

# Wadi development for agriculture in PDR Yemen

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## 1. Country background

### 1.1 General description

The People's Democratic Republic of Yemen (PDRY) is located in the south west corner of the Arabian Peninsula bordering the Yemen Arab Republic (YAR) and Saudi Arabia to the north and Oman to the east with the Gulf of Aden along its southern coast. The country is divided into six governorates: Aden, (including Socotra and other islands), Lahej, Abyan, Shabwa, Hadramout and Al-Mahra (see figure 1). PDRY has a total area of about 338 000 km<sup>2</sup> and a population estimated at 2.2 million with an average annual growth rate estimated at 2.6 percent. Over 60 percent of the population lives in the rural areas and up to 10 percent is nomadic. The total arable land is about 0.7 percent of the total area (i.e. 260 000 ha) of which 110 000 ha is cultivable. However, due to shortage of water and other factors, the average cultivated area over the past ten years was equivalent to only 64 000 ha. Although the population density averages 7 persons per sq. km of total land, the average density on cultivable land is much higher, at about 2 000 per km<sup>2</sup> or 20 persons per hectare.

### 1.2 Socio-economic development

Under the British Colonial rule, which lasted for 129 years (1839-1967), the country's economy was centred around Aden Port. The British Petroleum (B.P.) Refinery was also the focus of industry and trade during that period. However, with the closure of the Suez Canal in 1967 and the British withdrawal in the same year, the young Republic had to turn to other countries for financial and technical aid to enable it to change from a service oriented economy to one based on agriculture and industry. By 1976, total foreign assistance was YD 36 million. In 1982 this had risen to over YD 70 million, mainly from the socialist countries led by the USSR. Arab countries and Arab and International Organizations also assisted in the economy.

In fulfilling its tasks, the Government, led by the Yemeni Socialist Party (YSP) (formed from the National Liberation Front and other progressive parties), has followed a strategy of developing the country based on a centrally planned economy. The main objectives were: (a) to satisfy the basic need of the population for food, essential consumer goods, housing, employment, health care and social

services, (b) to develop the productive capacity of the economy especially in agriculture, industry, construction and minerals, (c) to strengthen the infrastructure in different sectors, such as in transport, power and telecommunications, (d) to raise education standards, emphasizing technical and higher education and (e) to increase exports of domestic products.

The Government is trying to develop the vast rural areas of PDRY, which until independence were almost entirely left to tribal rule and feudal agriculture. There were no roads to connect the scattered villages, schooling was a luxury for few, and clinics in villages and small towns were non-existent.

Paved roads have been constructed from Aden to Mukalla to Seiyun, from Naqaba to Nissab and from Aden to YAR border. The remaining links to integrate the country are now either under construction or consideration for future development plans.

Two new ports outside Aden, in Mukalla and in Nishtun, were constructed to facilitate delivery of materials and equipment as well as landing fish in the eastern half of the country. There are fishing cooperatives and modern fleets for harvesting fish. Two fish canning factories function at Mukalla and Shukra. Industry now contributes 25 percent of the GDP, the Aden Oil Refinery being the major contributor.

In the health sector, hospitals, health centres and rural health units were established. Medical care is free. In 1975, the Faculty of Medicine was established with the help of the Cuban Government. About sixty new doctors graduate each year.

### 1.3 The agricultural sector

Although cultivated land is scarce in PDR Yemen, agriculture provides employment for 45 percent of the labour force. The agricultural sector contributes about 13 percent of the GDP and 35 to 40 percent of the export earnings of the country.

Of the annually cultivated areas, 70 percent are irrigated by fluctuating spate floods, 25 percent by groundwater and the rest are rainfed. Cereals occupy about 46 percent of the cultivated land. The major crops are: cotton, sorghum (fodder and grain), millet, wheat, sesame, maize, tomato, potato, dates, bananas and some other tropical fruits, coffee and tobacco.



The main agricultural areas are concentrated in Lahej, Abyan, Shabwa and Hadramout Governorates. Agriculture is mainly carried out on state farms and cooperatives. At present there are 43 state farms and 56 cooperatives in PDRY, which together crop about 48 000 ha annually.

Since the early 1970s, the Government has invested in irrigation projects (Wadi Tuban, Wadi Bana, Wadi Beihan, Wadi Hajr and Wadi Hadramout), land improvements, machinery and equipment, research and extension services and production inputs. A major goal of the current Third Five Year Plan in agriculture is to increase the production of crops and livestock through intensification using improved irrigation, improved agricultural technology, better water management techniques and the introduction of high yielding varieties.

PDRY has about two million goats and sheep, 100,000 cattle and 100,000 camels. Livestock forms at least 40 percent of the agricultural GDP. Specialized state farms for dairy, sheep and goat production have been established. The Public Poultry Corporation, established in 1974, produced 59.5 million eggs and 1 250 tonnes of meat in 1986. Improvements are constantly sought.

Despite the improvements, however, in March 1982 the country witnessed the largest flood in recent recorded history. This was due to heavy rains, mainly in Western highlands of PDRY. Wadi banks were eroded, large tracts of agricultural land were washed away, and more than 12,000 families lost their houses. Most of PDRY's limited spate irrigation infrastructure and road communications were disrupted.

## 2. Spate improvement projects

### 2.1 Climatic and soil conditions

The PDR Yemen occupies about 338,000 km<sup>2</sup> in area, and is situated between 12 and 16°N in latitude and 43 and 53°E in longitude with, in general, a tropical arid climate. However, due to differences in altitudes, the country could be divided into three agroclimatic areas, namely: (a) the coastal areas with an altitude of less than 600 m, (b) the middle altitude areas, ranging from 600 to 1 500 m above sea level; and (c) the high altitude areas, ranging from 1 500 m to 2 400 m above sea level.

In each of these areas, as well as climatic similarities, some common features with regard to soil cover and agricultural production could be found. These similarities are as follows.

**2.1.1 The coastal areas.** The major agricultural areas are located here such as Abyan Delta, Wadi Tuban, Ahwar and Lower Hajr. The climate in these areas is characterized by hot summers with mean monthly temperatures of about 35°C and mild winters with mean monthly temperatures of about 27°C. Humidity is extremely high with a mean of about 80 percent during the year. The rainfall is scarce and within a mean of about 50 mm/year. Agricultural production depends totally on irrigation from spate open wells and, to a lesser extent, shallow and deep tubewells. Most crops are produced in the winter season.

**2.1.2 The middle altitude areas.** Areas such as Lowder, Mudia, Wadi Hadramout, Nissab and Beihan are characterized by hot summers with a mean monthly temperature of about 37°C and mild winters of about 15°C. Humidity ranges between 40 and 60 percent. Rainfall ranges between 50 and 250 mm/year with most rain falling in the summer rainy months. The different wadis here are less homogenous than in the coastal areas with regard to agroclimatic conditions and crop production, each depending on its altitude, its distance from the sea and its closeness to desert. The agricultural season is wider and crops depend on rainfall, spate or most commonly, irrigation from wells.

**2.1.3 The high altitude areas.** Areas such as Mukeiras, Daman, Yafa'a and Dhalla are characterized by mild summer and cool winter where the summer temperatures are around 27°C and winter temperatures range from 5°C to 10°C. Rainfall ranges mostly between 250 and 400 mm/year. Crop production is practised throughout the year using either rainfall or open wells. Terraces are used for agricultural production where there are steep slopes.

**2.1.4 Soil cover.** The total arable area in the country is about 260 000 ha (0.7 percent of the total area). However, due to shortage of irrigation water and rainfall the cultivated area per year is about 64 000 ha with about 70 percent depending on spate irrigation. The soils are alluvial, light to medium textured, belonging to the orders Entisol and Aridisol. These soils are clacareous with a mild alkaline reaction and low organic matter and total nitrogen, low to medium in available phosphorous, and medium to high in available potassium. Problems of salinity and alkalinity are found, especially where groundwater of poor quality is the main source of irrigation.

### 2.2 Abyan Delta

**2.2.1 Description.** The Abyan Delta, located in the Abyan Governorate, is a segmented alluvial fan which lies approximately 55 km north-east of Aden. The two major wadis which emerge from the mountainous hinterland and discharge regularly into the Abyan Delta are Wadi Bana and Wadi Hassan. Wadi Suhaybiah and Maharia also approach the Delta from the west and join Wadi Bana (see figure 2).

The total catchment area of Wadi Bana is 7200 km<sup>2</sup>, of which 66 percent lies in the Yemen Arab Republic. The catchment area of Wadi Hassan is about 3300 km<sup>2</sup> and it lies completely within the PDR Yemen borders. The mean annual basin rainfall input for Bana and Hassan is 2590 million m<sup>3</sup> per year and 660 million m<sup>3</sup> per year respectively (Atkins 1984).

Agricultural lands in the Abyan Delta are mainly under cooperatives and state farms. There are five cooperatives in the Delta having an average yearly cultivated area of about 10 000 ha, mainly on spate irrigation, and ten state farms cultivating an area of 1400 ha, mainly on tubewell irrigation.

The major crops grown under spate irrigation in the Abyan delta are cotton, sesame, sorghum (fodder and grain), watermelon and millet. Vegetables and fruits are the main

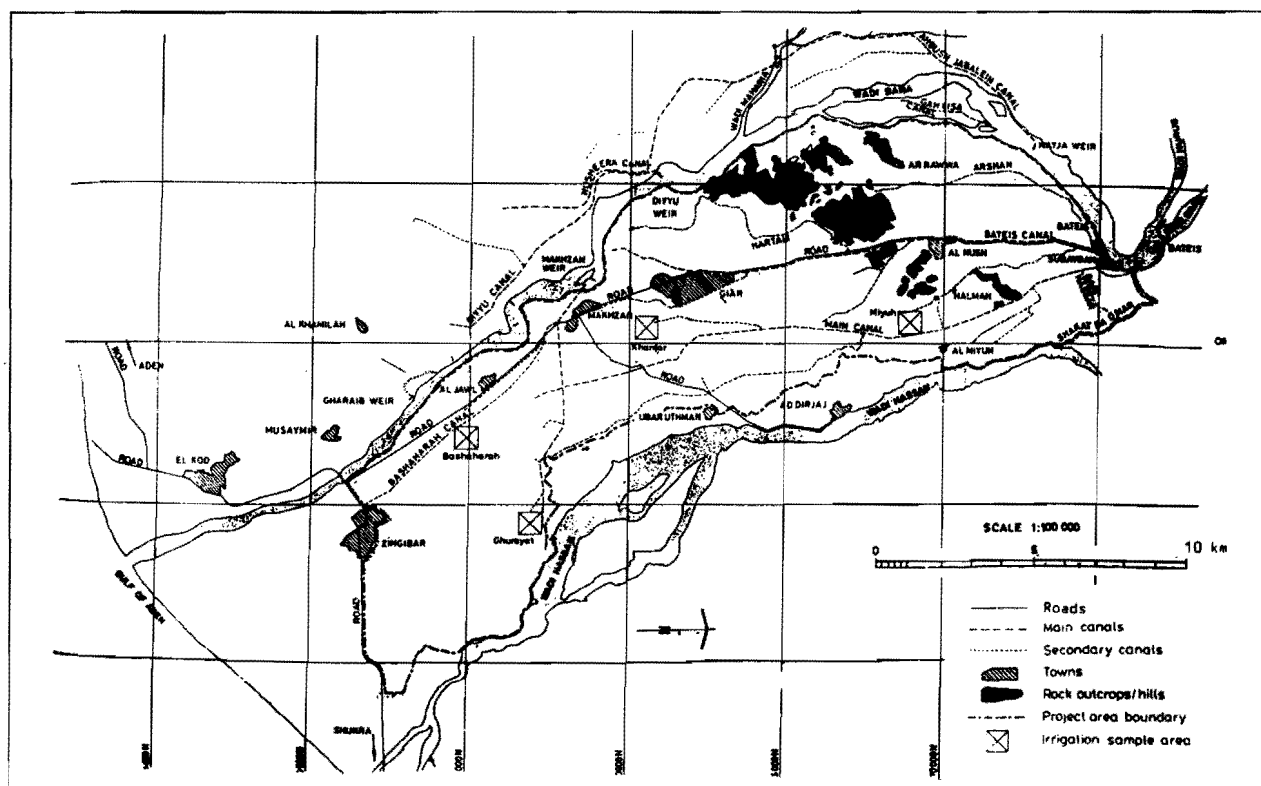


Figure 2: Wadi Bana and Hassan areas

crops grown under pumped groundwater.

In traditional spate irrigated areas the field application depth is assumed to be 70 cm and the average annual potential evapotranspiration is estimated to be 2380 mm. Crop water requirement varies from 25 to 50 cm for vegetables, 60 to 75 cm for cotton and about 150-170 cm for bananas.

In the Abyan Delta a number of weirs and "ogmas" are used to control, divert and train the wadi floods to the command areas. The existing weirs in the Delta are: Batais, Hayja, Diyyu, Makhzan and Garaib.

The gross commanded areas for the different weirs and offtakes in Wadi Bana are as follows.

Batais	9182 ha	Makhzan	3470 ha
Hayja	3430 ha	Garaib	3390 ha
Diyyu	3840 ha	Massani	350 ha

On Wadi Hassan, however, the gross commanded area is about 5300 ha.

**2.2.2 Objectives of wadi development** There were five old diversion weirs on Wadi Bana and two small weirs on Wadi Hassan with a number of traditional offtakes on both wadis. These diversion works were severely damaged by the big floods of September 1981 and the catastrophic floods of March 1982. After these disastrous events the government, under the supervision of the irrigation department, initiated a new emergency project with the following objectives:

- erection of earth diversion bunds—"ogmas"—in both wadis of the Delta to ensure irrigation of the maxi-

mum possible area;

- wadi training and protection works against erosion of soil and existing canal systems by use of gabion spurs;
- reconstruction of some damaged headworks and irrigation structures; and
- operation and maintenance of the traditional irrigation systems in the Abyan Delta while implementing the programme of reconstruction of the main weirs.

The first feasibility study for the Abyan Delta Development Project was undertaken in 1971/72 by Dar Al Handasah Consultants. The study covered soil survey, hydrology and design of irrigation networks for about 18 000 ha in Wadi Bana.

In 1983/84 a feasibility study for Wadi Bana and the Abyan Delta Development Project was undertaken by the consultants W. S. Atkins & Partners, in association with Binnie and Partners. This study recommended the reconstruction of three weirs in Wadi Bana with the required training works supplemented by preliminary designs.

Wadi development projects in the Abyan Delta under the supervision of Yemeni-Soviet Projects have completed the reconstruction of Batais weir with 3 km of main canal to supply spate water to an area of 9 000 ha and of Hayja weir with 1 km of main canal commanding 2 400 ha. In addition, wadi training and bank protection works to the upstream and downstream side of the weir was done by providing gabion spurs.

## 2.3 Wadi Tuban Delta

**2.3.1 Description** The Wadi Tuban Delta located in Lahej Governate is a major agricultural region. The capital of the

Governate of approximately 40 km north of Aden. The delta has a catchment area of about 5 600 km<sup>2</sup> which extends nearly 100 km northwest to Taiz and Ibb in YAR. The average annual rainfall at the head of the catchment is about 1 500 mm (figure 3). At present Aden is supplied with water from the Tuban Delta, especially from groundwater stored in the delta alluvium.

Wadi Tuban Delta encompasses approximately 10 000 ha of cultivable land (about 9 percent of the country's total) of which 2 100 ha are under well irrigation and 8 000 can be spate irrigated. Almost 50-60 percent of the cropped area is covered by cotton (medium staple) and the remaining area is covered mainly by sesame, sorghum (grain and forage) and melons.

The annual flow of Wadi Tuban and its tributaries averages about 125 million m<sup>3</sup>, most of which is diverted in the upper part of the Delta for the irrigation of seasonal crops. However, about 70 percent of the flow is lost before it reaches the fields, mainly as groundwater recharge (GDC, 1981). The total recharge to the Tuban aquifer averages 80 to 90 million m<sup>3</sup>/year, equivalent to 60 percent of the average annual recharge (GDC, 1981).

**2.3.2 Objectives of wadi development** In Wadi Tuban the main irrigation development works were implemented by the Yemeni-Soviet Projects since 1970. These works are as follows:

- construction and reconstruction of seven diversion weirs, viz Al-Arais, Ras-Alwadi, Faleg, Mujahed, Beizag, Al-Hadarem and Al-Bustan;

- construction of 87.8 km of main canals and 162 km of distributary canals serving the above weirs; and
- land levelling of 2 681 ha, of a planned 5 160 ha, for improved spate irrigation systems.

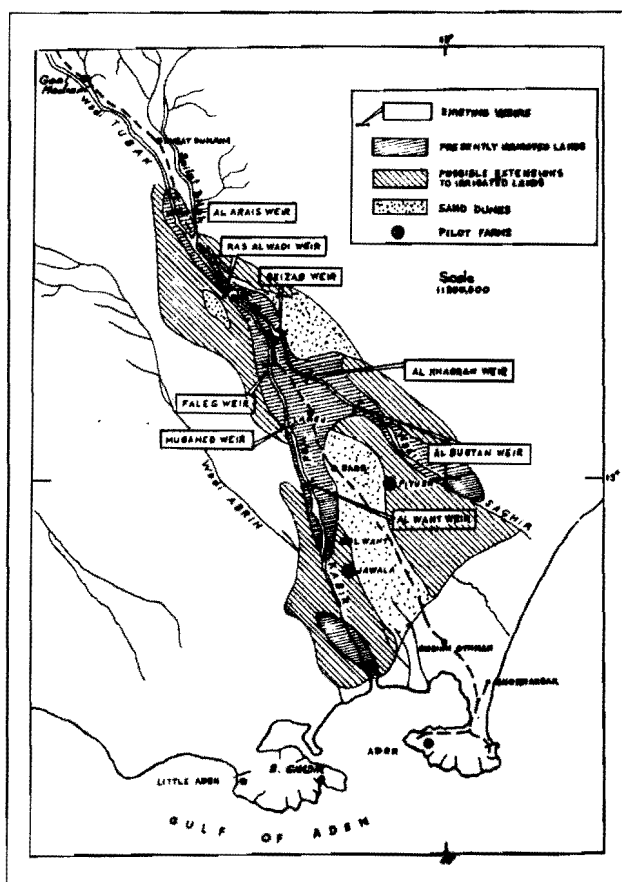
During the current Third Five Year Plan, the Yemeni-Soviet Projects will be implementing the construction of remaining main canals for the above-mentioned diversion weirs with improvement works on the existing irrigation minor canals and land-levelling of 1 000 ha for spate irrigation.

Studies for land and water resources potential for Wadi Tuban together with pilot works and experiments were first undertaken by Soil and Water Utilization and Conservation in the Wadi Tuban Watershed Area Project in 1971-75 (UNDP/FAO). This was followed by the Wadi Tuban Agricultural Development Project (1979-1986).

To increase the water use efficiency, irrigation improvement works were provided as a major component of the project for 10 state farms covering 1 755 ha, including rehabilitation of 26 km of spate canals and structures; construction of 93 km farm ditches and 110 km access and on-farm roads; and, to limit sand movement, the planting of about 40 000 seedlings for windbreaks.

A water management study was undertaken by a consultancy in 1979-81 as a component of the Wadi Tuban project. The basic objectives of the study were to produce a water management plan which would provide for the increased water demand of Aden and, if possible, allow some expansion of irrigated agriculture in the Tuban Delta.

Figure 3: Wadi Tuban area



## 2.4 Wadi Ahwar

**2.4.1 Description** The Wadi Ahwar Delta lies within the coastal zone of the Abyan Governate (figure 4). The delta has a total area of 10.5 km<sup>2</sup> with a catchment area of about 6 352 km<sup>2</sup>.

The average annual run off recorded from 1955 to 1982 was about 69 million m<sup>3</sup> while the maximum annual runoff recorded in 1982 reached 290 million m<sup>3</sup> with a peak discharge of 5 340 m<sup>3</sup>/s.

The total area of Delta Ahwar is 5 252 ha and only 76 percent of it (3 992 ha) is suitable for agriculture. About 80 percent of the agricultural land is irrigated by floods. After deep ploughing is performed, the land is irrigated only once.

The main crops of Wadi Ahwar Delta are long staple cotton, cereals (sorghum and millet), vegetables and melons. About 20 percent of the remaining agricultural land is irrigated by groundwater or by a combination of wells and floods. Here, the main crops grown are onion, watermelon and vegetables.

## 2.4.2 Objectives of wadi development

Under the development works of Yemeni-Soviet Projects, two diversion weirs (Ahwar and Hanad) were constructed and reconstructed with main canals and distribution system and levelling of about 2 661.6 ha. Establishment and expansion of Shakka State Farm is carried on by the same project.

## 2.5 Wadi Rabwa

**2.5.1 Description** Wadi Rabwa is located in the mountainous part of the country 100 km north-east of Aden at an elevation of 400-800 m. The catchment area is about 1 433 km<sup>2</sup>.

The average annual runoff recorded at Saba Weir from 1972 to 1982 was 30 million m<sup>3</sup>.

Groundwater was found at various depths of 7 to 25 m with salinity varying from 1.1 to 3.2 g/l, increasing downstream. The recharge to groundwater is about 19.6 million m<sup>3</sup> per year and the groundwater abstraction is about 12.1 million m<sup>3</sup>.

The total cultivable land is about 3 193 ha of which 80 per cent depends on spate irrigation. The cropping pattern during the study period was as follows: 52 per cent cereals (sorghum, maize and millet), 5 per cent sesame, 29 per cent fodder (sorghum/pulse), and 2 per cent cotton (medium staple).

**2.5.2 Objectives of wadi development** Under the development works of the Yemeni-Soviet Projects, a diversion weir (Saba) and a diversion work was constructed with main canals and distribution systems. About 560 ha of land is improved by land levelling and irrigation improvement works. This year a new project has started to study the groundwater storage.

## 2.6 Wadi Beihan region

**2.6.1 Description** Wadi Beihan is located in the north west of Shabwa Governate of PDRY bordering the YAR and Saudi Arabia at an altitude which varies from 800 m to 1 600 m. It has two tributaries—Wadis Nahr and Khirr—which join to form Wadi Beihan (figure 5). Wadi Beihan has an average width of about 3 km and flows approximately 30 km before reaching the borders of the Rubo al-Khali desert. The catchment area for Wadi Beihan at Naqub is 3 300 km<sup>2</sup> and that of Wadi Nahr and Wadi Khirr 2 500 km<sup>2</sup> and 530 km<sup>2</sup> respectively.

The total cultivable area is about 7 500 ha of which it is estimated that about 3 000 ha is used for groundwater and conjunctive irrigation and 4 500 ha can be used for spate irrigation.

Surface water is in the form of floods when rainfall exceeds 17 mm, providing an average annual inflow of 48.4 million m<sup>3</sup> (surface flow). About 44 million m<sup>3</sup> of the surface flow infiltrates and is stored in the aquifer and the rest of it is mostly lost in the desert. Groundwater forms a water table at a depth of 10 to 25 m below ground level (Sogreah, 1979).

The traditional spate system is well developed with different types of intakes. A weir was constructed in Nuqub area in the 1960s. The mean annual calculated flow for the Nuqub weir is 509 m<sup>3</sup>/s.

**2.6.2 Objectives of wadi development** The land and water resources of Wadi Beihan were studied by the consultants Sogreah in 1977 and proposals for development of the area were presented to the government.

Based on this study, the Wadi Beihan Development Project was prepared and started implementation in 1982 to fulfill the following objectives:

- increase agricultural production and farm income in

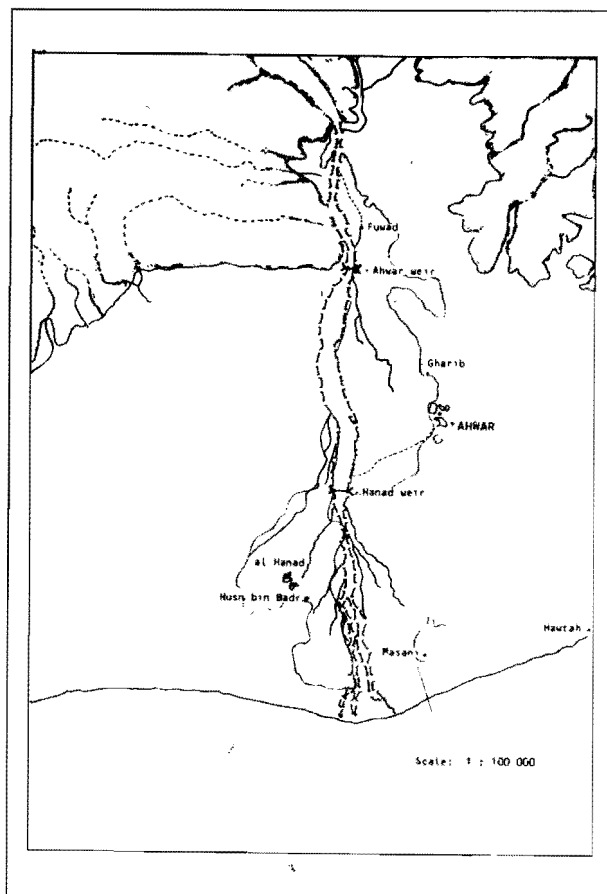


Figure 4: Wadi Ahwar region

the project area by rehabilitating the spate irrigation network and improving the groundwater irrigation system of Wadi Beihan, and providing technical assistance, farm inputs and agricultural machinery for both Wadi Beihan and Wadi Ain;

- assess the surface and groundwater potential of the area and confirm the technical feasibility of attaining a stable groundwater level within reasonable limits of aquifer draw-down under existing groundwater usage to Wadi Beihan by setting up a programme of hydrometeorological observations;
- provide access to important centres of population and agriculture in the area to facilitate movement of agricultural inputs and products by constructing feeder roads and providing maintenance equipment; and
- improve nutrition of the rural poor by growing a wider range of crops and fruits for local consumption.

Irrigation and civil works form the main component of this project: about 500 000 m<sup>3</sup> of earth work in spate canals was executed and construction of 31 000 m<sup>3</sup> of gabion works for erosion control, wadi training and canal intake structures and construction of four sluice gates for diversion of spate flows in Timna State Farm; in addition there is the installation of low pressure buried PVC pipe system for 250 ha under tubewell irrigation and the construction of feeder roads.

In addition to the above works, the project established agriculture extension service and supplied agricultural inputs and farm machinery in the project area. Further





water resources studies have been undertaken to ensure sound exploitation of precious resources.

## 2.7 Wadi Hajr Delta

**2.7.1 Description** The area is situated in the Hadramout Governate at a distance of 540 to 545 km from Aden. The catchment area is about 9 160 km<sup>2</sup>. Wadi Hajr is the only wadi with a perennial flow, discharging into the sea 72 km west of Mukalla. Average discharge is 6 m<sup>3</sup>/s with a total annual runoff of 470 million m<sup>3</sup>.

The Upper Hajr has a total area of 2000 ha divided into three blocks of land within confined valleys along approximately 70 km of the upper wadi.

The Lower Hajr encompasses 2500 ha of predominantly flat alluvial plain in the wadi delta.

**2.7.2 Objectives of wadi development** A feasibility study for agricultural development of Wadi Hajr was undertaken in 1983/84 by Tesco Viziterv Consultants. Based on that study the above-mentioned project started implementation in 1987 to fulfil the following objectives:

- ❑ construction of irrigation works in the Lower Hajr area: rehabilitation of two overflow type diversion weirs in Wadi Hajr and two feeder canals with lengths of 17 km and 2 km; rehabilitation of 835 ha perennial and of 482 spate irrigated areas; rehabilitation of surface drainage canal system of the irrigation areas and the implementation of 40 ha experimental sub-surface drained areas; and construction of farm centre at Lower Hajr;
- ❑ improvement of the road from Al-Sufal at Lower Hajr over a distance of about 70 km;
- ❑ provision of earth moving and agricultural machinery and equipment for operation and maintenance and agricultural activities for the project area;
- ❑ establishment of a date processing plant; and
- ❑ provision of technical assistance for project management through consultants to supervise construction works and preparation of designs for wadi training and protection against erosion in Upper Hajr area.

## 3. Comparison of technical features of wadi development projects

### 3.1 Water resources and water balance

Water resources and water balance in PDRY are mainly related to the spatewater and groundwater. To maintain the proper groundwater and spatewater balance is the main goal.

**3.1.1 Characteristics of spate hydrology.** Precipitation itself is not sufficient to supply groundwater or create floods in PDRY since the rain falls on sandy rocks or soils and flat desert terrain. A more favourable situation is in areas surrounded by extensive hard rock massifs.

However, in the mountainous areas of the northern part of Yemen, the rainfall shows higher values (Table 1). The most important fact is that it falls on hard rocks thus forming surface run-off; then it streams in narrow boulder-type wadis, later ending in alluvial-type wadis in the lower areas. In fact the origin of floods is in the upper part where the precipitation exceeds the sum of the infiltration and

evaporation.

Exploitation of floods takes place in the lower areas where the collected flood water flows in alluvial-type wadis and is used for infiltration and spate irrigation and the rest flows into the sea or is lost in the desert. Infiltration and water use for irrigation exceeds precipitation in these areas (for example, Abyan Delta and Tuban Delta).

**3.1.2 Assessment of surface water resources.** The shape of floods in the upper, mountainous part is a function of geological and geomorphological characteristics. In the lower areas, it is influenced by man-made spate breakers (small structures, 'ogmas' of the traditional irrigation systems, etc.) which break the first flow reaching the 'ogmas' and, a few minutes later, the peak flood thus created joins the detained water.

Hydrographs drawing information from all along the wadi are the basic prerequisite for the water-balance computation. But it is difficult to convert meteorological data into hydrograph. Flow records for the wadis are generally insufficient and too specific to a few wadis to make it practicable to assess properly the water resources in Yemen. A more encouraging situation is in the wadis which have gauge stations in their lower reaches, such as wadis Bana and Tuban.

**3.1.3 Assessment of groundwater resources.** In PDRY aquifers have not yet been regarded as real ground water reservoirs. Their ability to store water results from the groundwater table gravity drainage and is directly dependant on the height of the water table and on the water storage coefficient in this position. A typical geological profile in an alluvial type of wadi may consist of loess, aeolian sand and gravel, sand stones and conglomerates with calc-clay cement, basalt, dykes, debris and bed rock of granitoid or of sedimentary origin. The storage coefficient may range from 0.2 to 0.01. The storage properties of aquifers range from 200 to less than 10.1 per m of aquifer.

The groundwater level decreases in the period between floods because groundwater is extracted for irrigation. From the amount the water table decreased and the volume of water extracted, the coefficient of storage was estimated at 0.19. During floods the groundwater level increases. Modelling this process enables us to reconstruct the infiltration rate for 1 m of wadi length as 667 m during floods (Mucha and Paulikova, 1982).

The groundwater reserve replenished during the April and May 1983 floods corresponded to flooding irrigation of 0.5 m depth. This quantity is not negligible and can be controlled and optimized by proper spate and groundwater management. The spatewater infiltration depends on aquifer parameters and spate characteristics, mainly on the duration of the flood. Control of floods is, therefore, the first step to ground water balance optimization to meet agricultural demand for water. Flood water control means also the partial control of sediment transport which rises exponentially with the height of flood peak. The aim of flood control should, therefore, be the temporary storage of the peak water. Special systems to control the floods in wadis should be developed and constructed.



**3.1.4 Optimal water balance.** Optimization of water balance in PDRY must be based on the fact that groundwater is limited and not always totally replenishable as floods are not permanent but mostly seasonal and variable in magnitude and time. In arid areas aquifers play the role of reservoirs of groundwater which are replenished by infiltration from short floods and used over a long period. The amount of groundwater used must be balanced by replenishment from floods. This is the main principle of optimal water balance. Plans for optimization should be based on:

- ❑ knowledge of the surface-soil-groundwater system expressed in a model;
- ❑ knowledge of the hydrological probability of spate water inflow into the optimized area; and
- ❑ definition of the objectives which should be achieved by optimization.

Proper spate irrigation, flood control, spate and groundwater balance, sediment transport control and flood warning systems all depend on the construction of gauge-height record stations, estimation of their stage-discharge relationship, groundwater monitoring systems and knowledge of aquifer parameters.

In PDRY groundwater is the only permanent source of stored water, which can be exhausted if not replenished time after time from flood infiltration. The estimation of aquifer storage parameters must therefore be achieved before estimating transmission rates. Computation of aquifer storage parameters carried out by various consultants were, unfortunately, based on methods not applicable to aquifers in PDRY. The only way to make this evaluation in PDRY is to use a numerical modelling method. One such approach was developed on the basis of field work (Mucha and Paulikova, 1982 and 1984), and was reported by Mucha, Paulikova, Fara 1984. This method was prepared as a user manual and a computer program of the pumping test (Mucha and Paulikova, 1986) especially suitable to arid lands, including ordinary, large-diameter wells. The manual is available from FAO, UN Technical Department, in Rome. A similar, but simplified approach was given by Rathod and Rushton, 1983, which was used in PDRY by John Taylor and Sons in 1984.

**3.1.5 Sediment yield and transport.** Nearly all the transport of sediment occurs in wadis only during heavy floods. It can carry along coarse sediment and gravel. The finest sediment comes to rest at the end of the flood and may clog the wadi bed. The heavy flood, however, destroys this mud cake and renews the wadi bed infiltration ability. A number of investigations have been carried out by different consultants using different methods to determine sediment yield and transport in spate flows in a number of wadis in PDRY.

In Wadi Tuban, suspended solid load concentration varies between 11.4-55.65 g/l, as found by gravimetric analysis of samples taken from Dukeim in 1973 (Italconsult, 1973), and may reach an upper limit of 100 g/l as shown by photometric analysis in 1981 (GDC, 1981). It was also evident that concentrations of sediment load are much higher in the early period of floods. However, in order to estimate the annual sediment transport of Wadi

**Table 1 Monthly Rainfall Records**

Station	Altitude (m)	Record	Mean annual rainfall (mm)
Jawala	52	1972-76	100
Fiyush	65	1972-80	51
Lahej	129	1973-80	60
Jol Madram	450	1972-79	126
Musaymir	600	1972-79	288
Al Kiesh	750	1972-79	192
Milah	600	1972-78	201
Arisa (Al Durayjah)	900	1972-79	369
Qarad	1100	1972-79	298
Dhala	1500	1972-79	370
Khalla	1350	1972-79	258
Mukeiras	2150	1977-79	221
Ibb, YAR	1900	1969-80	1760
Bany Mudsem ('Udayn), YAR	1800	1970-79	594
Sumarah (Al Makhadir), YAR	1650	1969-77	803
Yarim, YAR	2650	1969-80	691

**Data Sources**

1. Italconsult, 1973 and/or MAAR files
2. Tihama Development Authority
3. Tipton and Kalmabach, 1979

Tuban, a mean value of 25 g/l may be taken which will yield, on average, 3.5-4 million tonnes of sediment transport per year, with an estimated annual stream flow of 150 mm (Italconsult, 1973). The bed load transport is assessed as 10-20 percent of suspended solid load (Italconsult, 1973). The grain size composition of the sample collected has considerable variation. However, on average the most common classes are those of coarser material above 5 cm (31.4 percent) and of finer material under 0.77 mm (25.5 percent). The sediment load concentration in spate flows of Wadi Bana was investigated (Dar Al-Handasah, 1971) and found to be in the range of 3.2-13.6 g/l with grain size mostly less than 0.1 mm (i.e. fine sand to clay). In Abyan Delta, the average yield of overall sediment percentage is in the order of 1 mm, with an average annual flow of 160 mm, while the concentration of suspended sediment load in spate flow in Wadi Hajr was found to be within the range 6-8 g/l (Tesco-Viziterov, 1984).

**3.1.6 Spate management and establishment of flood warning system.** Spate management is mainly the responsibility of local authorities in the governorates, represented by agriculture departments which include an irrigation section. A water distribution plan is usually proposed by the department of agriculture and then submitted to the executive bureau of the People's Local Council for study, discussion and approval. It is based on an accepted system of priority of sequence of irrigation and on the annual agricul-

**Table 2 Retention capacities of soils and permanent wilting points for different textural classes**

Textural classes	Retention capacity (% by weight) at pF 2.5	Permanent wilting point (+1% by weight) at pF 4.5
Loamy sand	7.3	1.8
Sandy loam	11.5	4.5
Loam	18.9	7.2
Silt loam	23.9	9.1
Clay loam	27.9	11.4
Silty clay loam	30.4	8.7

\* From Dar Al-Handasah 1973

tural plan of the Ministry of Agriculture. Spate irrigation is achieved by traditional methods whereby water is diverted from the wadi to traditional canals ('ubar') in which a barrage of mud ('Ma'aqam') is constructed to raise water to sub-channels and then to the plots of the fields, whence irrigation continues from one field to another within the capacity of flood flow from the respective channel. The same operations are repeated in other traditional channels downstream in the wadi.

Knowledge of the hydrological probability of floods, flood control and better management of spate irrigation, and better surveys of floods, depend particularly on a good, working, warning system. A warning system enables the use of emergency protection procedures and also allows more efficient spate-water control, measurements at gauging stations and a better spate-water distribution policy. The first flood warning system in Yemen, for Wadi Bana, has been disappointing, but completion of this work is now well in hand. The warning system, based on a radio network, will give the traditional irrigation staff in Abyan Delta at least eleven hours warning of a flood approaching Batais weir, and some idea of the magnitude of the flood.

This will enable the staff to distribute the water much better than at present and also to protect properties and lives.

### 3.2 Agriculture and spate irrigation

**3.2.1 Soils and their water retention capacities.** The soils on the edges of wadis are usually of alluvial origin and the major environmental factor that influenced their formation was the dry and hot climate. Although water is usually the major agent of transport and deposition where flood water contains an average of 1.47 percent of silt, as is the case for Wadi Bana, wind also plays an important role in some regions. Soils are, therefore, mostly alluvial with some aeolian sand. In addition to these two factors, saline groundwater and human activities have played a role in the soil development. PDRY soils are usually medium in texture with a profile composed of layers of different textural classes ranging from loamy sand to silty clay loam, depending on the effects of water and wind.

The infiltration rates of soils are generally moderate with an average of 4 cm/hr. Soil retention capacities and permanent wilting points for different textural classes are presented in Table 2. Total carbonates are mainly composed of CaCO<sub>3</sub> with some MgCO<sub>3</sub>. Their contents vary between 10-40 percent. They mainly occur in the silt and clay fractions. The soil pH is slightly alkaline and ranges from 7.5 to 8.5. With the exception of Wadi Hajr and areas irrigated with poor quality groundwater, the salt content averages about 0.07 percent throughout the soil profile.

Fertility is generally low. Organic matter is low: it does not exceed one percent in the surface of the soil and decreases through the soil depth. Corresponding nitrogen contents are approximately between 0.13 and 0.01 with a mean of 0.07 percent. On the plus side, available phosphorus is adequate and potassium is in high quantities for most crops.

Spate irrigated land occupies nearly 70 percent of total agricultural land in the country. The capacity of these soils to hold a single application of spate water is defined on the basis of available moisture holding capacities to a depth of three metres. This, in turn, is directly related to the soil texture and stratification. The land distribution in

**Table 3 Land distribution in relation to water-holding capacity**

Capacity	Class	Abyan Delta* (Wadi Bana)		Tuban Delta* (Wadi Tuban)		Wadi Beihan***	
		(ha)	(%)	(ha)	(%)	(ha)	(%)
Good	1	19437	49.5	3980	23.8	2624.2	22.1
Fair	2	10928	27.9	3840	23.0	2478.2	20.9
Poor	3	4625	11.8	2700	16.0	1961.4	16.5
Very Poor	4	-	-	-	-	61.6	0.52
Non arable	6	4245	10.8	6210	37.1	4727.4	39.8
Total Classified Area		39235	100	16730	100	11850	100

\* Dar Al-Handasah 1973

\*\* Ital Consultant 1974

\*\*\* Sogreah 1978

relation to capacity to hold irrigation water is shown in Table 3. From the table it can be noted that about 50 percent of the total classified area in the three wadis are located in classes 1 and 2. The texture of these soils is loam or heavier, capable of storing sufficient available water in three metres soil depth to maintain crop growth during the season. The remaining area of spate irrigated land is in classes 3 and 6; their soils are lighter than those mentioned above, and consequently have lower water holding capacities.

**3.2.2 Crop water requirements and application depths** Most of the research conducted at ElKod, starting in 1955 when it was established, was on cotton. Considerable work was done on the crop-water requirements of long staple cotton in relation to irrigation treatments. Cotton was grown under single irrigation given before planting.

Water consumption of cotton was studied by many research workers (Ogborn, 1960; Anthony, 1963; Farbrother, 1962; Rijks 1964 and Al-Shoubihi 1978). Ogborn (1960) stated that in the areas in which the water table is high, commercial yields of cotton were obtained with the application of 15-30 cm of water. On the other hand, Anthony (1962) pointed out that in localities where the water table is deep, the yield of cotton—in a long-term experiment in which 15 and 30 cm water applications were compared—was higher in the first year and progressively declined in subsequent years. This was presumed to be related to decreases in reserve stored water.

Although the above data have been used to give practical advice in areas with conditions similar to those where the experiments took place, the knowledge of crop-water relations was needed to explain the inconsistent results in other parts of the spate irrigated area. Farbrother (1962) carried out an experiment in which the pattern of water use by cotton receiving 15, 30, 45 and 60 cm of water before planting were compared. He found that the growth of cotton was limited due to lack of available moisture content and that the actual evapotranspiration from a fully grown crop receiving 60 cm of water exceeded the evaporation from a free water surface.

Rijks (1964) work indicated the pattern of water use by cotton which received presowing irrigation of 15, 45, 60 and 90 cms. He found that the water used, estimated from changes in soil water content and gradient of humidity and temperature, was of the order of 14, 34, 46, and 67 cm, respectively. He concluded that an estimated water use for maximum cotton yield was about 85 cm, but the most efficient use of water for production of an economical yield would be 50 cm.

Al-Shoubihi (1978) conducted studies on medium staple cotton. He showed that 45 cm of applied water along with stored soil water before irrigation brought the available water to 45 cm. He explained that on the basis of soil water determination, 45 cm water was required to raise the moisture content to field capacity throughout 3 metres of soil profile. Excess water would percolate down beyond the root zone.

The distribution of soil water throughout the profile during the season is described by Rijks, 1964. He shows that water in the early stages was first removed from the

upper layers, later from deeper layers and finally, when water stress increased throughout the profile, from all levels. This sequence shows that the roots explore the soil for water at low tension before an appreciable amount of water at high tension is used and this coincides with the root penetration in the soil. The root of cotton can reach to well over 100 cm depth in the first month after sowing, to about 200 cm after 2 months, and finally to well over 300 cm (Anthony 1962 and Hearn 1964).

### 3.3 Planning, design and construction

Irrigation projects are of long-term benefit and usually involve relatively large investments compared with other agricultural projects. It is particularly important to plan and design irrigation projects carefully, based on reliable hydrological and agro-economic data.

**3.3.1 Diversion weirs and canal head work** During the past 17 years the MAAR, under the supervision of Soviet-Yemeni Projects, has constructed and reconstructed 13 weirs on Wadis Tuban, Rabwa, Ahwar, Bana and Hajr with capacities ranging from 1000 m<sup>3</sup>/s to 6620 m<sup>3</sup>/s.

The formation of spate streams occurs mainly in the north of the country and specific features of floods (peak discharge in the initial period with heavy sediment and trash load) as well as the short duration and high intensity of the floods have prompted the use of a frontal design of diversion weirs. Such weirs consist of a water intake structure, a flush sluice way, an opening for the discharging floating trash, a wide spill weir front, downstream and upstream wing walls and divide guide walls.

The diversion weirs built before 1982 were not very effective. They had insufficient downstream side protection and were mainly destroyed by the floods of 1981/82. The designing and construction of weirs and head works is mainly based on the topographical conditions of the construction site, size of flow and probability as well as the command area. For example, the Batais weir (the furthest upstream weir on Wadi Bana) is designed to command 9000 ha of irrigated land, to pass 2500 m<sup>3</sup>/s (at 5 percent probability) and, to reduce the construction cost and volume of work, the design provides a breaching earth embankment.

A contrasting design is that of Al Haija Weir, which is located 7 km downstream of Batais Weir in Wadi Bana (Fig. 6). The site differs greatly from Batais Weir, as the former is surrounded by agricultural lands. To avoid damages to these lands, it was decided to construct Al Haija Weir to pass a spate flow of 5000 m<sup>3</sup>/s (with a probability of 1 percent). A gabion barrage beside the concrete solid portion was constructed instead of the breaching plug. Self-controlled automatic spillways are provided in the design of all head works of canals.

**3.3.2 Wadi training and bank protection works** The geological, topographical and hydrological conditions of most of the wadis of PDRY lead to bed scour and bank erosion. Moreover, the frequency and magnitude of floods during the year are highly variable. For example, in Wadi Rhwar during the year 1976/77, there were only two floods

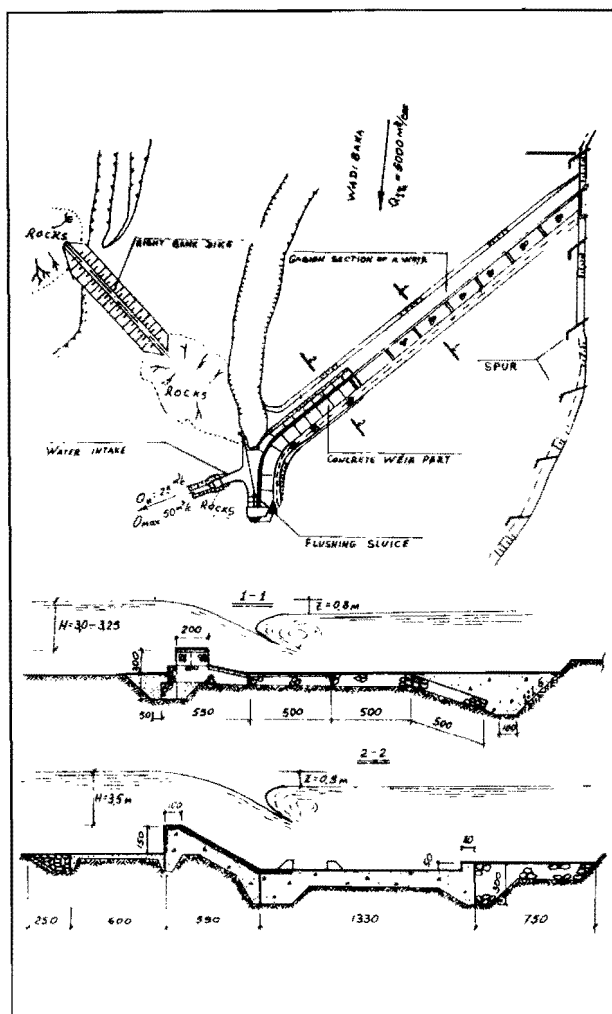


Figure 6: Reconstruction of Hayja Weir on Wadi Bana

while in 1978 there were 12 floods. In 1974 a flood flow of  $1\,800\text{ m}^3/\text{s}$  was recorded, whereas in 1977 it was  $3\,000\text{ m}^3/\text{s}$  and in 1981 it was  $1\,500\text{ m}^3/\text{s}$ . In 1982, however, a catastrophic flood of  $5\,340\text{ m}^3/\text{s}$  was recorded (Wadi Rhwar, Yemeni-Soviet Project, 1983).

In PDRY some experience has been accumulated in the construction of wadi training and bank protection works. Dykes of various designs have been erected, including cement concrete facing, precast cement concrete blocks, stone pitching and stone filled gabions.

**3.3.3 Design of canals and distribution network** When designing a canal and its distribution system, the specific flood characteristics such as spate flow magnitude and duration, irrigation water requirement and soil conditions must be considered. The design of the hydraulic structures on the main canals, having regulation gates and site overflow spillways, is intended to protect the main canal against scour during unexpectedly high floods.

The flooding of basins at low water flow in the distribution canal is ensured by concentrated discharge to high canal bed elevation. The system of commanding flooded basins by canal water surface level adopted previously required additional structures to hold water and divert it to fields. This complicated operation and maintenance and prevented feeding basins at low flood period. Command-

ing the canal bed elevation allows simultaneous flooding of two to four fields, considerably reduces the cost of construction and improves the operational characteristics of the structure (Fig. 7).

In state farms where agricultural operations are more mechanised, rectangular-shaped basins are adopted, whereas in private and cooperative farms the shape of the field plots tends to follow the natural contour. Depending on ground surface slope, soil condition and irrigation water requirements, the new canals designed have capacities ranging from  $25\text{--}90\text{ m}^3/\text{s}$ .

Because the floods are irregular, and yet groundwater is scarce and of poor quality, attention has been paid to the conjunctive system of irrigation (a combination of spate and groundwater irrigation). Here, the flooding basins are sub-divided into plots of  $0.4$  to  $0.8\text{ ha}$  with  $25$  to  $30\text{ cm}$  high levees (fig. 8).

**3.3.4 Improvements in field to field distribution system.** In the existing spate irrigation system the fields are usually  $0.1\text{--}0.5\text{ ha}$ , while the biggest may reach  $1\text{--}1.5\text{ ha}$ . Moreover,  $30\text{--}40$  percent of the total irrigated areas are occupied by field boundaries and canals lying outside the command area. Poor levelling of the existing fields, before improvement, is one of the main reasons for low irrigation efficiency. Small fields of irregular shapes do not permit efficient use of farm machinery. Considering the fact that the wadis of PDRY have irregular floods, it becomes evident that the field to field irrigation system, before improvement, is disadvantageous. This is because when the first field is irrigated and cultivated, it is not possible to irrigate the remaining fields from a second flood without damaging the previously irrigated and cultivated fields.

However, under the improved spate irrigation system, the irrigated lands receive  $4\,500\text{--}5\,000\text{ m}^3/\text{ha}$  of water compared with  $5\,000\text{--}8\,000\text{ m}^3/\text{ha}$  in case of unimproved, traditional irrigation system. But water use efficiency is increased. For example the following efficiencies have been recorded for Wadi Ahwar (Yemeni-Soviet Project, Wadi Ahwar, 1983):

Field application efficiency:  $83$  to  $85$  percent;  
Distributary concrete structures:  $95$  percent; and  
Irrigation Canals:  $85$  percent.

Hence the conveyance efficiency is  $81$  percent and the total irrigation efficiency of the system is  $68$  percent (but overall efficiency at the level of the whole wadi is much lower). In the improved system, an outlet is provided for each basin separately from the distribution canal, which ensures field flooding to the designed depth. This system therefore, avoids the field to field spate water distribution which operates in unimproved traditional spate irrigation systems.

**3.3.5 Farm access roads.** The importance of farm access roads for easy movement of agricultural machinery and for good control of spate flood distribution and maintenance works is considered while designing the new improved irrigation systems. Most of the main canals are provided with a road each side, and distributary canals with one road.

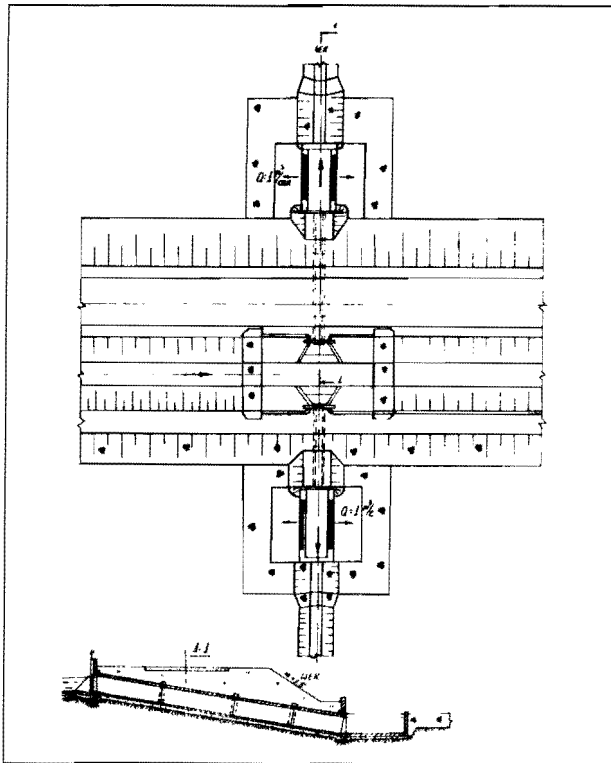


Figure 7 Plan of two-side water outlet from spate irrigation canal

To avoid land losses and to reduce construction costs, the following minimum design standards are considered:

- ❑ road width = 5.6 m;
- ❑ gravel coating with 0.15-0.20 m thickness;
- ❑ minimum turning radius (taking into account heavy trucks and machinery) = 20 m; and
- ❑ culverts and small bridges

### 3.4 Operation and maintenance

The annually irrigated and cultivated land in the country is about 64 000 ha, of which about 45 000 ha is under traditional and improved spate irrigation; about 16 000 ha under well irrigation; and the remainder is rainfed. The irrigation networks of these systems include 13 diversion weirs, 1 600 km of canals and about 11 000 small irrigation structures. The main wadis (Tuban, Rabwat, Rhwar, Bana and Hadramout) have 374 tubewells. Improved irrigation networks serve an area of about 20 000 ha. All the irrigation networks need maintenance, otherwise they are threatened with deterioration. The main objects of maintenance and improvement are as follows:

- (a) to increase irrigation efficiency in the irrigation networks; and
- (b) to establish a system for the distribution of surface and groundwater for irrigation according to the technical specifications of the irrigation networks of the improved and traditionally irrigated areas. Other factors such as the properties of soil and water, the size of the discharge (whether from the wadi or the well), the implementation of an agricultural production plan and the existing water right customs have to be taken into consideration.

**3.4.1 Design criteria and operating rules for spate diversion and sediment.** The spate floods in almost all wadis in the PDRY carry floating materials such as bushes and trees. The spates also transport a good deal of suspended load and heavy bed load. Strict rules have been adopted on operating the diversion weirs and main canals.

Most of the floating material passes over the overflow diversion weirs. A special wide opening is usually provided near the head regulators of the main canal (in between the gates of the main canal and sluice gates) with the same elevation as the crest of the overflow weirs. This type of opening provides good control of floating material while operating the structure.

This method was recently adopted for Rhwar and Batais weirs. Bed material deposition is highly controlled by well-designed sediment sluices. Approaching spate flow is divided into layers by providing different elevations for the crest, head-works and sediment sluices. The difference in elevation between the crest and sediment sluice varies from 2-2.5 m depending on the approach channel characteristics, the geological conditions and the slope of the wadi. Using a lower sediment sluice, and with the help of a dividing wall and a curved cantilever-type head regulator bed still, higher velocities and a good circulation stream can be obtained, which provides for efficient transfer and discharge of the heavy bed load to the downstream side, through the sediment sluice.

Fine suspended material is accumulated and collected in the sediment catch basin in the main canal, just below the head regulators, where the canals are made wider.

Because of the deficiency of irrigation water, the head stretches of the main canals and the sediment catch basins must be cleaned, by machines, once or twice a year after the floods. This helps to ensure a normal water supply to the irrigated fields.

**3.4.2 Problems of sedimentation in the fields and loss of command.** When distributing spate water it is necessary to take into account the availability of water in the wadi and the number of previous floods and floodings of the fields. Water application priority charts should be adopted on the basis of water availability during the year.

Commanding the fields by distribution canal bed elevations ensures the discharge of suspended load on to the irrigated fields. This is useful fertilizer for the land and its discharge improves the operation and maintenance of the hydraulic structures. The traditional practice consists of commanding the irrigated fields by the water surface level in the canals. Such systems require the construction of a number of control structures with many gates to raise the water head. As a result, the potentially useful fertilizer transported by the water is deposited in these canals, raising the problem of sedimentation. It is considered reasonable that in improved irrigation systems, provision should be made for canal bed elevation command over the irrigated fields to avoid siltation in canals.

**3.4.3 Maintenance of canals, structures and gates** In order to keep hydraulic structures, canals and roads in good condition, a number of maintenance measures should be

carried out each year. They include cutting trees and bushes, cleaning canals and sedimentation basins of deposits, repairing and maintaining gates of hydraulic structures and keeping the service roads network in good operating condition. These maintenance operations are carried out by special repair and maintenance services, but the distribution network and small structures down to the irrigation basins inlets are entirely controlled by cooperatives and farms. The experience in PDRY is that this maintenance of the distribution system is one of the bottlenecks of the spate system. However, measures have recently been taken to set up a centralized maintenance service which will be in charge of the operation and maintenance of the entire irrigation system in the Republic.

### 3.5 Established water rights customs

In PDRY, the water which flows in wadis and main channels and subchannels is recognised by all as a common property. Main channels and subchannels are regarded as "marafiq" of the land, inalienable appurtenances, which may not be separated from the land they serve by sale or contract or hire. Every one has the right to drink water, or let his animals do so, from the water in the wadi or from springs or wells, while land, which has an established customary right, may be irrigated from the water of the wadi. These principles, firmly established and widely accepted, are enforced by a complex system of administration and safeguarded by universally respected customs.

In general, the basic principle of water right is that the water which comes out of the wadi has to be distributed according to the existing custom, which normally specifies the sequence of irrigation "rada'ah". The administration of water distribution is also left to custom, which may differ from one area to the other.

#### 3.5.1 Water rights and irrigation systems. Water rights vary with the types of irrigated area in the country.

In rainfed areas of high altitude, cultivation is done in terraces and at the foothills in small plots. Each plot has its own canals which collect rainfall for irrigation. These canals, with the land they serve, are the private property of the farmer.

In areas situated in secondary and small wadis, which are irrigated occasionally by spate, farmers have the right to irrigate their fields according to the sequence of irrigation starting from upstream.

In agricultural lands that are irrigated almost annually by spate floods in wadis relatively bigger than those mentioned above but without irrigation structures or improved irrigation networks, spate irrigation is achieved by diverting water from the wadi to the land that has the priority of irrigation, before the downstream land. Here the sequence of irrigation "rada'ah" is strictly observed.

In agricultural areas situated in main wadis that are irrigated by spate twice a year (Seif and Kharif seasons) as well as perennial flow, the government has executed Irrigation Development Projects. They included the building of diversion weirs and canals, land levelling and making improved irrigation networks.

In these agricultural areas, which are mostly under co-

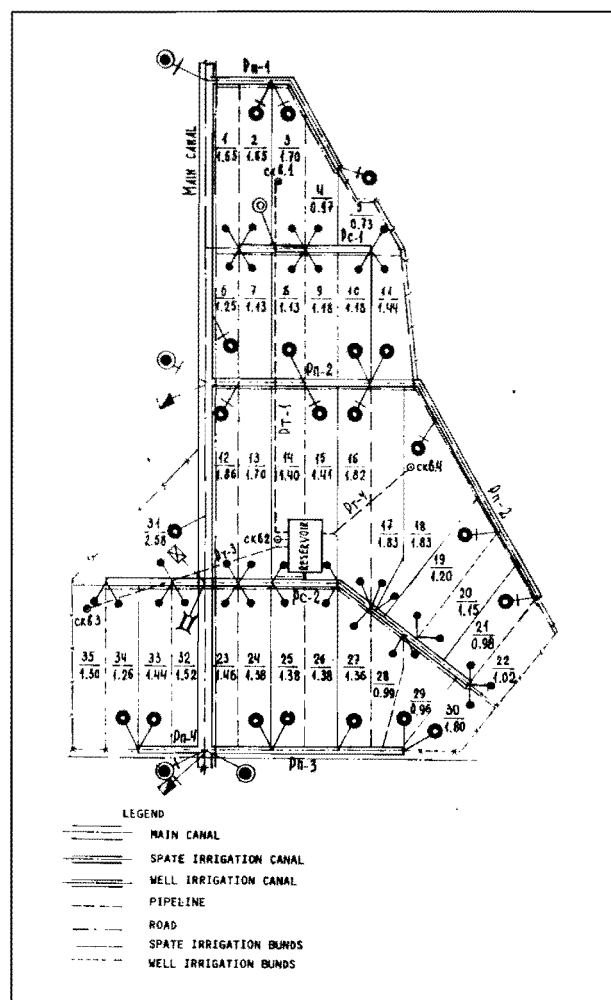


Figure 8 Combined irrigation area in Lenin State Farm

operatives, water distribution is controlled by the MAAR through its departments of agriculture in the different governorates of the Republic. These departments distribute water according to a seasonal spate irrigation plan which is based on the agricultural production plan. Irrigation starts by diverting spate floods from the most upstream weir through different gates and canals to irrigate the lands downstream through the respective weir and canal system according to the plan and in keeping with the "rada'ah" system as much as practicable.

This improved spate irrigation practice is followed in the delta areas of Lahej and Abyan Governorates. In each of these governorates the irrigation plan is supervised by a local committee headed by the director of agriculture. For the implementation of the irrigation plan, an irrigation supervisor is in charge of diverting and distributing spate water from weirs and main canal offtakes. Irrigation at the field level beyond the tertiary canal is the responsibility of a committee formed from the respective agricultural cooperatives. However, these committees perform their tasks at the field in close liaison with the irrigation extension officers of the department of agriculture. Under this system, priority of utilization of flood water is given to the spate irrigated areas but, in the case of high floods, well-irrigated areas may be supplemented with the flood water. In spate irrigated areas, crops are irrigated once per season



except for some areas situated in the upstream of the wadi where crops might be given two irrigations ("zahw").

In areas irrigated by wells, the right to abstract groundwater for irrigation is governed with the property of the well which is considered part and parcel of the irrigated land whether it is state, cooperative or privately owned land.

**3.5.2 Methods of assessment, levying and collection of rates for operation and maintenance costs** Current irrigation fees cover hardly any of the operation and maintenance costs of the spate irrigation system. They are levied in some areas in the main wadis. In these areas, farmers pay to the ministry of finance through their cooperatives, irrigation fees of one dinar per acre for all crops except cotton, for which the fee is half a dinar per acre. This system, however, is old and impractical, and the rates are low. Recently MAAR reviewed the taxation policy on agricultural production and proposed a new system for land taxation that included irrigation fees.

### 3.6 Organization and management

In PDRY, the main institutions in charge of wadi development works, including execution of irrigation projects, are the Irrigation Department and the Department of Yemeni-Soviet Projects of MAAR.

**3.6.1 Responsibilities of the irrigation institutions** At present, the above-mentioned institutions are responsible for:

- ☐ detailed topographic surveys of project areas;
- ☐ water resource surveys and assessment;
- ☐ site surveys and geotechnical investigations;
- ☐ planning and programming, including preparation of pre-feasibility and feasibility studies and project designs;
- ☐ implementation of irrigation projects including construction of diversion weirs, canals and irrigation networks, reclamation and levelling of agricultural lands, construction and improvement of irrigation systems in groundwater and spate irrigated farms; and flood protection works;
- ☐ wadi training and protection of land against erosion by spate floods in the main and secondary wadis;
- ☐ management, operation and maintenance of completed schemes; and
- ☐ training staff in irrigation work.

**3.6.2 Management objectives and targets.** Management objectives of the irrigation institutions fall within the government policy in achieving the following goals:

- (a) increasing food production, aiming initially at self-sufficiency in vegetables and fruit production, and reducing the gap between importation and consumption of main crops in order to meet the demand of a growing population and the newly established agro-industries;
- (b) earning and/or saving foreign currency;
- (c) increasing opportunities for employment; and
- (d) improving living standards in rural areas and raising

the income of the rural poor.

To fulfill such broad objectives the irrigation institutions set forth the following targets:

- i) rational utilization of land and water resources in order to increase the irrigated and cultivated areas;
- ii) better water management by improving water scheduling and application;
- iii) introduction of new irrigation systems and technology where applicable;
- iv) improvements to irrigation system efficiency and maintenance; and
- v) the establishment of water rights and adequate legal administrative authority.

It is now recognized by the Irrigation Department that the establishment of monitoring and evaluation units at the sectoral and project level is a pre-requisite for sound management practice. The introduction of monitoring and evaluation systems will play an important role in improving the efficiency of on-going project management and in contributing to more effective planning of new projects on the basis of experience gained and lessons learned. It will also help in promoting cooperation and coordination among the participating agencies.

## 4. Evaluation of wadi development works

### 4.1 Investment in irrigation

Of the annually irrigated and cultivated land in the country (about 64 000 ha), an average of 70 percent is irrigated by spate floods, 25 percent by groundwater, and the rest by rain. This cultivated area amounts to only 58 percent of the total cultivable land. This is due to the limited availability of irrigation water, in terms of both quantity and quality. Water, therefore, is the limiting factor for extensive and intensive agricultural development.

The above situation has given irrigation projects high priority within the agricultural sector. About 118 million YD have been expended in implementing basic irrigation projects. This comprised about 60 percent of the total investment in agriculture.

These projects, executed by the Department of Irrigation, were mainly oriented to build the infrastructure required by the agricultural sector in a number of wadis in the Republic. They were:

- ☐ studies and surveys for land and water resources undertaken for most of the main and secondary wadis in the Republic;
- ☐ the construction or reconstruction of thirteen diversion weirs, with their respective systems of canal and flood protection works;
- ☐ survey and land levelling of a total of 7 000 ha of spate irrigated land and consequent irrigation improvement works;
- ☐ survey, land levelling, irrigation improvement and farm construction on some 5 000 ha of well-irrigated state and cooperative land, in addition to some other preliminary irrigation works;
- ☐ the drilling and digging of about 2 200 boreholes and



- open wells for irrigation;
- the provision of earth-moving equipment and farm machinery and tools for the above irrigation development works;
- the establishment of a central workshop in Aden Governorate and 15 machinery renting stations and workshops in the other governorates; the establishment of 18 agro-meteorological stations and 17 rainfall stations, distributed all over the country;
- the establishment of stream-gauging stations for the measurement of spate floods in Wadis Tuban, Bana, Beihan and Hadramout;
- the establishment of observation well networks for monitoring groundwater level in the Wadis Tuban, Bana, Beihan and Hadramout; and
- the establishment of an irrigation training institute for training middle level technical cadres, field supervisors and surveyors.

#### 4.2 Main constraints

During implementation of irrigation projects for wadi development and spate control works the following constraints were observed:

- (a) lack of qualified experienced technical staff for planning design and management of big projects (a situation which makes MAAR depend heavily on expatriate staff);
- (b) incompatibility between feasibility studies, designs and costs of some irrigation projects; and
- (c) lack of financial resources to complete implementation of remaining wadi development projects, especially for flood rehabilitation works in areas affected by the catastrophic flood in March 1982.

#### 4.3 Lessons learned from irrigation projects

During implementation of irrigation projects, some drawbacks have been observed. The conventional techniques for monitoring and evaluation of projects have only recently been introduced, but our experience has already brought to light the following.

The benefits of irrigation projects are long-term and the impact of such projects on agricultural production is difficult to quantify.

More attention should be given to the participation of the eventual beneficiaries at the preparation and implementation stages of irrigation projects. The beneficiaries should be aware of the immediate and long-term objectives of the project and the social and economic benefits and impact expected from it. During project preparation, careful understanding and realistic data on the existing situation (e.g. traditional spate irrigation system) have to be acquired. This can best be achieved through meeting beneficiaries using the present system who may provide data (e.g. for big flood events) from memory or from what they learned from their fathers and grandfathers. Such information, at one design stage, may help to reduce the degree of risk to the new weir or dam once it is constructed. During project implementation, it is a good idea, where possible, for beneficiaries to participate by actual working

on the project. This ensures their sympathy with the project and helps to ensure that effective maintenance will be carried out after its completion.

After implementing a number of wadi development projects, including the construction of diversion weirs, the excavation and lining of canals and land levelling, and bearing in mind the catastrophic floods of September 1981 and March 1982, the approach to wadi development and improvements in spate control have been reviewed and now tend to keep as much as possible to the traditional methods of diversion of spates. As a result, the present approach tends towards the adoption of some of the more flexible features of the traditional methods. In fact, present-day spate projects are really improvement schemes, as spate irrigation has been practised for hundreds, if not thousands of years, on the alluvial coastal plains of the south-west Arabian Peninsula.

Some aspects of our re-evaluation are:

- i) after independence, the government, through MAAR, implemented a number of irrigation projects to control and minimize the destructive effects of the peak floods in the main wadis of the Republic where there is a one percent probability. Where technical conditions and location make it possible to reduce construction cost, measures have also been taken to control the floods (by providing breaching fuse bunds) in areas where there is a 5 percent probability of maximum discharge, as in Batais Weir;
- ii) each diversion structure is designed in accordance with the conditions of the location and a certain level of probability of maximum spate flow;
- iii) well developed wadi might have perhaps 30 to 50 or more individual diversion canals offtaking from the wadi. If this system is to be improved to provide better control of spate flows then it may be necessary to construct some 40 to 60 diversion structures to replace the 30 to 50 traditional offtakes;
- iv) much more attention needs to be given to sediment control of spate irrigation headworks;
- v) the overall irrigation efficiency of spate improvement schemes involving a series of diversion weirs is likely to be in the order of 30 to 40 percent for the spate irrigation system of the delta. This means that the net consumptive use of surface water might only be about one-third of the mean annual flow. However, extensive spreading of spate irrigation is probably the best means of recharging groundwater, mainly through wadi bed seepage and canal losses. Thus the overall water balance would allow somewhat greater groundwater abstraction than for the schemes with higher irrigation efficiencies;
- vi) the optimal spate application depth for a single irrigation should lead to an average of 400 mm of stored water in the root zone of the soil. This is about as much as the average soils in spate areas can retain;
- vii) conjunctive use of flood groundwater on the spate yield would give good results provided that the field is divided into smaller plots to allow for efficient use of groundwater for irrigation. The conjunctive system of irrigation would be more favourable where

salinity problems are encountered and soil conditions are unfavourable;

- viii) improvement works as outlined above will be in keeping with traditional water rights and operating procedures in control of spate flows. This development concept lends itself to a phased programme for implementation. The first phase could provide diversion and control of spate flows and deliver irrigation supplies to the existing canal systems in quantities that the groups of farmers have been accustomed to handling. The operation of the new canal offtakes should be handed over to the groups of farmers responsible for each canal as soon as they have demonstrated that they can handle the system without difficulty, but under the general supervision of the authority concerned. When these farmers have gained complete confidence in the improved diversion system the next phase should be planned in close consultation with them. This second phase would improve distribution and control, where necessary, on the traditional canals. In the areas which are able to grow more than one crop, the field-to-field system could be changed to a system of small distributaries delivering supplies to each field or, at least, to smaller groups of fields than at present. After the first phase development has been in operation for a few years, there will inevitably be some requirements for minor alterations and improvements which will have become evident, and these could be incorporated into another phase of improvement of the secondary irrigation system. Such phased series of improvements seems appropriate; and
- ix) since about 60 percent of the total commanded area in the main wadis will only receive one irrigation per year, full improvement works to deliver water by minor canals to each field of the whole delta cannot be justified. In the upstream part of the delta, where the possibility of reaching spate water is greater than in the downstream part, the full improved system of irrigation, provided with diversion weirs, main canals, distributary canals, levelling of lands and construction of regulating outlets with gates for each field basin separately, should be adopted. In the downstream part of the delta, the wadi development projects must take into account the need for a minimum volume of work, which should, however, include the construction of a diversion weir with the required main canals to supply water to existing canals, and other minor improvements.

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