Wadi development for agriculture in Yemen Arab Republic

Tihama Development Authority
Yemen Arab Republic

1. Country background

The Yemen Arab Republic (YAR) lies at the south-western corner of the Arabian Peninsula between longitude 43° and 45° east and latitude 13° and 17° north. The country has four geographical zones which are, from east to west:

i. desert area connected with R'ub el Khali Desert;
ii. central highlands rising to almost 3 500 metres above sea level;
iii. midlands, a mountainous region of medium altitude; and
iv. lowlands, or Tihama, a coastal plain parallel to the Red Sea; 30 to 60 kilometres wide, sloping gently seaward, with little local relief, and the highest point about 250 metres above sea level (Figure 1).

1.1 Climate

The Yemen has a dry climate. Potential evapotranspiration exceeds monthly precipitation throughout the year. In some rain-exposed locations on the western escarpment, e.g. the area around Ibb, the rainfall equals or exceeds potential evapotranspiration for about three months per year. Temperature varies greatly with altitude: from the hot, tropical climate of the lowlands to the temperate climate of the mountain areas.

1.2 Soils

Most of the soils in the Tihama area are arable. There is a wide, fairly flat, alluvial fan formed by flood deposits of mixed sediments which has a 0.5 percent to 1 percent slope east to west. The soils have relatively narrow ranges in colour, texture, clay minerology, chemical and physical properties. Much layering has occurred due to frequent depositions of silt by flood waters. There are small areas of sandy soils. A schematic hydro-geological cross-section of the Tihama Plain for Wadi Zabid is shown in figure 2.

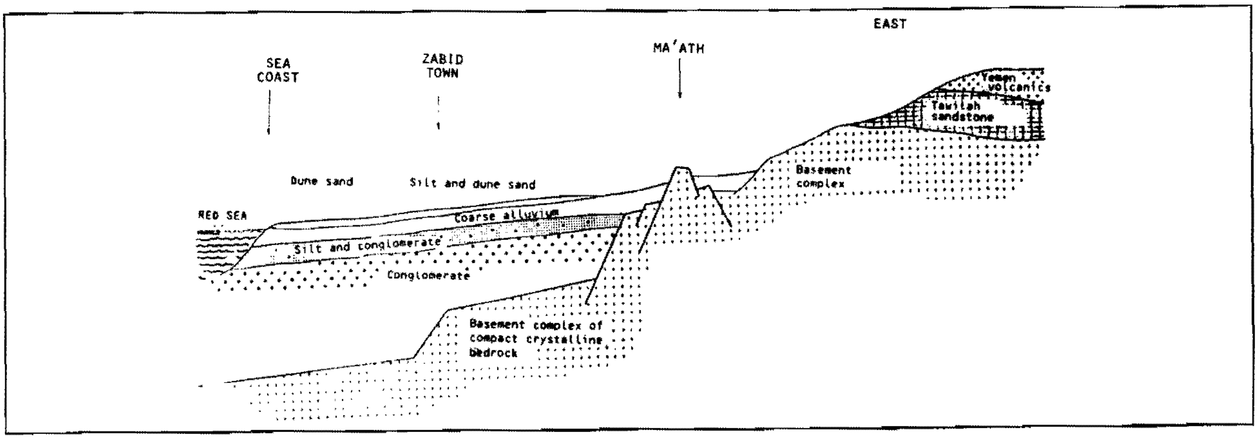
The soils are classified as Entisoils (recent soils without profile differentiation) and are light brown in colour, have a high silt content (most of them are silt loams), a moderate water holding capacity, and are low in organic matter (0.4 percent to 0.5 percent). The cation exchange capacity is about one milli-equivalent per gram of clay. The clay is montmorillonitic and the soils are slightly alkaline (PH 8-8.4) with a lime content of 1 percent to 9 percent.

Few of the soils are saline and fewer are high in exchangeable sodium. The physical properties of these soils are favourable, and drainage is not a problem because of the slope and permeable subsoil layers.

1.3 Wadi hydrology

The principal Tihama catchment basins are shown in Figure 1. The main wadis are, from north to south: Wadi Mawr, Wadi Surdud, Wadi Siham, Wadi Rima, Wadi Zabid and Wadi Raysan. Wadi Al-Jawf and Wadi As-Sudd, the site of the Marib Rock-fill dam, are to the east of the main water divide.

Figure 2. Schematic geological section of Wadi Zabid in east-west direction (after Tesco-Viziterv-Vituki 1971)



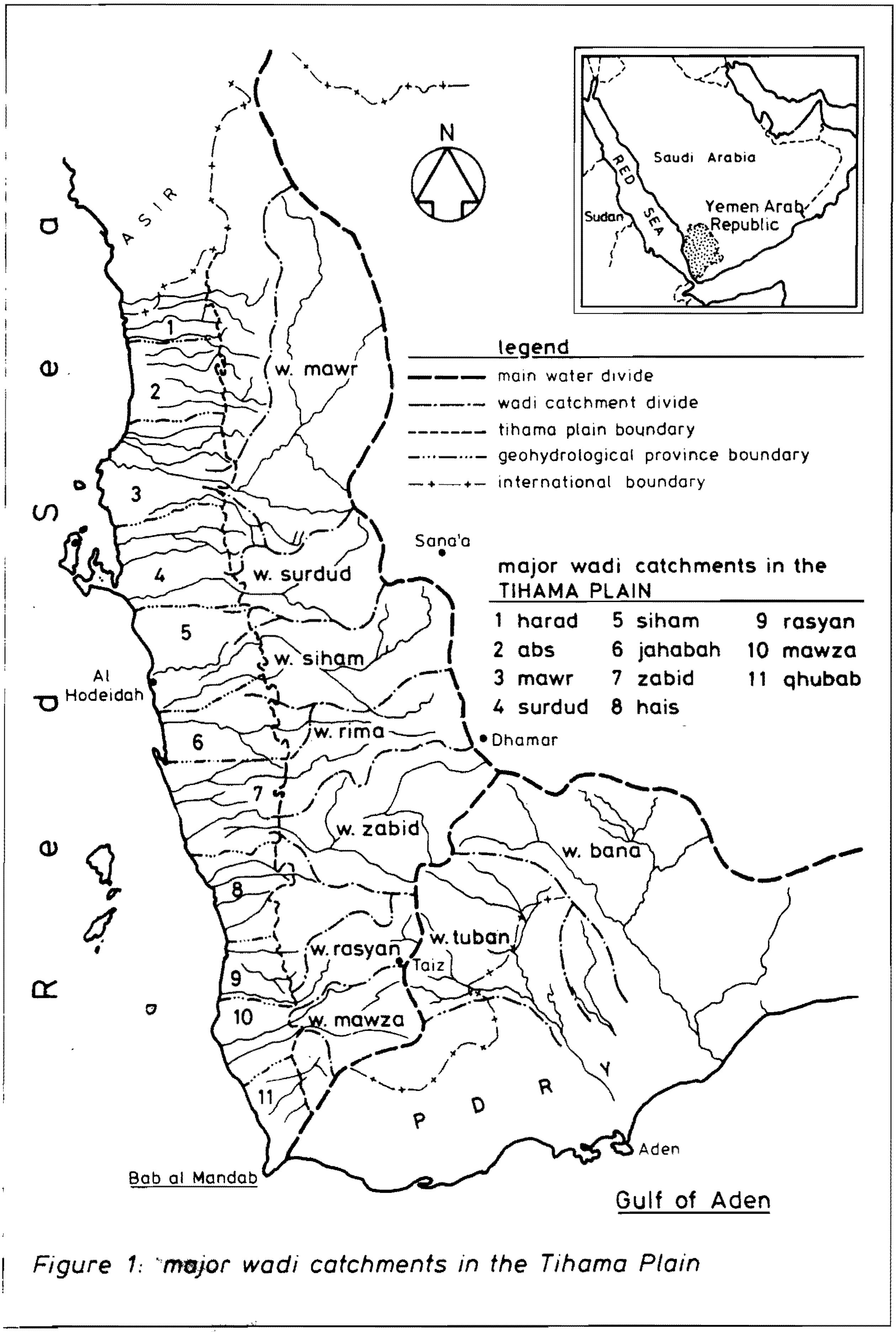


Figure 1: major wadi catchments in the Tihama Plain

Figure 1 Catchment areas of the major wadis in the Tihama plain

Table 1. Runoff volumes reaching the Tihama and the eastern zone

Zone	Runoff-producing area (km^2)	Mean annual precipitation (mm)	Estimated mean annual runoff (mm)	(10^6 m^3/yr)
Western escarpment				
Wadi Mawr	7800	480	30.4	237
Wadi Surdud	2750	650	44.0	121
Wadi Siham	4050	500	32.0	130
Wadi Rima	2750	570	37.6	103
Wadi Zabid	4450	560	36.8	164
Wadi Rasyan	1700	500	32.0	54
Wadi Mawza	1600	400	24.0	38
Other basins	5000	400	24.0	120
Total	30100			967 (= 32 mm)
Eastern escarpment				
Wadi Al Jawf	11000	140	3.2	35
Wadi As Sudd	8300	150	4.0	33
Wadi Bayhan	3800	150	4.0	15
Other basins	6000	120	1.6	10
Total	29100			93 (= 3 mm)

Estimates of the runoff volumes reaching the Tihama and the eastern zone are shown in Table 1. The estimated mean annual runoff in the western escarpment is about 967 million m^3/year, and about 93 million m^3/year in the eastern escarpment and other basins. The monthly flow distribution of Wadis Mawr, Rima and Zabid is represented in figure 3.

Water samples collected from Wadi Zabid flood flows contained about 550 ppm soluble salts. The electric conductivity of water samples taken from base flow in Wadi Mawr was 500-800 micro mhos-cm, and very well suited to irrigation.

Table 2. Distribution of agricultural land in YAR

Rainfed	area (million ha)	
Less than 450 mm/year	0.71	
450 - 600 mm/year	0.22	
over 600 mm/year	0.19	
Total rainfed		1.12
Irrigated		
Spate irrigation	0.11	
Pump irrigation	0.12	
Total irrigated		0.23
Total agricultural land		1.35

1.4 Agriculture

The main problems of agriculture in the YAR stem from climate and physiography. Their combined effect limits its agricultural area to approximately 3.5 million hectares, of which about 1.35 million are cultivated regularly. This is shown in Table 2.

The stagnant agricultural economy created problems within the YAR. Some of the farm labourers emigrated abroad or into the cities to seek more remunerative employment in industry, which amplified the social and economic problems of urban areas in Yemen. (See: *"World Bank Report No. 5574"*, 1985 (5)).

Although approximately 75 percent of the YAR's resident work force is engaged in agriculture, this sector generates only about 45-50 percent of the Gross Domestic Product (GDP).

The greatest potential for agricultural development lies in the Tihama region. Most of the mountain runoff flows into the plain through seven major wadis, namely: Mawr, Surdud, Siham, Rima, Zabid Rasyan and Mawza, besides numerous minor wadis. Cereals and vegetables are grown in the rainfed areas in the south and midlands, where rainfall is 450 mm and above. Where rainfall is greater than 600 mm, other crops are also grown. But most crops are grown in agricultural areas with spate and pump irrigation. Table 3 shows the estimated crop areas by source of water in YAR. Most of the spate and pump irrigated areas are in the Tihama region.

In the perennially irrigated areas, especially from tube wells, vegetables, fruits and even cereals are grown.

2. A brief review of recently developed projects

2.1 Tihama irrigation projects

The greatest potential for agricultural developments lies in the Tihama where spate and pumped ground water irrigation are available. The flash floods of the main seven wadis, and other minor wadis, have been used for irrigation since the dawn of human civilization and present development is taking place against the background of existing, well established spate irrigation systems.

The Tihama plain has a generally arid and tropical climate with annual potential evaporation rates of around 2 500 mm. The rains, which are concentrated in tropical storms over the mountain catchments, cause short, often multipeaked floods. Peak discharges can rise to more than 2 000 m^3/s. Flood hydrographs exhibit an almost verticle rising limb, with recessions lasting several hours. Wadi flows are seasonal with about 80 percent of the total annual discharge occurring between April and November.

Bed materials in Tihama Wadis range in size from silt to boulders. Very large quantities of sediment are transported during floods. The sediment concentrations are far in excess of the carrying capacity of any canal system. The positions of the low-flow channels within the wadis beds are often unstable and large lateral shifts are observed following floods.

2.1.1 Wadi Zabid. Wadi Zabid contains one of the oldest spate irrigation systems, and was the first to be developed with new diversion structures. The traditional system consisted of 16 canals, each with an independent intake from the wadi. The water rights for various canals and areas were established some 500 years ago, and still exist. The water distribution of Wadi Zabid is uniquely ingenious. The Islamic rule of al-a'la fi/ti-'l-a'la is practised in general, but with some notable exceptions, particularly during the base flow period.

The new irrigation system, constructed between 1975-1979, consists of five diversion weirs across Wadi Zabid. A diversion structure typically consists of an overflow weir and one or two canal head regulators each placed adjacent to a sluice way. An earth fuse plug is incorporated into the design. Guide bunds, armoured with riprap, are used for training. Four of the five diversion structures have canal regulators on both sides and the other (Diversion No. 2) has a single head regulator, making nine canal offtakes from five diversion structures. Some of these nine canals divide two or three times along their course, and so all of the 16 original canals are served from the new system.

The design of the system was largely influenced by the old water rights and traditions. To some extent the technology was adapted to the old customs and practices. The fact that five diversion structures with over-sized conveyance and distribution networks were built, was largely due to the local pressures.

The operation of the Wadi Zabid has provided important findings, namely:

(1) Division of flow between the right and left bank canals is generally difficult, modular division of low flows is not possible.
(2) Rapid sedimentation of the canals occurred, which proved to be the most serious problem. The scour sluices provided in the system did not prove adequate. This is partly due to operational problems, but the design and layout of the headworks is also to be blamed.
(3) Gravel and boulders in the wadi bed caused abrasion of concrete at the weir glaciers and chute blocks. The weir and the scour sluices in the upper two structures had to be overlayed with stone masonry.
(4) Earthen fuse plugs have functioned satisfactorily so far. Floods in excess of the design capacity of the weirs have been safely conducted. Even the cata-

Table 3. Estimated crop areas by source of water('000 ha)

	Rainfall (mm/year)					
	450	**450-600**	**600**	**Spate[1/]**	**Pump**	**Totals**
Cereals and Legumes	379	219	129	84	38	850
Qat	-	-	22	-	25	47
Vegetable[2/]	-	-	21	10	15 46	
Tree Crops[3/]	-	-	5	-	35	40
Tobacco	-	-	-	1	5	6
Cotton	-	-	-	7	-	7
Fodder[4/]	-	-	-	?	2	2
Sesame	-	-	-	10	-	8
Totals	379	219	185	112	120	1 015
Value added, incl, qat (%)	4	4	37	7	48	100
Value added, excl.qat (%)	14	14	18	16	38	100

1/ Includes about 25 000 ha from perennial flows; 2/ Includes potatoes; 3/ Grapes, dates, fruit trees; 4/ Berseem
Source: World Bank Report No. 5574—YAR, June 10, 1985

strophic flood of May 25, 1985 (estimated 2 800 m^3/s) passed safely, breaching only the fuse plugs.

(5) The position of the low flow channel is not stable. Difficulties are experienced in diverting water to the head works, even at diversion structure No. 2 which has canal head works on one side only.

(6) Floating debris or trash sometimes block the canal regulators. The scour sluices are less affected as these are provided with over-flow type gates.

2.1.2 Wadi Rima. The Wadi Rima irrigation system has been designed on a concept that differs radically from the Zabid system. Here the traditional spate irrigation system, aiming to divert flood waters at maximum flow rates at many locations, is replaced by a system relying on the diversion of low flow rates at only one location. From the analysis of hydrologic data it was determined that the lower hydrograph ranges are the main contributors to the total flow volume. The design discharge of the main supply canal has been fixed at 15 m^3/s. With this capacity the system can divert from 75 percent to 89 percent of the annual volume, depending upon the hydrologic conditions.

The system, completed in 1983, consists of a diversion structure, a main supply canal, a division structure, an inverted syphon and two canal systems on left and right sides of the wadi.

The weir is a mass structure with a bucket type stilling basin. A tunnel type sediment excluder is provided in front of the headworks which have a maximum discharge of 15 m^3/s. In the head reach of the main canal, a small sediment basin traps gravel and coarse sand at the end of which is a sediment ejector, to sluice out gravel and sand, and an orifice type flow regulator spillway with an escape channel.

The main supply canal, after about 5 km is divided into the North and South Bank Supply Canals, of 5 and 10 m^3/s respectively. An inverted syphon, containing two steel pipes 1.2 m diameter, conveys the flow across Wadi Rima. Eight primary canals offtake from the South Supply Canal and five from the North Supply Canal.

A free wadi offtake was constructed to provide water to the South System in case of breakdown of the main supply canal or trouble in the syphon. Two similar offtakes were constructed to feed two lower canals of the system which could not be supplied from the South Supply Canal.

The Wadi Rima irrigation system has been operating since 1984. The performance of the system is monitored intensively, by the Tihama Basin Water Resources study. In the initial stages of operation a number of corrective measures had to be taken to overcome the problem of trash carried by the water, after which the system performed satisfactorily. The main supply canal has not undergone any significant erosion or sedimentation. In the middle reaches of the South Supply Canal, some deposition of sand occurs which is cleared mechanically. The quantity of material deposited is much less than in the canals of the Zabid system. This phenomenon is perhaps due to the smaller size of the sediment basin or some discrepancy in the sediment handling methods. Detailed information on this aspect is expected from the Tihama Basin Water Resources study.

As stated earlier, the design objective was to abstract the lower hydrograph range instead of diverting maximum flow rates. Experience so far indicates that the upper and middle canals receive more regular irrigation supplies. The same, however, cannot be said about the lower canals. In view of this, the farmers in some areas are supplementing the supply from the new system with water from their traditional deflectors. Crossings have been provided at some locations to convey a limited amount of traditional Water across the new supply canals.

A special study of the water rights of the Wadi Rima area was made. With the help of seven years' measured hydrologic data, including the wet and dry years, an optimum gate operation schedule was worked out by computer simulation. The operation schedule had to be adjusted in view of water rights' disputes, which at one time could have become quite violent. The distribution of water has been monitored since 1984 and the data will be evaluated. If the evaluation shows that adjustment is required to attain equitable distribution, the gate operation schedule will be revised.

2.1.3 Wadi Mawr. Wadi Mawr is one of the largest drainage systems in the YAR and has a catchment area of about 8 000 km^2. The mean annual flow of the wadi is estimated at 117 mm^3. Agriculture is practised on about 23 000 hectares in the Wadi Mawr area. As in the previous projects, the major component of this project is to improve the traditional spate irrigation system. Experience from the Wadi Zabid and Wadi Rima projects has largely influenced the design of the irrigation system in Wadi Mawr. Its basic concept also aims at abstracting the lower, most dominant, range of wadi flow (as in Wadi Rima). 40 m^3/s was determined to be the optimum capacity of the canal. At this capacity it is estimated that about 87.9 percent of the wadi flow will be diverted in an average year.

The cost of the scheme in terms of Rials per hectare, increases for large headworks capacities, with little or marginal increase in benefits. This capacity corresponds to a rate of 2 litres/s/ha. Very elaborate sediment handling measures are incorporated in the headworks. The objective is to minimize entry of sediments into the canal system bearing in mind the inherent difficulties in regulating the spate flows and the limitations of operation and maintenance.

The system contains a diversion weir, a scour sluice, twin canal head regulators, vortex tubes, two settling basins, each equipped with a flushing sluice, and the canal head regulator. A division structure, located at 4.2 km, on the combined head reach canal splits the flow in two parts, one of which continues on the right bank of the wadi as the North Supply Canal, with a design capacity of 15.6 m^3/s. The other passes under the wadi in a syphon under-pass and feeds the South Supply Canal, with a design capacity of 22.5 m^3/s. The North Supply Canal is 22.6 km long and serves 18 primary canals whereas the South Supply Canal is 24.5 km long feeding 21 primary canals.

The most salient feature of the design is the various levels/methods of dealing with the sediment; namely (i) scour sluices; (ii) vortex tubes, and (iii) settling basins with flushing sluices. It is expected that these methods would keep most of the sediment, coarser than fine sands out of the canal system. The canals are designed to transport from 4 000-7 000 ppm of fine material with a median diameter of 100 microns. This rate should be sufficient to carry the fine material passing the settling basins. Increased canal gradient has resulted in economising construction costs by reducing the number of check drop structures.

A gate operation schedule, derived from a computer simulation of hydrologic data, has been prepared. The output is blended with the traditional water rights, in order to achieve an equitable water distribution which has relevance to tradition. The operation of the system, in particular the quantity of water passed to various canals, will be closely monitored. The system, as built, has sufficient flexibility, so adjustment based upon experience would be easily made.

2.2 *Marib Dam*

The Marib Dam, with its reference in the Holy Koran, has become an established symbol for the millenia old tradition of irrigation in the Natural Yemen. The newly constructed dam in Wadi As Sudd, commissioned only in October 1984, is 120 km east of Sana'a on the eastern escarpment. The height of the dam is 40 m while the rock-fill body with a clay core has a total volume of 3 million m³. The length of the spillway is 200 m, and the irrigation outlet is a steel-lined tunnel, 2.5 m in diameter. Maximum flow capacity is 35 m³/s regulated by a radial gate of 1.5 m x 1.8 m. The main diversion head reach canal should provide irrigation water at a maximum capacity of 35 m³/s.

The estimated area to be irrigated from the dam is about 6 890 ha and the cultivated area about 10.18 ha. The climate is dry and hot with an average yearly rainfall of 50-100 mm, while evaporation is about 2 700 mm with maximum temperatures at 40°C.

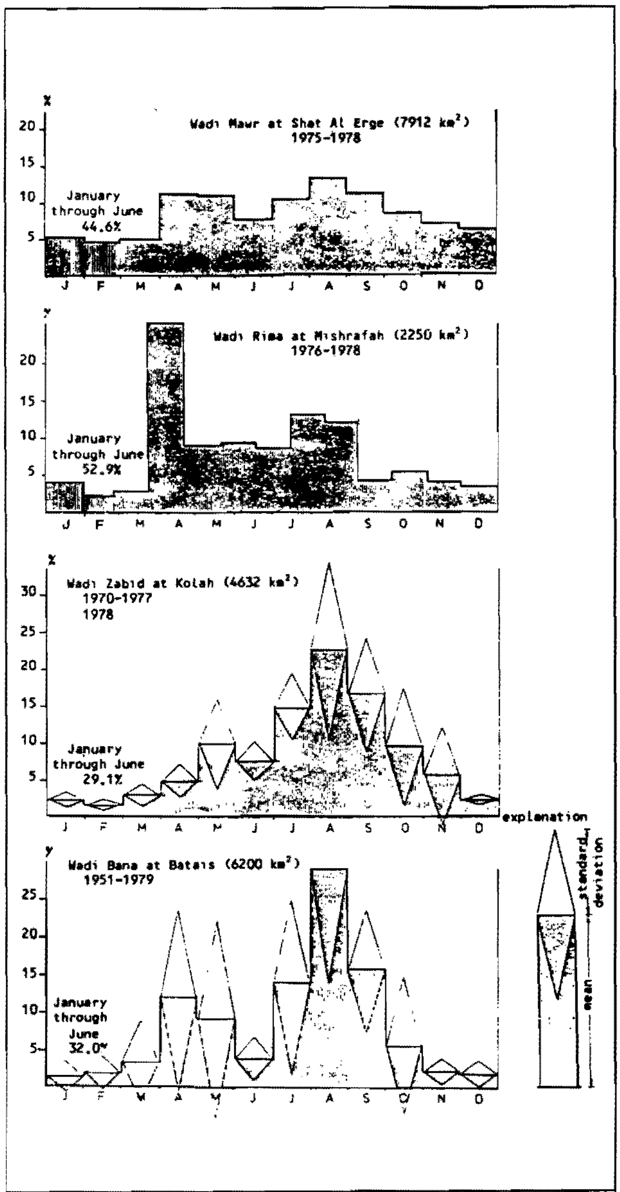


Figure 3 Monthly flow distribution

3. Socio and agro-economic aspects

3.1 *Traditional water rights*

Traditionally, water is diverted from the wadi into main canals by means of temporary earth check bunds across part of the wadi bed. Each canal has its intake set in the bank of the wadi with an uncontrolled open headreach. Flood damage to the deflector or to the canal head may lead to the partial loss of wadi flows.

Once the topmost basin has been filled (up to one metre), one of the field bunds is breached and the water is allowed to flow across the top field to fill the next basin in an ordered succession of fields. No field can obtain water until the one preceeeding has taken its quota. Only when every field in a given block has received water, is the main canal check breached.

The flow is allowed to continue down to the check bund commanding the next block of fields, and so on, until the entire flow is dissipated. The reliability of the traditional spate irrigation system is essentially a function of proximity to the wadi, and distance downstream from it.

Thus, land situated near the wadi and towards the mountain front may be irrigated by flood flows and base flows, allowing up to 12 waterings a year. This land can be triple-cropped, especially after the construction of the new diversion structures.

By contrast, on the more extensive lands further doownstream, even a single watering may be an uncertain prospect. Moreover, the distribution of spate water is, in general, a function of the size, extent and frequency of the floods, besides the relative strength of the deflectors and the individual canal capacities.

During the dry season, from November to March, there is usually no flow at all in the smaller wadis, while the base flow of the larger wadis is generally below 2 m³/s. The wadis start rising in April, and the main flood season is between July and September.

Along a wadi, the old system seems to function on a relatively equitable basis. This inherent equity arises because upstream users can divert minor floods, while larger floods will destroy upstream structures and flow on to downstream diversion structures.

Each canal has a water master who arranges the priority of water rights to the various fields and farmers according to the historically developed water rights. In addition, he is responsible for the repair and maintenance of both the canal and the deflector structure. The size of the fields, and not the location of the fields along the canal, usually determines the share in the total costs for an individual farmer.

The principle of priority to upstream lands, "upstream right to water", however, does not apply to all wadis in the Tihama. The differences in types of water rights in the various wadi areas seem to be partly a reflection of the differences in technical irrigation practices. Those wadis with an extensive irrigation network, that is Wadi Zabid and Wadi Rima, seem to have the largest body of local water laws, and the traditional principle of water rights apply more to those wadis with a rather primitive irrigation network, that is Wadi Sihan and Wadi Rasyan.

3.2 Land tenure and type and size of holding

Four general patterns of land ownership in YAR can be distinguished:

a) Mulk, or private land, which constitutes 70 percent to 80 percent of cultivated land in the YAR.
b) Miri, or state land, which was confiscated from former Imams or powerful families, constitutes 2 percent to 3 percent of the cultivated land.
c) Wagf, or religious endowment, the use of which is granted by the holder to mosques, schools, etc. constituting about 15 percent to 20 percent of the arable land.
d) Hima, or communal land which covers uncultivated land used for pasture and grazing.

The majority of farm holdings in the Tihama region belong to the category of small scale farms. About 60-75 percent of all holdings are smaller than 5 ha, while 40-50 percent are estimated to be smaller than 2.5 ha.

Estimates of the number of landless families in the Tihama, who are either tenants or farm labourers, range between 35 percent to 50 percent, while about 35 percent to 45 percent of the remaining land-owning families are mainly share-croppers.

Crop harvests are shared by landowner and tenant, and if applicable, the pump owner too. The most common system of crop-sharing, in the wadi cultivated areas, is that the harvest will be shared equally between the landowner and the tenant, and that the tenant will have to bear most, if not all, the costs of production.

Generally, the cost- and crop-sharing systems in practice, and their ratios of distribution between landowner, tenant and pumpowner, when applicable, constitute a serious bottleneck to the introduction of new technologies which could induce additional inputs and then additional costs. Thus, the tenant can hardly be encouraged to adopt new technologies implying additional costs that he should bear alone, while the crop-sharing ratios will remain unchanged.

3.3 Farm income

Most crops, except fruits and vegetables, are grown under spate irrigation. The main crops are: sorghum, millet, sesame, cotton and maize. Bananas can be extensively cultivated near the mountain front and in the middle catchment basins. However, supplemental irrigation by pumps is necessary. But, because of limited and irregular water supplies, the use of inferior seeds, the lack of fertilizers, herbicides and pesticides, the farm income in spate irrigated agriculture is low. A second watering can double crop yields, i.e. increasing grain yields in millet from 0.5 to 1 ton/ha and seed cotton yields from 0.4-0.9 ton/ha.

With more reliable irrigation in the wadis, following the recent irrigation improvements in Wadi Zabid, Rima and Mawr, changes in cropping patterns and higher yields are expected. Such improvements are already noticeable in the Zabid and Rima areas where the availability of perennial water, the integrated extension activities, and the supply of improved seeds, fertilizers, pesticides and land levelling are taking place.

According to the World Bank Report (No. 5852—YAR February 25, 1986)(4)), the income of a 3 ha farm under spate irrigation in the upstream reach of the wadi was about 53 038 Yemeni Rials (1$ = 10 Y.R.) before implementation of the project, and about 80 054 Y.R. at full development.

For a 6 ha farm, located downstream of the wadi, income before the implementation of the project was estimated to be about 17 897 Y.R. and about 27 923 Y.R. afterwards.

Comparative and additional figures were published in the World Bank Report (No. 2613—YAR) December 13, 1979(3).

4. Conclusions

It is well established that water is the limiting factor in the agricultural development of wadis in the YAR. A larger portion of the floods used to be lost to the Red Sea, especially the large floods. The construction of weirs across the wadis, and the new offtakes to divert spate water to existing irrigation canals are an attempt to conserve flood waters and improve agricultural production in the country.

The first wadi improvement works were in Wadi Zabid, and were constructed with an overall cost of about 9 million U.S. dollars. The huge structures were almost covered with coarse sediment and cobbles after floods in the first year. The meandering behaviour of the flow channel in the wadi complicated the diversion of the base flow and low floods to the newly constructed offtakes on both sides of the wadi.

The new structures did not improve the water allocation among farmers. Sediments were deposited at the entrance of the ungated canals which resulted in an effective reduction of the canal capacity. Furthermore, high floods do not reach the downstream farms any more.

In 1980 the Wadi Rima development was initiated. The development concept was different from that of Wadi Zabid and the total cost was about US$6 million. The structures were more elegant and the implementation time was shorter, and the same traditional system of water allocation among farmers was applied. New legislation is considered necessary in order to prevent upstream farmers from misusing the scarce spate water and to allow downstream farmers to have their fair share.

No specific provision for siphon maintenance against sedimentation and trash was clearly defined. Although sediment basins and trash rocks were provided at the entrance of the siphon, this would not be sufficient to prevent sediments, and other materials obstructing the two—120 cms pipes of the syphon.

Recently, in 1983, the Wadi Mawr project, in one of the largest wadis in YAR, was commissioned for a total cost of about US$10-18 million.

More sophisticated structurs were used at the offtake and the headreach of the main canal in order to prevent sedimentation in the irrigation canals and in the syphon. Traditional water allocation systems still apply but the old canals and new pipe intake structures were remodelled. A water aqueduct across the wadi may have been a better hydraulic alternative instead of the syphon, as operation and maintenance would have been easier and safer.

It is anticipated that the total irrigated areas in the three wadis will not be much increased. The 11 500 ha in Zabid, 18 000 ha in Mawr, and 8 000 ha in Rima are approximately the same as before the project. Production could, however, be increased in the future due to an increase in cropping intensity of 30 percent to 50 percent. Legislation, land levelling, extension services, better water allocation among farmers, and better operation and maintenance services are needed.

The development of the hydraulic structures in the wadis is just one aspect of the development. Other aspects need to be looked at, in particular the socio-economic developments.

Farmers should participate in the operation and maintenance of the new system of water allocation under the general supervision of the Government authorities (e.g. T.D.A.).

The Tihama integrated agriculturral extension services, implemented by FAO and aiming at strengthening of the extension programme and training of the rural women, was an important initiative in improving the extension activities in YAR.

The operation and maintenance of spate irrigation systems require a completely new approach due to the very specific characteristics of the system. Spates will often arrive at night and a forecasting system is needed. Sediment removal facilities at the diversion structures are essential to avoid entry of large quantities of coarse sediments into the canal systems.

Spate irrigation requires an uninterrupted diversion at the head-works during spate in view of the short duration of these spates.

Maintenance work, such as repair of the concrete, masonry and mechanical parts of the structures, as well as the canal embankments and side slopes, will be routine operations. The mechanical removal of sediment deposits downstream of the intakes, and the removal of trash, will have to be arranged on a continuous basis.

Equipment required for maintenance and operations should be available on site during the whole irrigation season. The present lack of equipment, skilled operators and adequate funding for maintenance, forms a serious constraint and results in the less efficient operation of the new system.

Computer aided spate management of the limited spate water resources, may if properly applied, raise the efficiency of water use and lead to the optimization of agricultural productivity in the spate irrigated areas.

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