sorghum, cucumbers, melons, watermelons, pumpkins, and date palms.

Seeding rate for wheat is 80 - 120 kg per ha; the yields of up to 12 tons per ha have been reported for this crop. The highest yield of *Mazãfati* date palms has been 120 kg per tree. The high yielding "*khooshãbs*", which may produce two crops with a single flooding, are very valuable, and a fraction of each makes the main portion of a dowry. These structures testify to the ingenuity of their builders. They benefit immensely from storms (monsoon), which usually produce runoff, to grow their summer crops with the moisture conserved in the upper part of the soil profile. Then they plant wheat in the fall when there is enough precipitation to wet the depleted top soil; germinated wheat seedlings send their roots down along with the falling watertable and its capillary fringe. "*Khooshãbs*" and "*darbands*" cover about 12,000 ha in Saravan, Nikshahr, Sarbaz, and Iranshahr, all in northern Baluchestan Floodwater irrigation in the Fars Province dates back at least to the Sassanid dynasty (226 - 641 AD); narrow stone-walled terraces and rather wide stone-walled basins in the valley bottoms around Kazerun, Noor Abad, and Afzar are close to buildings attributed to that dynasty. Small boulders, up to 1.5 tons each, make the lower walls of the terraces built on a 10 % slope at Bahloo, 15 km to the northeast of Noor Abad. Accumulation of the suspended load behind these walls has made absolutely level terraces. Torrent enters the lead terrace from a few places and flows to the lower ones through step-like drops. These terraces are still under wheat cultivation in alternate years. Unfortunately, some people remove the boulders and smaller stones and use them for construction materials.

Spate-irrigated cooperative farms, sometimes up to 300 ha in extent, occupy 40,000 ha of the Izadkhãst Plain, Dãrãb (southern Iran). The soil texture is silty clay loam to clay loam; the general slope of the land is 3 - 4 ‰. Very large basins surrounded by short earth banks (30 - 60 cm) are planted to wheat and barley. The mean grain yield of wheat in good years is 2.5 tons per ha; the highest wheat yield recorded has been 6 tons per ha. These basins are planted every year with the expectation of receiving a good runoff once every 5 years, medium runoffs twice every 5 years, and 1 - 2 complete failures during the same period. It is interesting to note that the depth to a good-yielding water table in this plain is more than 300 m!

Floodwater irrigation of date palm groves is practiced along the Oman Sea and Persian Gulf coasts, and on the Qeshm Island and in the Bushehr, Lamerd, and Larestan areas.

Water harvesting for fruit trees has been practiced from time immemorial in Iran. Fig trees growing in individual run-on basins cover about 26,000 ha in the Estahban and Neyriz areas in eastern Fars. There are 45 - 100 fig trees per ha; the mean annual yield is 10 kg of dry figs per tree. The highest recorded yield is 60 kg of dry figs per tree. The yearly total yield of these fig orchards is 20,000 metric tons. Some of the rain-fed vineyards receive runoff from the rocky outcrops in the Saadi district of Shiraz.

Modern Spate Irrigated Systems

The disastrous drought of 1970 - 71 in southern Iran (Table1) bankrupted the transhumant population whose main occupation is raising sheep and goats. As we had a very wet winter in 1969, in which flooding caused many deaths and enormous financial damage, I proposed rangeland improvement through spate irrigation. The enormity of the task called for spreading large flows on extensive grounds; this necessitated application of a more appropriate technology. Therefore, we modified the technique developed by Phillips (1957) and improved by Newman (1963, 1966) and Quilty (1972a, b, c).

The simplest SI system is a single, level-silled channel (LSC) that receives the floodwater from one or more draws, watercourses, or gullies on a debris cone, an alluvial fan or a foothill. Flow of culverts or small, bridged streams may also be drained into an LSC and used for SI. A full system includes a diversion weir or an apron, an inundation canal, which diverts floodwater to the head of the first spreader, a wasteway, a stilling basin (conveyance-spreader channel, CSC), which spreads the water as a thin sheet over land, a few LSCs, gaps (some times with masonry drops or chutes), trail dikes, and a tail drain. However, if the system is a dual-purpose one, which also functions for the ARG, a recharge pond is added to its end.

The CSC is the most important hydraulic structure in SI. We have discovered, initially by trial and error, and later by models that for achieving the best results, the slope of the front-end of the CSC should be 0.0003 in the direction of flow for about 85 % of its length; the slope of the next 10 % decreases gradually to zero; the final part is quite level. This design ensures that at least a small parcel of land is irrigated with a rather small flow.

5. Water diversion structures

The most widespread form is the inundation canal that diverts floodwater automatically as the water level in the stream rises. The intake is called *barq* in Khorasan and *varezah* in the Izadkhast Plain, Darab. Gated intakes are used in a few places; however, as they are manually operated, we do not advise their installation.

Deflecting spur constructed from earth and gravel are used in many places. The brushwood “dams” are common in southern Baluchestan. A row of short (about 1.5 m) wood piles are fixed into the stream bed very close to each other. Brushwood and bushes are formed into bundles and left upstream of the piles on the river bed. The first front of the flood carries the bundles upstream of the piles and forms a deflecting spur, even a diversion dam. Gabions are used in the modern systems. Masonry and concrete diversion weirs are constructed only on solid foundations.

The simplest apron, which stabilizes the river bed at the diversion point, is one row of gabions formed into a prism with a right triangular cross-section whose hypotenuse forms the chute over which water flows. One gabion mattress at each end stabilizes the underlying bank. The costs of building this apron is < 1 % of a reinforced concrete ogee diversion weir of the same capacity (Kowsar and Zargar, 1991). The crest of this apron may be easily raised when siltation in the command area raises its level to that of the crest. Addition of one course of stones in the original gabion, or a new one, makes the apron functional again.

6. Water distribution methods

Fair deal is the keystone of water distribution in arid zone as the infringement in someone's right might mean a certain death for the family involved. The riparian right is very much observed in the spate-irrigated farming communities. The most upstream farm has the one that receives the floodwater. The farms down the line receive their "fair share".

Breaking diversion bunds is done manually in small streams and constructed waterways. However, breaching is usually achieved by the stream flow, when the upstream systems are inundated and further diversion cannot take place. Breaking the lower embankment is practiced in pals in Khorasan, when the operator feels that the soil has been wetted to the required depth. It is obvious that the tail-end irrigators are not happy with this system. In case that a floodwater right owner has scattered fields along the stream or the inundation canal, he may plug an upstream intake in favor of the spate irrigation of a lower field.

As the flow rate of a stream is quite variable, the level of the river and the duration of rainfall event on the main watershed dictate the floodwater share each irrigator receives; the higher the flow and the longer its duration, the larger volume that a field receives. As fairness is a highly respected moral value in the desert communities, the upstream irrigators try not to over-indulge in wetting their fields. Second or third turn in SI occurs only in prolonged flooding.

A more equitable distribution system is a methodical division by a just authority. This is a person of high character that cannot be cowed or bribed easily. This position had been so important in the past that the appointment should be approved by the king.

This is done where the spate-irrigated fields are situated on one or both sides of a river with or without base flow. A strong floodwater manager divides the flow among the beneficiaries who await their turns by the river.

A very rich tradition of SI exists in Khorasan. The hand-dug conveyance canal, up to 10 km in length, is called "*dah yãr*" (10 friends). Floodwater-irrigated cooperatives flourish in many districts in Khorasan, of which those belonging to the Dowlat Abad and Jungle villages, south of Torbat Haydarieh, are discussed. Nine farmers, each owning 20 ha of land, form a cooperative named "*sahra*" (field). Each year 1 of the 9 accepts the position of being the irrigator, "*abyãr*", whose responsibility is receiving the floodwater share of each "*sahra*" from "*pay sãlãr*" (assistant to the commander) and taking it safely to the fields. The river that irrigates thousands of ha along its 100 km length is called "*Kãl-e-Sãlãr*" ("*kãl*"is an ephemeral river in the Khorasani lingo). The commander of the river is "*kãlsãlãr*", who assigns the share of each village to its "*pay sãlãr*". This river conveys the surplus base flow from the upstream villages and floodwater to the downstream farming communities. One-half the area of each "*sahra*" is allowed to lie fallow every year.

It is unfortunate to report that most of the flow in large floods is wasted. For example, the maximum flow in the Dorz-Sãyehbãn area in southeastern Fars is estimated at 1,000 m^3s^{-1} of which < 10 % is harvested. Our concern for a sustainable environment discourages us from the total diversion of even the small floods. This is a dilemma we are facing: what is equitable in floodwater diversion regarding the environmental quality?

7. Area under spate irrigation

400,000 ha in Khorasan (Arabkhedri & Partovi, 1997; Filehkesh, personal communication, 22 Jan. 2008, disputes this figure; he claims that only 57,500 ha were under spate irrigation in 2003); 42,000 ha in Baluchestan (Hoseini Marandi, 2005); 40,000 ha in Izadkhast, Darab (Rahbar& Kowsar, 1997, 2006); 58,300 ha at 38 research stations, and 221,700 ha scattered in different localities around the country (Nejabat, Ph.D. dissertation in preparation). All of these receive floodwater as it arrives. They have received spate in the past 5 - 10 years. The volume received by the research stations amounts to 897,407 million m^3 up to March 20, 2007. We do not have reliable data from other places. The systems in Baluchestan receive 1 - 10 watering per annum.

It is imperative to realize that spate irrigation in most of the Land of Iran functions as the artificial recharge of groundwater as well; the only exceptions are southern Baluchestan and the Izadkhast Plain, Darab, where there is a complete absence of coarse-grained alluvium at easily reachable depths.

Although SI is technically practicable, environmentally sound, financially viable and socially acceptable, simplicity and inexpensiveness (low cost) have put it in disfavor with the national planners, particularly with the consulting engineers whose fees are adjusted by the cost of projects. Therefore, all SI farms operated prior to 1980 are private. They range in area from 0.25 ha to a cooperative, which operates a 300 ha system. These farms are located in Khorasan, Baluchestan and the Izadkhast Plain, Dãrãb.

Please note that the common source of water for the spate irrigation systems in our country is mostly floodwater from ephemeral streams. There are very few permanent rivers whose base flow in winters is used for SI; Kal-e-Sãlãr in Torbat Heydarieh is a case in point.
As the ARG activities are going to cover very extensive farm lands, we hope to see that spate-irrigated cereal fields receive supplemental irrigation from underground resources during droughts. Irrigating the 2nd crop in the summer is another possibility.

As our irrigated agriculture is facing an impending crisis due to groundwater shortage, both private and public concerns are looking deeply into floodwater harvesting for the conjunctive use of SI and supplemental irrigation using groundwater. This is heralding a new era in our water resources management.

Table 2. Categorization of the spate irrigation systems that are common in the I.R. Iran indicating their size: small (S), medium (M) and large (L)

Infrastructure O & M	Traditional systems (TS)	Improved infrastructure (II)	Modernized/New Systems (MN)
Farmers (F)	S, M, L	M, L	M, L
F + Local Gov (LG)	M, L	M, L	M, L
F + Agency (A)	M, L	M, L	M, L
F + LG + A	M, L	M, L	
Specialized Agency[1]			

Table 3. Gender responsibility in the spate irrigation related activities

Activity	Men	Women[2]
Infrastructure related	*	
Operation (water distribution)	*	
Maintenance	*	
Agricultural Practices	*	*
Harvesting	*	*
Marketing	*	*
Others	(List. Farm cooperatives...)	

1) *About 230 ha of the ARG system have been construed with financial cooperation of UNU, UNESCO, ICARDA an the Flemisch Government of belgium as a part of the Sustainable Management of Marginal Drylands (SUMAMAD) program.*
2) *I have met only one lady who did all of the farming chores in Fars province. I do not know about other places in I.R. Iran*

8. Local water users organization

Strict rules regulate floodwater distribution as most people's livelihoods in deserts depend on ephemeral floods. There are fights on the fair share that a downstream district or farm fields should receive. Disputes are usually settled amicably by arbitrators from both sides and/or a third party; however, "shovel fights" sometimes erupt among the claimants in far away places.
It goes without saying that benefiting from a common resource entails a lot of hard work in the repair and maintenance of the delivery system. All of the beneficiaries have to participate in dredging the intakes and conveyance canals. This tradition is so deeply ingrained in Iran that has become an adage: "one who does not live in a village is not obliged to dredge the canal"; i.e. a person who does not benefit from any activity should not share the costs and responsibilities. Construction of the diversion spurs and maintenance of the water distribution system is a survival technique in desert communities.

Considering the vital importance of floodwater utilization in this water-short country, it is surprising that the rules and regulations governing floodwater harvesting systems are not easily accessible. Although there might be written documents regarding the division of floodwater and maintenance of the systems, I have not found them. It is only through the word of mouth, which passes from one generation to the next that people manage their spate irrigation systems. The oldest document available to me is a passage in the Naseri Farsnameh History (Fasaii, 1895) in which the writer has apparently quoted Vassaf (1264 - 1330) without crediting him. Giving the accounts of 1227 during the reign of Abol Mozaffar Atabak Abu Bakr Saad bin Zangui Solghori (praised by Saadi, the famous Persian poet) he stated:

"...then he [the king] made the laws for Shiraz concerning entry taxes and tithes on horses, camels, livestock, donkeys and cows. He [further] levied a 50 % income tax on the farms and estates that utilized floodwaters for irrigation..

Construction and maintenance of SI systems in "pre-tractor era" was mainly by manual labor and draft animals. Now it is done by dozer mounted small tractors, front-end loaders, and graders. The most important and economical earth moving machines are ripper-equipped bulldozers. Small bulldozers are mostly used in farm fields, as the canals and banks occupy about 10 % of the area of an SI system. Larger machines are used in rangelands, particularly for the ARG. Front-end loaders are more suitable for sandy soils in which wire-leaf sedge (*Carex stenophylla Wahl.*) is growing; bulldozers peel the rhizomatous layer that protects the sand against wind and water erosion. A combination of bulldozer and grader gives the best result; bulldozer does the ripping and bank construction; grader does the final leveling of the spilling lip and canals' lower side slope. As most public water works are subsidized, the costs are much lower if one acquires the services of Government-operated bulldozers.

9. Administration

As the majority of the SI systems were constructed by the desert-dwellers themselves, the Government does not interfere with their operation. Thus:

a) All of the systems in Khorasan, Baluchestan and the Izadkhast Plain, Darab, are privately owned.
b) All of the systems at 38 research stations are operated by the Government.
c) 222,700 ha, which have been constructed with the financial and technical assistance of the Government are operated by both public and private bodies.

10. Soil and water conservation

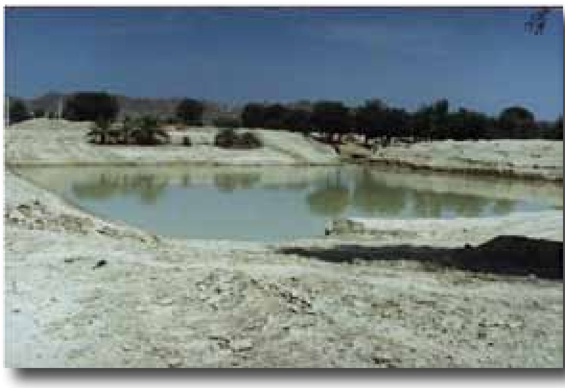
The only traditional soil moisture conservation activity in the SI farms apart from floodwater harvesting is ploughing after the first irrigation, as it ensures seed germination. Ploughing on the contour is a recent practice, particularly in modern systems.

11. Food security strategies

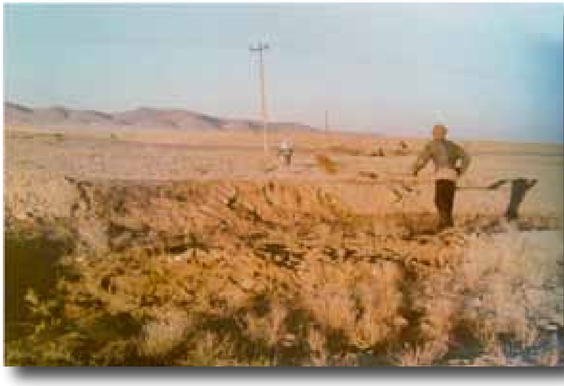
Practicing SI for millennia has taught desert-dwelling farmers hard lessons in coping with droughts. They only grow low water demanding crops and varieties adapted to local agro-climatic conditions. These crops do not fail completely if the floods fail. Another strategy practiced in Baluchestan is plating more water demanding crops, such as maze, on the lowest parts of the fields.
Although we plant small-grained cereals usually

Bandsãr, a spate irrigation system in Khorãsãn, NE Iran

Degãr, a spate irrigation system in Baluchestãn, SE Iran

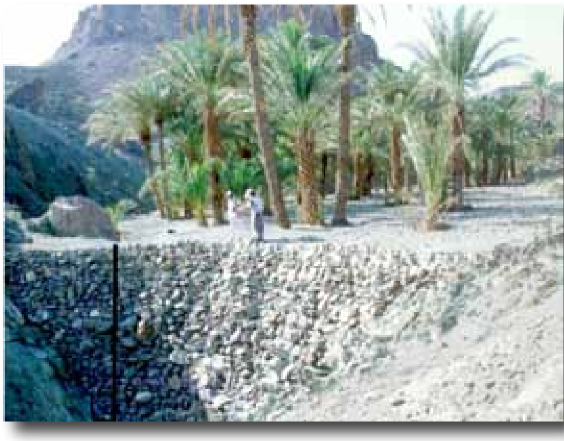


Hootak, a small water reservoir in Baluchestãn, SE Iran

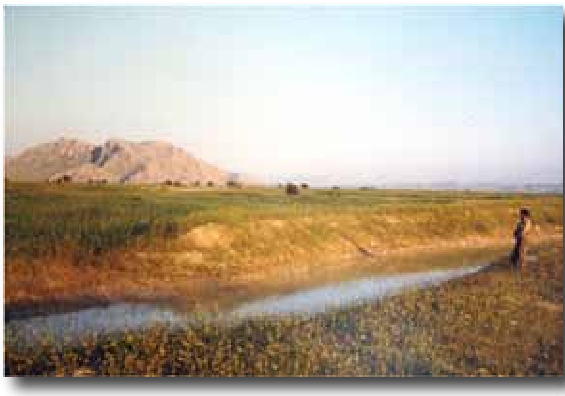


Pal, a spate irrigation system in Khorãsãn, NE Iran

Khooshãb, a spate irrigation system in Baluchestãn, SE Iran



Darband, a spate irrigation system in Baluchestãn, SE Iran



Spate-irrigated wheat in Imãmzãdeh Jaafar, SW Iran

A spate-irrigated barley field at the Kowsar Station in the Gareh Bygone Plain

in the fall, we risk planting them even in late February if there is a good flooding then.
Planting date palms in the spreaders is the surest method of not facing famine during droughts, as these trees fruit in alternate years; therefore, some palms are liable to bear fruit even in the worst of droughts.
Palm groves in southern Fars and the Persian Gulf coast that are spate irrigated are sometimes intercropped with fodder or green-eaten vegetables.

12. Crops grown in the spate-irrigated fields

1. **Baluchestan:** sorghum and corn for silage, mungbeans, wheat, barley, watermelon, melon, peas, alfalfa, sainfoin, onions, lentils (in order of area grown in 4 agricultural communities. The data from 2004 that were published in 2007, give the following average yield of wheat and barley as kg per ha for Chahbahar, Saravan, Sarbaz and Nikshshahr, respectively. Wheat: 1166, 564, 1043, and 1200; Barley: 1937, 717, 2000, not available. The data are from 3243 ha owned by 2020 households; 7.7 % of the spate-irrigated area in Baluchestan). It is imperative to realize that Baluchestan was experiencing one of its longest droughts during the 1999 - 2006 period. The range of yield of spate-irrigated crops in kg per ha for Dargas Village, in Chahbahar follows: sorghum, 2,000 - 6,500; mungbeans, 800 -1100; barley, 600 - 2,500. These crops are grown simultaneously on the same water spreaders. Moreover, soil and water practices are not applied on these farm fields. Wheat yield ranges 500 - 1,500 kg per ha, and date yield ranges 4 - 7 tons per ha in Nikshahr, Qasrqand and Sarbaz.

2. **Khorasan (Sabzevar area):** wheat and barley, 75 %; watermelon, 10 %; caraway, sunflower, sorghum, and corn, 10 %; almond, mulberry, sumac, saxaul, and tamarisk, 5 % (in order of area grown). The ranges in yield as kg per ha in the water-spreaders and control (only rain-fed) are: wheat, 700 - 1200, and 400; watermelon, 10,000 - 13,000 and 7,000; caraway seeds, 200 (not available for the control). These yields are expected in average years when the annual rainfall is 180 - 200 mm. As a rule of thumb, the yield of crops in spate-irrigated fields is 1/3 - 2/3 of the fields using surface irrigation.

3. **At the Kowsar Station in the Gareh Bygone Plain**, we have produced Barley ranging 700 - 2,000 kg per ha with only 145 mm of rainfall and 2 spate irrigation. The average yield of barley in a year with 330 mm of rainfall was 2,300 kg per ha with 3 flooding events. Spate irrigated wheat in Joonegan County, Mamassani (Fars province) produced 1,700 kg per ha, which was 1000 kg higher than that of the rain-fed control (Kowsar & Rahbar, 1991). Dry mater yield of berseem clover in the same place and year was 5 tons per ha in one cutting and 6 tons per ha in 2 cuttings.

13. State of spate-irrigated systems

The falling water tables all over Iran has forced cityward migration of many farmers. Considering that SI farms do not generate all of the income that the operators receive, some are forced to abandon their farms to seek employment somewhere else. This causes deterioration of the SI systems. This calls for Government services in form of subsidized seeds, fertilizers, land preparation and harvesting. However, as research and extension stations are providing demonstration for floodwater harvesting activities, we hope to educate young farmers to become our unpaid extension agents. This along with the Government's initiative offer some hope for the survival of the abandoned systems.

Recurring droughts, which seem to follow cycles in different parts of the country, is another cause for the deterioration of the old systems. Right now we are facing a drought in eastern and southern Fars, while we have abundant precipitation in other provinces.

One of the main constraint for expansion of the modern system, as mentioned before, is their simplicity and low cost as opposed to other methods of water resources engineering.
The “large dam mafia” is the most obvious opposition group.

14. Size of the systems

Geomorphology is a determining factor in the size of the SI farm fields. The farms in mountain valleys are relatively small; those on plains are rather large. Therefore, categorization of size

Table 4. The relative size of the spate-irrigated systems in I.R. Iran; S detones small, M detones medium and L detones large

Infrastructure O & M	Traditional systems (TS)	Improved infrastructure (II)	Modernized/New Systems (MN)
Farmers (F)	S, M, L	M, L	M, L
F + Local Gov (LG)	M, L	M, L	M, L
F + Agency (A)	M, L	M, L	M, L
F + LG + A	M, L	M, L	
Specialized Agency[3]			

should be viewed in the context of location. Thus, a 2 ha *khooshãb* is "large" in northern Baluchestan, and a 10 ha gaband is "small" in the Izadkhast Plain, Dãrãb. However, to be more to the point, the relative size of the SI systems are depicted in Table 4.

15. Bank protection

The banks in the old systems are protected by vegetative cover. Deposition of brushwood on the banks by floodwater, or through dredging operations, help stabilize the banks. Construction of gabion aprons to stabilize the river bed level is a new practice in I.R. Iran, which protect the banks at the diversion points, too.

16. Costs of construction

Note: The only reliable data that I may present and verify their correctness is from our own station in the Gareh Bygone Plain. I quite disagree with other claims, in one case about 30 times as what I report! The listing bellow was for a 100 ha system including a permanent diversion weir (gabion) and bunds guide for 2006. Please note that these costs are for systems that only long time (50-100 years) sediment deposition shall make them useless for the artificial recharge of groundwater, but still well-prepared for spate irrigation.

Surveying @ $ 10.00 per hour	$ 6.00
Bulldozer rental @ 18.00 per hour	$ 54.00
Masonry structure @ 18.00 per m^3	$ 27.00
Gabion structure @ 30.00 per m^3	$ 15.00
Tree planting @ $ 1.00 per tree	$ 18.00
Total	$ 120.00

With the high inflation rate we are facing, $ 160.00 per ha is a good estimate for 2008. The cost of maintenance is 5 - 10% of the original outlay. The benefit: cost ratio for our system, considering the beneficial age of 20 years, has been 20 : 1 without considering its environmental attributes. If one includes the environmental attributes in the analyses, the B: C ratio would increases to 90 : 1; both cases without considering the human casualties incurred in flooding. As our system has been functioning rather smoothly for 24 years, those ratios should increase as well.

The most recent spate-irrigated system constructed by our Center in Galehdar, a remote area in southern Fars cost $ 180 per ha with a sturdy gabion diversion dam. Installment of masonry chutes in the gaps will add another $ 30 per ha.

Construction of earth embankments surrounding pal and bandsar requires 20-25 hours of a 65 HP dozer- equipped tractor at $ 2.20 per hour.

17. Sources of income

The main source of income of the farmers on the Gareh Bygone Plain is the irrigated agriculture, where the artificial recharge of groundwater project supplies the needed water. Most families

3) *About 230 ha of the ARG system have been construced with financial cooperation of UNU, UNESCO, ICARDA an the Flemisch Government of belgium as a part of the Sustainable Management of Marginal Drylands (SUMAMAD) program.*

also own sheep and goats. Raising poultry and warm-water fish is also practiced by some households. Many women weave carpets for an extra income. Many men are employed as manual laborers in off-season periods. The annual per capita income of the villagers in the plain as of September 2003 in US purchasing power parity ranged $ 1061 - 7425, with the average of $ 3044; thus, the mean annual income of an average household in US purchasing power parity would be $19,330. There were 362 households with 6.35 persons per household (Kowsar & Pakparvar, 2004). 10 - 90% of household income is from spate irrigation in Baluchestan (Hoseini, 2005).

18. The national policy

Declaration of aquifer management as a national plan by President Rafsanjani on 26 March 1996 marks a watershed in floodwater harvesting in I.R. Iran. Establishment of 38 research stations in different ecological zones of the country, with the ARG systems covering an area of 58,300 ha in them, has resulted in harvesting about 897,407 million m^3 of floodwater from the fall of 1996 to 20 March 2007. These stations have provided a fertile ground for implementing basic and applied research projects. To the best of my knowledge, 5 doctoral theses have been written on the different aspects of aquifer management, and 3 Ph.D. dissertations are under preparation; moreover, upwards of 20 master's thesis have been written on this subject at these stations. In addition, 221,700 ha of spate irrigation and ARG systems have been constructed by the Forests, Rangeland, and Watershed Management Organization since 1980.

A prolonged drought, 7 - 8 years in different parts of the country, persuaded the policy-makers to decide on a large extent application of aquifer management as a means of drought mitigation. Construction of ARG-SI systems on 1.5 million ha during the 2006 - 2010 period was an outcome of that decision. A solid evidence of this landmark declaration is the appropriation of US $ 1 billion for the management of aquifers and watersheds on 9 July 2006.

19. Spate irrigation: the most logical method for flood-damage mitigation

Contrary to an old adage, "*flood and famine is the twin and alternative curses*", flood is a blessing in disguise; thus, famines may be effectively prevented by floodwater harvesting. Take the turbid water out of floods and nothing remains but prosperity (Kowsar, 1991, 1998a, b)!

Spate irrigation, particularly when intended for implementing multipurpose projects, is taking an integrated approach towards achieving a fraction to whole of each of the 8 Millennium Development Goals to 2015 in most drylands of the world. Flood-damage mitigation (FDM) is the most obvious function of SI, as its short-term dividends in casualty and destruction reduction is enormous. The following published studies clearly demonstrate the efficiency of SI in FDM.

The Gooyom meadow, 20 km to the NW of Shiraz, I.R.Iran, had been functioning as a flood-mitigation reservoir for millennia, minimizing the flood peak entering that city to a manageable flow. However, conversion of that meadow to wheat fields in the early 20th century had deprived the city of this natural defense system against flooding. Construction of a 550 ha of spate irrigation system (SIS), which was originally intended to substantially slow down the rapidly rising watertable in southeastern district of Shiraz, was materialized during the summer of 1982.

The average final infiltration rate of the Gooyom SIS was 37.3 mm hr^{-1} in the spring of 1984 (Raeisi and Kowsar, 1998), which translated to 103 liters per second per ha. Therefore, the 550 ha system retained about 57 m^3s^{-1} of of the flood that was entering Shiraz on 3 Dec. 1986. The peak flow in that event at a bridge close to the Governor General's Office was 343 m^3s^{-1}. Thus, the Gooyom SIS had decreased the maximum flow by 14 %. Therefore, this 550 ha SI wheat fields saved parts of the city from flooding, and decreased the natural recharge of the Shiraz aquifer by about 8 million m^3.

When a flooding of almost the same magnitude, but without the benefit of the Gooyom SIS occurred on 11 Jan.2002, 30 people died, and the city was inflicted with $ 3.75 million in flood-related damages in only one of its shopping districts. If the city had compensated the residents affected by the flooding, and paid the indemnity to the survivors of the diseased, the total monetary damage would have increased at least ten fold of the reported $ 3.75. The unfortunate conversion of the Gooyom SISs to residential area during the 1990s has deprived Shiraz of a safety valve against flooding.

The 8 floodwater spreading systems, covering 1365 ha in the Gareh Bygone Plain in I.R.Iran, accommodated about 100 m^3s^{-1} of the maximum flood stage of 2 rivers with a combined peak flow of 500 m^3s^{-1} on 3 Dec. 1986. The Fasa District, in which the GBP is located, suffered 40 casualties and sustained about $ 1 million in flood-related damages (Kowsar, 1991). Simple arithmetic reveals that this damage could have been prevented if we had 40,000 ha of SISs.

Assuming the flood stage capacity of the Shur River of Jahrom as it leaves the Fasa Basin is 500 m^3s^{-1}, the $ 1million worth of damage incurred by the basin in the deluge of Dec. 1986 was due to 1500 m^3s^{-1} of flow rate above that of the flood stage. This damage, on average, amounted to $666 per m^3s^{-1} of the flow rate. As the average infiltration rate of our SISs in the GBP in that event was 26.4 mm hr^{-1} (74 liters per second per ha), 13.5 ha of the SIS was enough to accommodate 1.0 m^3s^{-1} of floodwater (Kowsar, 1991). Construction cost during the 1983-1986 period was $ 8 per ha; therefore 13.5 ha × $ 8 ha^{-1} = $ 108. Thus, the damage could have been prevented at 1/6 of the financial damage to the Fasa residents, while not causing over 40 deaths. At least 424 people were drowned in that historical flood of Dec.1986 in southern I.R. Iran. As nobody compensates the drowned, no one can accurately estimate the damage incurred by the community.

It is informative to know that we harvested 14.7 million m^3 of floodwater in our GBP systems in the reported event (Kowsar, 1991). As about 80 % of the captured flow reaches the aquifer, we netted 11.5 million m^3 in that event. If we had 6825 ha of SISs operational at that time, we could have harvested 73.5 million m^3 of floodwater, enough for a 7 year rainless period for the agricultural community in the GBP!

A 40 ha SI wheat field has saved the Podonak village in Mamassani from flooding since 1980, when we initiated constructing the modern SISs there (Anon., 1981). This has also happened in Dorz and Sãyehbãn in southeastern Fars province in the deluge of 1995, and in Behrooz Ãbadãd, Dãrãb in the deluge of Dec. 1986. In fact, the SISs mitigate flood-damage wherever they have been installed.

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Recommendations

a. A paradigm shift in water management policies.

As long as the engineers, who are illiterate in ecology-related fields, decide on the fate of floodwater in our country, nothing substantial would happen in applying this technically practicable, environmentally friendly, economically feasible and socially acceptable traditional art and science. It is my dictum that the rulers of a fragile land should be ecologists or at least seek their advice!

b. Public education in conservation of natural resources.

The majority of our population assumes that soil and water are easily renewable resources; therefore they waste both of them. We annually waste upwards of 61 km^3 of floodwater, while suffering 200 deaths and billion of dollars in flooding-related damages. Floodwater harvesting, particularly for the artificial recharge of groundwater, and the prudent utilization of soil and water resources are our only choice for survival; nothing short of miracles can insure the continuation of life in drylands if the current over-exploitation of natural resources, particularly soil and water, continues unchanged.

c. Capacity building and deployment of masses in water-short areas.

Cityward migration, mostly due to water shortage in agricultural communities and nomadic pastureland, is beginning to wreak havoc on our society. Provision of livelihood is the first step in turning back the migration wave. Employing farmers and nomads to construct the spate irrigated systems, particularly for the artificial recharge of groundwater, is a logical way to remedy many social ills. Training the engineers and technicians is very easy; one week to one month, depending on their background. A side benefit of this revolutionary move is the mitigation of flooding casualties and damages, and the rejuvenation of thousands of qanats, our most precious water collection and conveyance systems. Over-pumping has lowered the watertable below the galleries that used to drain the aquifer.

d. Collection of carbon sequestration rent from industrial countries.

At the Kowsar Station in the Gareh Bygone Plain, the above ground carbon sequestration potential of an 18 year old, spate-irrigated *Eucalyptus camaldulensis* Dehnh. was 2.221 tons $ha^{-1}yr^{-1}$; this for *Acacia salicina* Lindl. was 1.304 tons $ha^{-1}yr^{-1}$. As windbreaks mitigate wind erosion, we have to plant adopted trees in our ARG systems. Moreover, the root channels formed after decomposition of fine roots increase the hydraulic conductivity of the vadose zone in sedimentation basins and recharge ponds. Collecting carbon rent from polluters and paying it to farmers is an incentive for growing trees in the vast ARG systems and protecting them from graziers and wood-cutters.

e. Selection of the most suitable crop species and improved varieties.

Modern plant breeders have never tried to select varieties of food and industrial crops for planting under spate irrigation. Spate irrigation is an intermediate between rain-fed farming and irrigation agriculture. Therefore, research on selection and development of the most suitable varieties is badly needed. Genetic engineering offers a tool for materialization of this concept.

f. Offering conditional land tenure.

Land preparation and spate irrigation require a heavy investment of funds and labor; therefore, the operator must be sure of permanent rewards. On the other hand, the shortage of arable land dictates that the field should be under cultivation. Therefore, the occupier of the spate-irrigated land must not leave the land idle. This and other pertinent points should be clearly understood by the concerned parties.

g. Strict enforcement of groundwater utilization.

The vicious cycle of over-exploitation of groundwater and its artificial recharge is going on for the past 25 years in the Gareh Bygone Plain and Dorz and Sãyehbãn in southeastern I.R. Iran. The main reason for an impending disaster in these 2 agricultural communities is a disregard for regulations, and the laxity of law-enforcers. As supplementary irrigation of crops, even in the spate-irrigated fields, is advantageous, utilization of groundwater must be regulated and enforced. Installment of water meter on the pump head should become mandatory.

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List of abbreviations

ARG	artificial recharge of groundwater
AWC	available water capicity
B:C	benefit cost ratio;
CSC	conveyor-spreader channel
FDM	flood damage mitigation
GBP	Gareh Bygone Plain
GIS	Geographic Information System
HP	horse power
MAP	mean annual precipitation
LSC	level-silled channel
SI	spate irrigation
SIS	spate irrigation system

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This Overview Paper is prepared by Professor Sayyed Ahang Kowsar (ahangkowsar@hotmail.com). Special acknowledgement for the preparation of this paper are due to: Esmaeel Filehkesh, Hamid Hoseini Marandi, Mojtaba Pakparvar, Habib Raeisi, Gholamreza Rahbar, Moeineddin Saeedi, and Foroud Sharifi.

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