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ĀBYĀRĪ, “irrigation” in Iran.

Introduction. Although dry farming is important in Azarbaijan, Kurdistan, and Khorasan, as well as some other districts, a large proportion of Iran’s agriculture has always depended upon irrigation. Approximately half the annual grain crop, and an overwhelming proportion of other crops, are irrigated. With the exception of the Caspian littoral almost the whole of Iran is classified as semi-arid or arid. As is characteristic of lands under this classification, precipitation is generally not only scanty (most of the country has an average of less than 400 mm per year) and poorly distributed through the year, but irregular and unreliable. Irrigation affords not only the necessary soil moisture for productive agriculture, but the regularity and dependability of agricultural production that facilitates settled life and allows the development of large settled populations. Given the availability of refillable and accessible water sources, especially in combination with soil deposits of good quality, irrigation technologies can greatly increase the productivity and carrying capacity of the land. However, the use of these technologies imposes social and economic conditions on the populations that become dependent on them. Irrigation has played an important role in Iranian history and civilization. It involves factors that are significant in the development of settlement pattern and morphology, in the socioeconomic relations of agricultural activities, in the political processes and legal formulations that are based on these relations, and in the associated linguistic, symbolic, and ritual forms of activity that evolve in the cultural elaboration of them.

It is not known when or how the various early irrigation technologies evolved. The systematic development of irrigation systems in Southwest Asia appears from archeological evidence to have begun in the sixth millennium B.C. close to the foothills of the Zagros in what is now Iraq and the southwestern Iranian province of Ḵūzestān (Oates and Oates 1976), based on the tributaries of the Mesopotamian river system. Between then and the first millennium B.C., the development of irrigation systems based on runoff and groundwater spread onto the Iranian plateau and throughout most of Iran. This process appears to have been particularly encouraged and facilitated by the Achaemenids (sixth to fourth centuries B.C.; see Polybius 10.28). One of these technologies, known in Iran mainly as *qanāt*, spread into Oman in southeast Arabia towards the end of the same period (Wilkinson 1977), later—with the Arab conquest—into Central and South Asia, North Africa and Spain, and eventually to the New World. There was no further significant technological innovation until the introduction of diesel pumps, tube wells, and reinforced concrete dams. In the middle of the 20th century all these technologies coexisted from the simplest small scale system based on runoff or springs to the largest, most investment-intensive systems based on deep groundwater or large rivers. An extreme example of the latter is now used to improve supplies for rice cultivation in the humid conditions of the Caspian littoral.

Since the more recent development of industrial methods is not specifically Iranian, this article concentrates on the preindustrial forms that not only have been important in the evolution of Iranian culture and civilization but have constituted an important Iranian contribution to the development of water management systems in other parts of the world.

Resources and technologies. Of Iran’s total territory of a little under 165 million hectares an estimated 15 million hectares are arable, and 3.5 million were under irrigated crops in 1973 (*Statistical Yearbook* for 1352 [Š.]). Water for irrigation is obtained from river and spring flow, runoff, and groundwater by means of various systems of barrages, canals and smaller channels, check dams, lifting devices, and underground conduits. These systems are categorized and discussed here in terms of their dependence on rivers, springs, runoff, wells, and *qanāt*s. Unfortunately, figures are not available for the relative contribution of each of these sources to the total, but it is likely that rivers now supply as much as half of the total, and that most of the rest comes almost equally from *qanāt*s and mechanized wells, though the proportion that comes from wells is increasing. Springs, runoff systems, and wells with traditional lifting techniques are probably now negligible on the national scale, although their role is still crucial in some isolated areas. A quarter of a century ago, before the big new dams came into operation, and before diesel pumps were introduced on a large scale *qanāt*s probably accounted for well over half of the total, and the runoff systems and wells with traditional lifting techniques were also proportionately more significant.

River flow, especially on the plateau, even in the larger rivers, varies greatly from season to season. For example, the maximum recorded April flow of the Kārūn is 60,000-75,000 cubic feet per second (cusecs), while the minimum recorded October flow is 7,000 cusecs. The same figures for rivers that are important sources of irrigation water in other parts of the country are 60,000 and 1,000 for the Zāyanda-rūd and 60,000 and 2,000 for the Helmand. This variation poses the major engineering problem for traditional and modern irrigation schemes. A rudimentary technique that was probably one of the earliest types of irrigation both on and off the plateau, as well as in Mesopotamia, was simply to facilitate the flow of flood water on to adjacent land. This technique is known as basin irrigation. It required minimal control or investment, and has been particularly important in the history of the Nile valley in Egypt. The length of time each year that the flow could be utilized was soon extended by the simple expedient of a primitive barrage of assorted materials—rocks, wood, brush, and mud—that would maintain the level of the river as the flood went down, so that the flow could be diverted into channels and led onto prepared fields. Finally, it would be washed away by the next year's flood. So long as there was no capability to build a structure that would withstand the annual flood at its height, the barrage had to be rebuilt annually. The Achaemenids and Parthians took the next steps in the extension of perennial irrigation, and the Sasanians brought it to a high level of sophistication by the use of cut stone and mortar with steel clamps cast in with lead. The most celebrated of the Sasanian dams is the Šādorvān (q.v.), which was built by the Sasanian king Šāpūr on the Kārūn river with the aid of prisoners taken in his victory over the Roman emperor Valerian in 260 A.D. Other examples are the Band-e Amīr in Fārs, and the Band-e Farīdūn in Khorasan, and ruins of others have been recorded elsewhere. The still intact Ḵᵛājū Bridge (q.v.), which was built on the Zāyanda-rūd at Isfahan by Shah ʿAbbās II (1642-66) on earlier foundations is a similar structure, which incorporates sluice gates and provides a permanent roadway across the river.

Unfortunately, the Sasanian engineers appear not to have understood the ecological need for adequate drainage of water from the land to complement their success in engineering the control of waterflow onto the land. In the succeeding period agricultural production appears to have dropped significantly on these river systems, especially in Ḵūzestān, where salinity is known to have been a factor. Reduction of soil fertility through salinization can be caused both by over-irrigation and by under-irrigation.

All water that might be used for irrigation contains minerals dissolved from the rocks it has flowed over. The rivers of Ḵūzestān contain common salt, gypsum, and calcium carbonate. Evaporation, intensified by the hot arid conditions, increases the mineral content of the water; and evapotranspiration (during irrigation) increases it still further, with the result that the minerals are precipitated in the soil. In due course the soil becomes too saline for crop growth. Over-irrigation may wash the minerals down out of the topsoil, but in time will raise the water table to the point where capillary action brings them back to the surface. Sodium salts have the added disadvantage of impairing the drainage properties of the soil and so of preventing desalinization. Southern Ḵūzestān, where greater heat and aridity increase irrigation needs, suffers particularly badly from this condition (cf. Kirkby 1977, p. 252).

The Helmand system in eastern Iran also declined in the 10th century, probably for similar reasons. Sasanian technologies were discontinued, and the population reverted to relatively primitive barrage systems. The annual rebuilding of the major barrage on the Helmand, the Band-e Sīstān or Band-e Kohak (which was essential in order to maintain a good head of water in the canal known as Rūd-e Sīstān, which took off just above it) was the most important event of the year in the area. It was described by a traveler at the turn of the century (Tate 1909, pp. 224-26). The operation was begun by government edict in mid-August between the summer harvest and the autumn plowing and took a month. Some forty thousand men took part in it. Construction was extended out from each bank simultaneously, meeting in an obtuse angle pointing upstream in the deepest part of the channel, which was considerably closer to the Afghan bank. Lines of upright stakes were laid out and the space between them packed with fascines of tamarisk twigs—some 450,000 fascines in all, representing as much as 2,000 tons of wood. Although a considerable quantity of water escaped through this weir, relieving the pressure on it, the purpose was adequately served, for the canal and its distributaries were filled. The top of the barrage constituted a causeway ten feet wide and 500 yards long.

Major investment in reinforced concrete structures was begun in the 1950s. These new dam systems are now estimated to provide storage capacity of 13.6 billion cubic meters, and new dams are planned that would double this (*Statistical Yearbook* for 1352). Based on international exchange of experience from other major systems in the Indus, Mesopotamia, and the Oxus, these new systems are being equipped with drainage networks. (They also provide hydroelectric power.) Another problem has now taken precedence which threatens to shorten their useful life. The dams are silting up faster than had been envisaged at the planning stage. This apparently accelerated rate of siltation due to soil erosion is blamed on reduction of vegetation cover resulting from the environmental effects of increased land use pressures. A number of watershed conservation programs have been instituted in order to combat this process. (See also articles on other rivers, e.g., Karḵa, Dez, Aras, Kašaf-rūd, Ḥabla-rūd, Safīd-rūd and Qom-rūd.)

Another technology for the use of surface water which has also been important in the history of settlement on the Iranian plateau is the *band* or checkdam. *Band*s were probably used as early or earlier than rivers as a means to increase agricultural productivity. They are generally developed on a smaller scale than riverine systems (although vestiges of large examples have been recorded and investigated by archeologists in Pakistan; see Raikes 1965). They afford the possibility of maximizing the use of irregular and ephemeral stream flow or runoff and at the same time accumulating soil deposits in mountainous or undulating terrain where either soil or soil moisture would otherwise be insufficient for cultivation.

The *band* is a dry stone or earthen structure built across the course of drainage to hold the water while it drops its silt and sinks slowly through the accumulated deposit. Although this technology is probably no longer of economic significance on the national level, it is still an important form of land use in many districts, especially in the east and southeast (Qāʾenāt and Makrān). As a low investment technology in isolated mountainous areas with sparse population such as Baluchistan, it provides nomads with the capability of raising small quantities of fruit and vegetables and supplementary crops of grain, while in arid agricultural districts such as Gonābād and elsewhere in Khorasan it allows the production of a large melon crop which would not warrant the use of the staple irrigation supply.

It is not known when wells were first used for irrigation. Wells are known archeologically to have been in use for domestic purposes in the Indus valley in the third millennium, and there are earlier instances from sites in Mesopotamia. It is likely that they were used for the exploitation of at least shallow groundwater throughout Southwest Asia from the earliest periods of settlement in the area. Without mechanization wells are of limited use for irrigation because of the technical problem of raising the water and the economic problem of raising it in sufficient quantities to justify the labor and expenditure. Both of these problems increase exponentially with the depth of the water table. Traditional techniques for raising water from wells include the *šadof*, a long pole with a bucket attached by a rope to one end and a counterbalancing weight on the other end, and the *gāvčāh*, a method by which one or two draft animals raise the bucket by drawing the rope down an adjacent runway into the ground. Such techniques traditionally used a skin bucket that according to reports varied in capacity from 10 to 60 liters. Other techniques for raising water from wells or from rivers in the ancient world, such as the Persian wheel, are not presently in use in Iran. Wells with traditional lifting mechanisms have been important mainly in the south of Iran, especially on the coastal plain of the Persian Gulf north of Bandar ʿAbbās and west of Bampūr in the Jaz Moryān depression in Baluchistan.

The most important technological development in the history of irrigation in Iran was the *qanāt*. It appears to have originated in the northwest of the plateau towards the end of the first half of the first millennium B.C. and to have been developed from mining technology. It spread over the plateau and further under the Achaemenids, suddenly opening up vast new areas to agriculture and settlement. Unlike Sasanian dam construction which was labor intensive and demanded a political system that allowed efficient organization of large numbers of people for limited periods in construction and maintenance, *qanāt* construction was relatively capital intensive. Although there is great variation in the length, depth, and discharge of *qanāt*s as well as in the difficulty of digging in different soils and substrata, typically *qanāt*s are over 0.5 km long, and the “mother well” where the underground channel begins is over 10 m deep. The longest recorded *qanāt* is over 50 km (in Kermān), and the deepest mother well is reported to be 300 m (in Gonābād). Yazd, Kermān and Gonābād, on the western, southern, and eastern margins of the central desert respectively, are the arid agricultural areas best known for their dependence on extensive *ganat* systems. *Qanāt* construction was normally carried out by three men—one to dig, one to send up the excavated material in a skin, and one above ground to operate the windlass and empty out the skin. Progress was seldom more than a few meters per day, because even if the earth was soft time would be spent lining the channel with pottery hoops to prevent collapse. Construction often required continuous investment for years, even generations. In the early 1960s a team of *moqannī*s (skilled *ganāt* diggers) worked around the clock continuously for a year to extend a *qanāt* in a village close to Yazd for 150 rials per meter. In that time they extended the conduit 3.5 km for a total cost of 537,600 rials or just over $7,000 (Bonine 1977).

The scale of a *qanāt* building operation in terms of labor and investment differed significantly from dam construction and the engineering of riverine irrigation. The latter, as for example under the Sasanians, depended on political organization and planning at the governmental level. The type of investment demanded by *qanāt* technology was well suited for the settlement pattern that it facilitated over the plateau. City and town based merchants and landowners operating as individuals, or in small groups, financed *qanāt* building in their agricultural hinterland and developed agricultural colonies on the land thus brought under cultivation. *Qanāt* building therefore did not encourage political processes that might have structured the political unification of the plateau, as for example has been suggested as a consequence of riverine irrigation systems in Mesopotamia.

In the mid-20th century a good estimate of the total number of working *qanāt*s in Iran would be close to 50,000. A great advantage of the *qanāt* in the pre-industrial era was that once the water was flowing, it continued flowing (barring disasters such as floods and earthquakes, or damage resulting from hostilities). In some cases the flow would fluctuate with precipitation levels, in others not—according to the nature of the water table. A certain amount of regular maintenance was necessary to maximize the flow—more where the *qanāt* was built through soft or sandy substrata, as in Kermān. In one example in Kermān in 1950, two *qanāt*s that cost in the region of $84,000 each to build and yielded 2 and 1.3 cusecs, and irrigated 80 and 50 hectares respectively, both had annual maintenance costs of around $400 (Beckett 1953, 1957). When ownership was divided among a number of farmers with unequal shares, there were often difficulties in organizing maintenance work, and these difficulties were cited in arguments against land reform in the 1960s. Generally, therefore, *qanāt*s were consistent with a subsistence economy, and they had the added advantage of being able to tap very poor aquifers (Beckett

1957, p. 27).

The industrial era with its attendant problems of population in relation to resources has put a premium on flexibility and economy and led to the need to turn off water flow when it is not needed. Little or no new *qanāt* excavation has taken place since the late 1960s and, as existing *qanāt*s fall into disrepair, they are often left to go out of use. Instead diesel pumps are being put on wells which can be sunk relatively easily at the most suitable site. The flow may be turned on and off as needed. The pumps can be moved from well to well if necessary, and the operating costs can be met from the current account of the cash economy. Furthermore, as more wells are sunk in a given district, the water table is lowered and the remaining *qanāt*s are left high and dry.

Delivery and distribution. Although making ground water and surface flow available is the primary engineering problem in irrigation, the water is useless without the organization that will put together the flow, the people who own shares in it and in the land to be irrigated, and the different needs of various crops. Water must be distributed to each parcel of each shareholder's land at intervals suitable for the particular crop in sufficient quantity. If the interval is too long or the water too little, the crop will suffer directly; too much water may leach out nutrients, keep air out of the soil, cause erosion, and reduce fertility. The amount of water arriving at the beginning of a particular irrigation system may be little more than a trickle in the case of a small spring or *qanāt* or a traditional well system with *šadof*; it may be very large in the case of a large river or modern dam system. Where the flow is particularly meager, it may be ponded in an excavated tank to allow sufficient "head" to build up before it is released into the channels that distribute it to the fields. By this technique the speed of flow is increased, and loss through seepage and evaporation is reduced. Where the flow is large it may be divided into two or more channels at the entry to the system by a sluice.

A typical *qanāt* delivers 1-2 cusecs. One cusec provides nearly two acre feet or about 8,000 cubic meters in twenty-four hours. Because of seepage and evaporation, flow will diminish according to distance from the head of the system. Losses of up to 50 percent have been estimated in extreme situations. For this reason, land closer to the water source is not only more valuable, but tends to be cultivated every year, while very distant land might be cultivated only in unusually good years. Land must be prepared so that the channel gradient will be sufficient to keep the water flowing and minimize evaporation and ponding, but not enough to cause erosion. Land parcels must be divided into leveled segments of a size that depending on slope, flow, and soil permeability will allow the far corners to be watered before the near end is over-irrigated, causing unnecessary loss of water down beyond the root zone. Water shares are measured in units of time, the names and values of which vary from place to place (for detailed lists and discussions, see Lambton 1953, p. 408 and Bonine 1977). Individuals may own the equivalent of a few minutes, hours, a half day, a day, or more. All the shares together amount to a period as little as six and as much as twenty-two days, which constitutes the cycle of the system, after which it starts again from the beginning. In some cases the cycle ends in an odd half day, so that an individual's share will fall alternately during the night and day in successive cycles and spread seasonal differences in day length and evaporation loss evenly among users. Crop needs vary, presenting a major organizational problem in relation to the water distribution cycle. For example, wheat and barley need only two to three applications at twenty to twenty-five day intervals and depending on spring rains, while some summer and early autumn crops require weekly applications.

In situations where relatively large amounts of water and fairly fine time measurements—by minutes rather than hours—were involved, an official known as *mīrāb* (i.e., *amīr-e āb* "commander of water") was appointed to oversee the system. The *mīrāb* sits at the head of the system and measures the shares. In the most common form of measurement, he would place a metal bowl with a small hole in it in a larger bowl filled with water. The smaller bowl would gradually sink as the water entered the hole. When it clunked to the bottom, a unit of flow would be ended, and the *mīrāb* would move a pebble from one side of the bowls to the other to mark the number of units elapsed. In 1943, the government instituted an Independent Irrigation Agency to oversee the full range of irrigation activities. In 1963, this Agency was incorporated into the Ministry of Water and Power which was later renamed the Ministry of Energy.

According to Islamic law water can not be bought or sold. However, the channels and other vessels through which the water passes are the subject of commercial transaction. Rates for sale and renting vary greatly depending on flow, type of systems, soil, predominant crop, marketing possibilities, and other social and economic factors. All rates have changed greatly as a result of the increasing industrialization and mechanization of the last twenty years in ways that make generalization difficult. Before these modern changes, the price of a given water source could be expected to vary annually in keeping with any changes in the flow. Water was generally reckoned at between one-quarter and one-eighth of the total cost of production according to place and system. Most commonly, the total costs of production are reckoned to be divided equally in five parts, which were allotted to water, land, seed, plow animals, and labor. The sale price of a share in the source did not fluctuate as much as the rental value but was typically valued at ten times the annual tent.

Islamic law provides the framework for the regulation of irrigation, which is supplemented by local law and practice. Where two or more communities share the same source, upstream communities have priority over downstream, unless there is general agreement on an integrated system of irrigation. An excellent example of such an integrated system is provided in the Isfahan basin by the traditional system for the regulation of the water of the Zāyanda-rūd. A manuscript account of this system has been translated and discussed by Lambton (1937-39). Although of uncertain date, it probably reflects an ancient dispensation. It depends implicitly on the political integration of the basin and demonstrates an important administrative emphasis on efficient agricultural production.

The important agricultural district of Garmsār, 100 km southeast of Tehran, provides an interesting example of a smaller, less formalized system, which also integrates seasonal river flow with *qanāt*s. River flow from the Ḥabla-rūd is divided where it enters the plain into a number of channels, one for a each village. In 1956, when the system was described by an ethnographer (Alberts 1963, pp. 297-301), this division was overseen by a control station maintained by the government Irrigation Agency. In summer, when water was scarce, villagers patrolled upstream from their own land to prevent poaching. In spring flash floods damaged channels sporadically, and men were often out day and night repairing and reinforcing the system and diverting floodwater away from the fields. Water flow was measured in *sang* or “stone”, traditionally interpreted to mean “sufficient water to turn a millstone” (although mills typically required more than one *sang*). The *sang* that Alberts measured approximated 15 liters per second. Other measures are used elsewhere, and the same measure often has different values in different places (cf. Lambton 1953, glossary). The seventy-three villages of Garmsār had 380 *sang*. Of these, 315 came from the Ḥabla-rūd and the remainder from *qanāt*s. Fifty-nine villages depended entirely on the river, three entirely on *qanāt*s, while the remaining eleven used both. There were thirty functioning *qanāt*s, some fifteen in various stages of disrepair, and others under construction. Allotment of river flow per village was determined by the Irrigation Agency according to acreage and population, but reallotment in accordance with changing conditions was difficult and irregular, and seven villages bought water to supplement their share. Others would have bought extra water if they could have found anyone willing to sell. The actual volume of water in such arrangements is determined by *šab-andar-rūz*, which is continuous flow for a twenty-four hour period at a particular rate of *sang*. Prices vary regionally and according to season. For example one *šab-andar-rūz* at one *sang* cost 40 rials in March, 50 in April, and over 60 in June. Since river water generally goes with land, some villagers seek to buy land in other villages in order to acquire additional water rights. Generally one *sang* was available for each 25 ha of irrigable land in *ḵāleṣa* (q.v.) villages in Garmsār, and one for every 37 ha in the remainder. Deep wells are now integrated into the Garmsār system and are replacing *qanāt*s, but at the time of Alberts' study well construction was still too expensive for private investors because of the depth of the water table, which was 40-45 meters in summer.

Irrigation and society. The different conditions that have developed from different solutions to the problem of supplementing precipitation to provide the necessary degree of soil moisture for optimum cultivation demand certain degrees and types of cooperation among cultivators. Specifically, cooperation is necessary to provide the financing and labor to develop and maintain the systems, and the spatial and temporal organization to run them. The structure of social relations varies from place to place, and this variation affects the ability to effect this cooperation. The organization of investment in *qanāt* maintenance for example appears from the range of relevant recorded examples to have run into trouble where a politically and economically dominant party was removed from the scene (see Spooner, "Irrigation and Society"); however, in more egalitarian situations examples are recorded where the irrigation cycle has been extended for a day or more and the value of the extra time used to finance the necessary work, effectively devaluing all existing shares (see, e.g., Bonine 1977).

The original colonization of most of the plateau, beyond the few centers that could be established on rivers, is likely to have depended not only on *qanāt* technology, but on the social and economic security that would allow these forms of cooperation to develop and spread over a number of generations. The Achaemenids were probably the first to provide this security, and the hypothesis that they were therefore responsible for the development of the present settlement pattern in Iran fits the available evidence. The most important aspect of *qanāt* technology in this context is that besides increasing the water supply it stabilized it, for *qanāt* flow is relatively unaffected by seasonal and annual fluctuations in precipitation. This effect of what may be termed the "*qanāt* revolution" would have made possible an unprecedented growth in settled agricultural life, and consequently also of urban population. Between the *qanāt* revolution and the recent oil revolution, the major *qanāt* systems of the plateau have fluctuated with the prosperity of the relatively stable paradigm of non-tribal peasant agriculture, economically dominated by fairly evenly distributed urban centers. During this period, in the absence of any significant technological innovation, cities on the plateau have gown and declined in succession, partly because of political decisions (e.g., choice of capital) and resulting changes in patterns of communications and trade and investment and partly because of migations onto the plateau and resulting fluctuations in security. The determining factor in the growth and decline of cities during this period was due not to changes in the basic availability of water or the occurrence of other environmental problems such as salinity, as has been the case in many economies based on irrigated agriculture, such as Mesopotamia, but to changes in the investment pattern. The exigencies of irrigation therefore help to explain the bias toward urban life in Iranian culture, because the exploitation of the countryside depended on the (largely private) financial institutions in the cities which determined ultimately where and when and to what extent satellite agricultural settlements would be developed (Spooner, "City and River").

Besides the role of irrigation in Iranian history, it may be seen in the morphology of settlements and sensed in Iranian literature and art. Before the introduction of mechanized and industrial forms of irrigation, settlements developed along the open channels that carried the essential water supply. The lines of the channels were determined by the simple fact that water flows downhill, and they were connected by cross streets forming a pattern resembling an irregular grid. Where settlement had spread onto agricultural land, which was the most common direction of development, the grid becomes even more obvious, because of the existing pattern of channels that delivered water to regular plots of land (see Bonine 1979). Elite settlement also tended to spread upstream where the water was purer and the air cooler (English 1966). Spread in this direction took the form of orchards, which in Persian are equated with gardens (*bāḡ*). The Persian Garden in its classic form is descended from Sasanian royal enclosures, but the tradition is closely related to the folk tradition of these orchards, where intensive perennial irrigation in a small part of almost every village creates, in complete contrast with the surrounding steppe and desert, a lush green environment which is linked in the symbolism of a rich poetic tradition with the concept of paradise.

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M. J. Kirkby, "Land and Water Resources of the Deh Luran and Khuzistan Plains," in *Studies in the Archaeological History of the Deh Luran Plain*, by F. Hole, Memoirs of the Museum of Anthropology, University of Michigan, number 9, Ann Arbor, 1977, pp. 251-88, assesses the environmental effects of irrigation in part of southwestern Iran; and J. A. Neely, "Sassanian and Early Islamic Water Control and Irrigation Systems on the Deh Luran Plain, Iran," in *Irrigation's Impact on Society*, edited by T. E. Downing and M. Gibson, Tucson, 1974, pp. 2l-42, and R. J. Wenke, "Imperial Investments and Agricultural Developments in Parthian and Sassanian Khuzistan 150 BC to 640 AD," in *Mesopotamia* 10-11, 1975-76, pp. 31-221, discuss the archeological evidence for the same area and period. The history of irrigation up to this point has been

put into larger geopolitical perspective by B. Spooner, "City and River in Iran, Urbanization and Irrigation of the Iranian Plateau," *Iranian Studies* 7, 1974, pp. 681-713.

The best general introduction to irrigation in the Islamic period is in A. K. S. Lambton, *Landlord and Peasant in Persia*, London, 1953, chap. 10. Lambton is mainly concerned with the social and economic aspects of the practice of irrigation in relation to Islamic law, and she includes discussion of relevant medieval Persian works. In an earlier article, "The Regulation of the Waters of the Zāyande Rūd," *BSOS* 9, 1937-39, pp. 663-73, she discusses the major riverine system on the plateau in relation to a description of it in a medieval text. The account cited above of the annual rebuilding of the barrage in Sīstān is from G. P. Tate, *The Frontiers of Baluchistan*, London, 1909.

Enbāṭ al-mīāʾ al-ḵafīa, written in 1017 A.D. by Abu Bakr Moḥammad b. al-Ḥasan (al-Ḥāseb) al-Karaǰī and translated into Persian and published in 1966 as *Esteḵrāǰ-e ābhā-ye penhānī*, analyzes ground water occurrences and the engineering and surveying techniques necessary to exploit them. This work is now translated into French with a detailed commentary by A. Mazaheri as *La Civilisation des eaux cachées, traité de l'exploitation des eaux souterraines, composé en 1017 par Mohammad al Karagi*, Université de Nice, 1973. Important research on the origins and spread of *qanāt*s has been carried out by H. Goblot; see, for example, "Le problème de l'eau en Iran," *Orient* 23, 1962, pp. 46-55, which had been translated as "Water Resources of Iran" in *The Economic History of Iran 1800-1914*, ed. C. Issawi, Chicago, 1971, pp. 214-19. Other articles by Goblot and others will be found in the bibliography to the article on *qanāt*, but the following are particularly noteworthy with regard to the use of *qanāt* flow for irrigation: E. Noel, "Qanats," *Journal of the Royal Central Asian Society* 31, 1944, pp. 191-202; P. Beaumont, "Qanats on the Varamin Plain," *Transactions of the Institute of British Geographers* 45, 1968, pp. 169-78; idem, "Qanat Systems in Iran," *Bulletin of the International Association of Scientific Hydrology* 16, 1971, pp. 39-50; and M. E. Bonine, "Traditional Irrigation Systems and Practices in Central Iran," paper presented at the Festival of Popular Traditions, Isfahan, Iran, October 12-19, 1977. Material relevant to water raising techniques may be found in M. S. Drower, "Water Supply, Irrigation and Agriculture," in *A History of Technology*, ed. C. Singer, E. J. Holmyard, and A. R. Hall, London, 1954-58. Archeological evidence of *band*s is discussed in R. L. Raikes, "The Ancient Gabarbands of Baluchistan," *East and West* 15, 1965, pp. 26-35. Probably the best all around account of irrigation technology is H. E. Wulff, *The Traditional Crafts of Persia*, Cambridge, Mass., 1966.

R. C. Alberts, *Social Structure and Culture Change in an Iranian Village*, Ann Arbor, University Microfilms, 1963, provides one of the best accounts available of the operation of a complex irrigation system in its social context, and P. W. English, *City and Village in Iran; Settlement and Economy in the Kerman Basin*, Madison, 1966, elucidates some interesting aspects of the interrelation of *qanāt* technology and socio-economic processes. Further information on the area around Kermān may be found in P. H. T. Beckett, "Qanats around Kerman," *Journal of the Royal Central Asian Society* 40, 1953, pp. 47-58 and "Agriculture in Central Persia," *Tropical Agriculture* 34, 1957, pp. 9-28, and on Mašhad in D. J. Flower, "Water Use in Northeast Iran," in *Camb. Hist. Iran* I, pp. 599-610. B. Spooner "Irrigation and Society on the Iranian Plateau," in *Irrigation's Impact*, above, pp. 43-57, seeks to sort out various aspects of the social and economic organization of irrigation in two small isolated villages in southern Khorasan, and M. E. Bonine "The Morphogenesis of Iranian Cities," *Annals of the Association of American Geographers* 69, 1979, pp. 208-24, develops the idea of a causal relationship between the delivery of irrigation water and settlement morphology. Finally, basic statistics can be found in the series *Statistical Yearbook of Iran*, Tehran, Statistical Center of Iran.

More specialized bibliographies may be found under the articles on specific irrigation technologies and particular rivers and districts.