DRAFT REPORT ON RAINWATER HARVESTING IN INDIA AND MIDDLE EAST

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P R E F A C E

In this Report, all technologies used in India and the Middle East for rain water harvesting on which some quantitative information was available have been described, except for some, like modern dams and diversion weirs, which have been very well documeted almost everywhere. Technologies used in India have been discussed in much more detail than those in the Middle East, partly because more published information was accessible on the former and partly because of difficulties in planning and organising travel outside. Technologies which are in the experimental stage but not yet under application (most of them in Israel) have been omitted in the spirit in which the UNEP undertook this programme.

My grateful thanks are due to Prof A K N Reddy for help throughout this study and to the UNEP for financial support. I thank the engineers of various state governments in India as well as the authorities and academic persons in Afghanistan, Iran and Israel who responded to my enquiries. Space does not permit acknowledgement of their valuable help individually.

CHAPTER 1: GEOGRAPHY OF INDIA

India, extending from 8°4'N to 37°6'N and from 68°7'E to 97°25'E, and covering an area of 3.28 million Sq.km, exhibits[1,6] a wide variety in topography (Fig.1.2).

(i) The Himalayan mountain region in the north, about 2500 km long and 250 to 400 km wide. The region has three parallel series of mountain ranges: the Great Himalayas, the northernmost range, have the highest peaks in the world; the Middle Himalayas have an average height of 3200m to 4500m; the Outer Himalayas or the Siwalik range, averaging 900m to 1200m in height, form the southernmost range.

(ii) The great Indo-Gangetic plain stretching from Sind and West Punjab in Pakistan in the west to Bangladesh in the east, with an average width of 300 km, formed by alluvium deposited over centuries by the rivers Indus, Ganga and Brahmaputra. At places the alluvium extends to a depth of 1800m below ground. The Indo-Gangetic plain is virtually rainless at its western extremity, but in the east receives heavy rainfall. The plain covers an area of 652 000 sq.km.

(iii) The west coastal plains, stretching from the Cape Comorin at the southern tip in a narrow belt about 10 to 25 km wide along the Arabian sea coast, ending in the vast plain of Gujarat.

(iv) The Western Ghats, separated from the Arabian Sea by the West Coastal Plains, consisting of hills with an average height of 1200 m and running almost parallel to the coast for about 1600 km from the Cape to the mouth of the river Tapti. The Western Ghats are not a true mountain range, but just the steep eroded edge of the Deccan Plateau, which occupies the major part of southern India. The Western Ghats are divided in two by the 24 km wide Palaghat Gap, belived to be a rift valley.

(v) The East Coastal Plains, running from the Cape along the Bay of Bengal Coast, with an average width of about 120 km, and joining the deltaic plains of the Ganga in West Bengal. The big rivers of peninsular India join the Bay of Bengal, forming deltas through the length of the East Coastal Plains.

(vi) The Eastern Ghats, separated from the Bay of Bengal by the East Coastal Plains, with an average width of about 200 km, running roughly parallel to the east coast from the southern end of the Western Ghats (for about 1000 km) upto latitude 21°N. The highest peaks in these mountain ranges rise more than 2500 m above the sea. They do not form a continuous range, however. The mighty rivers of peninsular India like Kaveri, Krishna and Godavari cut their way to the Bay of Bengal through the Eastern Ghats. The Eastern Ghats are not a true mountain range either, being only the eastern edge of the Deccan Plateau.

(vii) The Deccan Plateau, stretching from the Western Ghats to the Eastern Ghats and bounded on the north by the Narmada valley. It covers an area of 700 000 sq.km, and slopes eastwards and northwards. The topography features rounded hills and rolling plains.

(viii) The Central Highlands, situated between the Indo-Gangetic Plain and the Deccan Plateau, and characterised by rolling plains separated by flat-topped forested hill ranges.

(ix) The Eastern Plateau, stretching from the Deccan upto West Bengal.

(x) The Deccan Plateau is separated from the Central Highlands by the Satpura range of mountains. This range is difficult to cross, and has served as a natural dividing line between the north and the south. The presence of another parallel range of mountains, the Vindhya, on the other side of the Narmada Valley, has enhanced the importance of this dividing line.

As already stated, the Western extremety of the Indo-Gangetic Plain receives very little rainfall. Its south-western end forms the Thar desert.

CHAPTER 2 : CLIMATE AND RAINFALL

Climate and rainfall in India are influenced by its tropical location, the presence of the Himalayas and the Western Ghats, the sea surrounding the southern part on three sides and by the fact that it is situated in the monsoon region, i.e., where the direction of wind changes with season.

The monsoon winds are generated by the differential heating of air over land and the ocean by the sun. The ocean water, because of its convection and higher specific heat, experiences a lower rise in temperature during the day than land. The air over the land masses therefore becomes hotter and lighter than over the ocean, giving rise to low pressure areas. These "lows" move northwards with the sun from January to June, and so do the winds, which generally blow from highs towards lows. Because of the low pressure region centred over India (Fig.1.3) from May to September, winds tend to blow from the south to the north in this region, but are deflected to the east on crossing the equator, due to the rotation of the earth. They thus blow from the southwest, and hence from over the Arabian Sea to Peninsular India and Sri Lanka, and from over the Bay of Bengal to North-East India and Burma. The winds pick up moisture over the seas, and ~~deposit~~ release it on India in the form of rain during these months. These winds are called the Southwest Monsoons after the direction from which they blow.

From October to January, the sun will be in the southern hemisphere, and the large Asian landmass becomes very cold, with a consequent high pressure region to the north-east of India. At this time there are low pressure regions situated over Australia and East Africa (the summer of the southern hemisphere). A system of winds is set up under these conditions which blow from the north-east across Pakistan, India and Sri Lanka. These winds are known as the North East Monsoons, and are dry except after they cross the Bay of Bengal, where they pick up moisture. As a result, south-east India and Sri Lanka receive rainfall during the winter also[2].

Fig.1.4 shows the average dates of onset and withdrawal of the monsoons at different places in the Indian subcontinent[3]. Rainfall begins (ignoring the "pre-monsoon" showers) in Sri Lanka during the last week of May and covers Tamil Nadu and half of Kerala (See Fig.1.1 for the political divisions), the southernmost states of India, by 1st June, when the sun is already halfway across the Deccan. The southwesterly winds after producing rain in southeast India cross the Bay of Bengal, where they pick up moisture again, and below into Burma and Bangladesh which receive rainfall around the same time. The southwest monsoon is thus distinguished by its two branches, named respectively the Arabian Sea Branch and the Bay of Bengal Branch.

Fig.1.4 shows that the Arabian Sea Branch steadily advances northwards across peninsular India and covers the western state of Gujarat by the end of June. In the meantime, the Bay of Bengal Branch spreads over the northeastern states of India by the first week of June. The winds are deflected westwards by the Arakan hills of Burma and the Himalayas and this branch of the monsoon thereafter progresses in the western direction along the Gangetic Plain. By the middle of June, the two branches merge over Uttar Pradesh and progress towards Haryana and Punjab.

The amount of rainfall at various places on the Indian subcontinent depends on the orographical features and the distance from the coast measured along the monsoon current. The western Ghats force the Southeast monsoon winds upward, leading to moisture condensation and heavy rainfall on the West Coastal Plains. This loss of moisture results in a considerably lighter rainfall east of the Western Ghats. There is, in fact, a rain shadow effect in this area. This is illustrated in Fig.1.5, which shows the isohyetal lines connecting points of equal average annual rainfall. Parts of Gujarat, Punjab and Rajasthan as well as Pakistan receive much less rainfall than the neighbouring regions because the monsoon winds are obstructed by the Aravalli Hills, east of which there is good rainfall. The southern part of Assam receives very heavy rainfall again due to Orographic causes; the Khasi Hills (mean altitude 1500 m) catch the Bay of Bengal Branch in a relatively narrow valley and deflect it upward. As a result, the town of Cherrapunji in this region records the world's second highest annual average rainfall of 1142 cm. X Heavy rainfall similarly occurs in the Outer Himalayan regions of Bhutan and Arunachal Pradesh.

On June 21, the sun begins its southward journey from the Tropic of Cancer, which runs a little north of the Deccan Pltaoau. By this date, the monsoon covers almost the whole of India. Rainfall ceases in northwest India around 1st September, by which time the sun is situated well to the south of Sri Lanka. The monsoon withdraws from India gradually as shown in Fig.1.4, roughly in the same way as it advanced.

Southeast India and Sri Lanka experience, as already stated, a second bout of rainfall (the Northeast Monsoon) during the winter, which ends by the middle of December in India.

To summarise, the rainy season lasts about 6 weeks during July - August in northwestern India and about 6 months during June - December in the southeast. The latter region receives about 52% of its annual rainfall during the Southwest Monsoon and the rest during the Northeast Monsoon[2]. During the months from June to October, a number of depressions form over the Bay of Bengal and there is a high probability that a few of them will move inland across either the east coast into the Peninsula or the Orissa - Bengal coast into the Gangetic Plain[4]. These moving depressions have a life of 4 - 5 days and can cover considerable distances in this interval. Depressions also form over the Arabian Sea, but very few are likely to move into India. Rainfall occurs over a wide area under the tracks of these depressions (upto about 500 km wide), normally of the order of 10 cm - 20 cm per day. Maximum rainfalls of 99 cm in 24 hours in Gujarat and 90 cm in 24 hours in Bihar have been recorded under these depressions, which contribute a significant proportion of the annual rainfall over an area extending from the northern coast of Andhra Pradesh to the Punjab Hills. Table 2.1 shows the number of depressions which moved inland, in different months, over a 69 - year period from 1891 to 1960. It is seen that one depression each month can be expected to cross inland from the Bay of Bengal from June to October, sometimes more during July, August and September.

TABLE 2.1 NUMBER OF DEPRESSIONS MOVING INTO INDIA DURING 69 YEARS FROM 1891 to 1960

In the month of	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
From the Bay of Bengal	0	1	0	9	27	56	88	98	98	65	34	4
From the Arabian Sea	0	0	0	3	2	8	4	0	2	8	6	0

During April - May and October - November, when the Inter-Tropical Convergence Zone passes over the Bay of Bengal(7), heavy thunderstorms occur. Severe cyclones may cross the west coast causing devastation in the coastal regions.

Table 2.2 shows the mean rainfall distribution in India according to region and season(5), as well as the mean annual rainfall. Rainfall in any individual year may vary on either side of those figures. Generally speaking, variations from the mean are lower in higher rainfall areas, and vice versa(8). In the Arunachal Pradesh area, the standard deviation is about 15% while in the semi-arid Rajasthan region, it is of the order of 60%, reaching 80% in the desert region(4). Fig.1.6 shows the average number of rainy days (days on which the rainfall is at least 2.5mm) per year in different regions.

TABLE 2.2 - RAINFALL DISTRIBUTION IN INDIA

State	Meteorological Sub-division	Average Rainfall in cm during				Average annual Rainfall, cm
		Jan-Feb	March-May	June-Sept	Oct-Dec	
1	2	3	4	5	6	7
Andhra Pradesh	Coastal region	2	7	56	34	99
	Telengana	1	7	78	11	97
	Rayalaseema	1	7	39	19	66
Assam, Arunachal Pradesh, Meghalaya, Nagaland, Manipur, Tripura, Mizoram	North	6	59	151	17	233
	South	5	64	162	25	256
Bihar	Plateau	5	10	111	10	136
	Plains	3	7	104	8	122
Gujarat	Gujarat	-	1	84	4	89
	Saurashtra & Kutch	-	-	55	4	59
Haryana & Delhi	Haryana & Delhi	6	4	60	5	75
Jammu & Kashmir	Jammu & Kashmir	10	18	36	5	69
Kerala	Kerala	4	48	166	54	272
Madhya Pradesh	East	4	6	122	8	140
	West	2	3	96	6	107
Maharashtra & Goa	Madhya	1	5	53	11	70
	Marathwada	1	3	65	9	78
	Vidarbha	2	4	97	8	111
	Konkan & Goa	-	4	222	13	239
Karnataka	Coastal Region	-	16	295	23	334
	Interior North	1	7	58	13	79
	Interior South	1	16	42	22	81
Orissa	Orissa	4	12	120	19	155

Contd.

1	2	3	4	5	6	7
Punjab	Punjab	6	5	49	4	64
Rajasthan	East	1	2	63	4	70
	West	1	2	26	1	30
Tamil Nadu	Tamil Nadu & Pondicherry	6	12	27	53	98
Uttar Pradesh	East	4	4	96	7	111
	West	6	4	90	5	105
West Bengal	Sub Himalayan	3	41	219	17	280
	Gangetic	4	18	113	16	151
Himachal Pradesh	Himachal Pradesh	10	13	118	12	153
Islands	Andaman, Nicobar and Other Bay Islands	14	49	160	72	295
	Lakshadweep & Other Arabian Sea Islands	4	20	99	34	157

Due to the seasonal concentration of the rainfall throughout the country, techniques for storage of rain water have evolved. These techniques vary from one region to another, depending on the terrain, soil types etc.

'appropriate' to the local conditions

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CHAPTER 3 : RIVERS OF INDIA

India has a large number of rivers draining into the Arabian Sea or the Bay of Bengal, apart from a few desert rivers which flow for a small distance and disappear in the sands of the Thar desert. 11 of them each carry more than 10 000 million m^3 of water on an average every year, the two biggest being the Brahmaputra and the Ganga respectively. Next is the Indus, on the banks of which an ancient civilisation flourished, and from which the name of the country is derived. The estimated total annual average discharge carried by these 11 rivers is[4] 1.56×10^{12} m^3. 47 other rivers are estimated to carry a total of 1.23×10^{11} m^3, a number of minor rivers 1.17×10^{11} m^3 and the desert rivers 10^{10} m^3 of water each year on an average. The total average annual discharge carried by the Indian rivers is thus 1.81×10^{12} m^3. (cf the Amazon, which discharges about 6.3×10^{12} m^3 of water per year). The total annual flow in all the rivers of the world is estimated to be 27.14×10^{12} m^3, so that the Indian rivers account for 6.7% of the total runoff, draining 2.2% of the land area of the world.

The three biggest rivers, the Ganga, Brahmaputra and the Indus are fed by snow melting in summer, and hence carry substantial discharge throughout the year, though the peak discharge occurs during the monsoon. The other rivers being purely rainfed, either dwindle or completely dry up during the post-monsoon months. Fig.3.1 shows the important rivers of the subcontinent.

CHAPTER 4 : SOILS OF INDIA

Fig.4.1 shows the soil map of India, which has four major groups of soils:

(i) Alluvial
(ii) Black
(iii) Red
(iv) Laterite and Lateritic.

(i) Alluvial soils form the largest group, covering an area of 1.5 million sq.km, deposited as silt by the numerous rivers. They are found mainly in the states of Punjab, Rajasthan, Uttar Pradesh, Bihar, West Bengal (the Indo-Gangetic plain) and Parts of Assam and Orissa. They also occur in the valleys of the Narmada and Tapti in Madhya Pradesh, and of the Godavari, Krishna and Kaveri in South India.

(ii) Black soils constitute the second largest group, spread over about 550000 sq.km. They are derived from the lava deposits of the Deccan Trap under semi-arid conditions, and are found in central and western Madhya Pradesh, southern Orissa, southern and coastal Andhra Pradesh, northern Karnataka and almost the whole of Maharashtra. They also occur in parts of Gujarat, Rajasthan, Uttar Pradesh and Tamil Nadu. They have a large clay component, because of which they swell when wet and shrink and develop cracks when dry. They become sticky when wet and are therefore difficult to plough under moderately high moisture content. These soils are rich in nutrients like potash, iron, lime etc., and have good moisture-retaining capacity.

(iii) Red soils are found over an area of about 350 000 sq.km, and are the product of the weathering of ancient crystalline metamorphic rocks like granites, gneisses and schists. They occur in large parts of Tamil Nadu, Karnataka, Northeast Andhra Pradesh, Southeast Maharashtra, Madhya Pradesh, Orissa and South Bihar. Red soils have sandy to loamy structure and are generally porous with a lower moisture retaining capacity than black soils. They differ greatly in fertility.

(iv) Laterite and Lateritic soils cover an area of about 250 000 sq.km, and are found in the hill regions of the Deccan, Karnataka, Kerala, Madhya Pradesh and Orissa. They are composed of hydrated oxides of iron and aluminium, with the iron oxide sometimes separating in the form of nodules. The texture of the soils ranges from heavy loam to clay. They are low in fertility.

The other soils covering the rest of the country can be grouped under (a) forest soils, characterised by organic matter derived from forests, (b) desert soils found in the semi-arid and arid regions of Punjab and Rajasthan, characterised by a mantle of wind-blown sand, (c) saline and alkali soils, found in Punjab, Uttar Pradesh, Maharashtra and Gujarat, at places where soil drainage is poor, and (d) peat and marshy soils, which occur in small pockets in Kerala and north Bihar.

CHAPTER 5 : TANKS OF PENINSULAR INDIA

5.1 Introduction

The practice of putting small earthen dams (called 'bunds') across small local streams to collect the rain water running off the neighbouring region is very old in south India and Sri Lanka. The reservoirs so formed are called tanks, and the water collected is used for irrigation as well as domestic purposes. The waterspread of these reservoirs varies from a few hectares to a few thousand hectares, depending on the nature of the terrain, rainfall, nature of the land downstream, runoff from the catchment etc. No effort is made to treat the catchment to increase the runoff, since the tanks are built in areas of moderate to heavy rainfall. There are about 500 000 tanks in India[9], a majority of which is to be found in Peninsular India. A large number (about 100 000) of small tanks are found in West Bengal, but they differ from the tanks of peninsular India in that they are excavated in the ground, rather than formed by obstructing a stream.

The ideal site for a tank satisfies the same conditions as that for any other dam: firm foundation, a reasonably deep gorge at the bund site so that the length of the bund is small, and nearness to the source of good soil to build the bund. Since the quantity of water stored is small, one cannot afford to loose much of it in conveyance, and hence it should be near the place of use e.g., a village or the area to be irrigated by the tank. Sometimes, when a stream is large, many tanks are built in "series" along its length, so that water flows to a lower tank after the upper ones are filled.

5.2 Components of a tank system

The focus of a tank is the bund, which is built of soil, and whose top is at a fixed level. If flood water flows over the bund, the bund will breach rapidly due to erosion. Therefore, a "waste weir" "spillway" is provided, which is simply a masonry wall of suitable length whose top is at a level lower than the top of the bund. Excess water will escape over this waste weir, and is usually conducted back to the lower reaches of the stream through a channel. The top level of the waste weir therefore is the "full tank level" (FTL) and determines the amount of storage in the reservoir. The waste weir may be built alongside the bund or at any other suitable location around the perimeter of the reservoir. The maximum flood likely to occur in the stream during the life of the tank should be passed harmlessly by the waste weir, i.e., the maximum water level (during flood) in the tank is between the top of the waste weir and the top of the bund. The difference between the maximum water level and the top level of the bund is the "free board".

A tank usually caters for both domestic and agricultural needs. In northeastern India, fish are cultivated in tanks. Water for domestic purposes is manually transported in pots, and therefore steps are provided near the deepest part of the bund, since water is available there longer than in any other part of the tank. Water for agriculture purposes is transported through a system of channels. Normally two main channels, one on each bank of the stream, are taken out at a level between the FTL and the stream bed. All the land lying between the main channel and the stream is 'commanded' by the channel, and the actual area irrigated by the distributaries and/or the main channel is the 'achkat'. The channel takes off from the lake through an intake situated in the bund, and the discharge is controlled by a gate or a plug valve. Sometimes a good tank site lies across a very minor stream which cannot fill the planned lake. In such a case water is diverted from a neighbouring stream into it through a feeder channel.

5.2.1 The tank bund: The older bunds were massive (cf. §5.9), and were made entirely out of locally available mud. They were trapezoidal in section, and flat side slopes were used. In the bund at Madaga (Karnataka), for example, sideslopes of 1 vertical to 2.5 horizontal (in some places even 1:3) are used. Huge boulders were often used to protect the upstream slope from erosion (Fig.5.1). Modern tank bunds, however, have a cross section similar to that of earth dams (Fig.5.2). They consist of a 'hearting', made of impervious earth (e.g., clay), a 'casing' made of local earth, a cut-off wall, again of impervious earth, taken deep enough into the ground to meet the imp rvious stratum underneath and drains to lead seepage safely across the bund. The hearting, cut-off wall and the drains all serve to keep the downstream part of the bund from becoming wet, as otherwise the seeping water will erode the bund from the rear. Fig.5.2 shows the 'seepage line' which is the boundary of the wet part of the bund. The rear slope of the bund is covered with turf to prevent erosion from rain. The front slope (on the water side) is protected from sloughing and erosion due to waves by means of stone pitching from the bottom upto the expected level of the waves above the maximum water level.

The bund is built using human and animal labour. As a rule, no machines are used. The earth for the casing is excavated at some distance upstream of the bund position, transported by bullock carts, and dumped in layers throughout its length. The casing and hearting are simultaneously built up. The earth is automatically compacted as construction progresses, due to the walking of numerous men, women and animals. Besides, a bund takes two to three years to build, and the rains during the period also help in compaction.

5.2.2 The intake : The outlet from the lake into an irrigation canal is through an intake tunnel across the bund (Fig.5.3). The flow is controlled by a gate (or a plug valve in the case of small tanks) operated by a lead screw installed in the upstream side of the bund. Approach to the operating platform is over a small steel bridge. The tunnel is lined with masonry, and it is important to ensure a good watertight joint between the masonry and the earth to prevent erosion of the bund at this joint.

5.2.3 Feeder channels : If a very good site for a tank does not have a good catchment, tanks are nevertheless built there and a channel is dug to convey water from a neighbouring catchment into the tank. Such channels are called feeder channels. The feeder channels take off from either the bed of a stream or from an auxiliary tank. In the former case, a divide wall serves to divert the flood water into the channel (Fig.5.4a). The divide walls are temporary structures built out of mud and river sand just before the floods. A little distance from the stream, a control gate structure is built in the channel, which can shut off the flow after the tank fills (Fig.5.4b). This is necessary since the tank is built in a local depression, and not in the valley of a reasonably large watershed which can discharge a flood.

This type of feeder channel, in order to convey adequate quantities of water which will be available only during floods, has to have a large cross section. It will sometimes be cheaper to build an auxiliary tank at the head of the feeder channel to have some storage, and convey the water to the main tank over a longer period than the flood duration through a small feeder channel. Such a channel has several advantages over the other type. It is less liable to silt. If the channel breaches during a heavy rain, the auxiliary tank can be shut off till the channel is repaired and water could be fed to the main tank later. (Fig.5.5)

Feeder channels may be several kilometres long, and are aligned approximately along a contour. They therefore collect rain water which runs off from the watershed above them and convey it to the tank, in addition to drawing off water from the stream or auxiliary tank at which they start. Feeder channels are left unlined, since they function only during the floods when the soil is wet, and there is little seepage from them.

5.2.4 <u>The waste weir</u> : The waste weir is a very important component of the tank and should be designed to discharge the maximum flood likely to occur during the life of the tank without the water level rising above the designed maximum. In many tanks, the waste weir is situated at an extremety of the bund, so that the amount of masonry construction is small. Sometimes it is level with the ground, and in rocky areas, even excavation by blasting the rock is done to form the waste weir (Fig.5.6). Where the top of the waste weir is above the ground, a rather flat slope paved with stones is provided on its downstream side (Fig.5.7), so that the surplus water flowing out does not scour the ground below the bund. If the irrigation channel takes off at a position between the waste weir and the bed of the stream, the surplus water channel, on its way to the stream,will cross the irrigation channel, and a structure must be built at the intersection to manage the crossing.

5.3 <u>Terrain suitable for tanks</u>

Tanks used for the supply of irrigation water must hold a reasonably large quantity of water. On the other hand, the bund should not be too long, so that it would be economical to build. From the same consideration, not too much land should be submerged by the water which fills the lake. The terrain suitable for tanks is therefore of undulating nature, with hillocks or raised mounds in the gaps between which short bunds could be built, with fairly steep slopes so that a large quantity of water could be stored below a given contour. Such undulating terrain contains numerous watersheds, bounding small catchments, so that the flood to be discharged by the waste weir of a tank in a given catchment is not too heavy. In such a terrain, very long canals from rivers such as those in the Indus valley basin cannot be economically built, and tanks with their shorter canals therefore fill the need.

Fig.5.8 shows the region around Bangalore, a typical tank terrain. It is a LANDSAT photograph taken in February 1973 with a scale of about 1:1000 000 (each millimetre represents about a km on the ground). The monsoon ends in this region in November, and the black patches represent the tanks still containing water. The photograph clearly shows the numerous small streams and the tanks built across them.

Fig.5.9 shows a small part of this region, photographed from the top of the Nandidurga, a hill 40 km from Bangalore. Several tanks can be recognised from this photograph.

5.4 Dug tanks

In contrast to the type of tanks discussed so far, some tanks are built by excavating the ground, and not by constructing a bund across a stream. These dug tanks are found primarily in West Bengal and Bihar, and are used to rear fish. Other states where such tanks exist are Orissa, Assam, Manipur, Uttar Pradesh and Madhya Pradesh. The tanks collect rainwater running off the ground above them, and once filled, sealed from rain water on all four sides by embankments (Fig.5.10). Where water for the tank is supplied by a local stream, the tank is excavated sufficiently far from the stream to avoid the flood waters. It is estimated that 4 to 10 hectares of catchment area is required to fill one hectare of tank bed.

Fish tanks are best built in nonrocky sites with at least 2m deep topsoil. The water table should be high, so that too much water is not lost by seepage (the rate of fall in water level over a year should be less than 1 metre). The catchment area should be covered with vegetation, so that silt does not enter the tank along with rainwater.

5.5 Quantities of water harvested

Table 5.1 gives the area irrigated by tanks in relation to the total irrigated area as also the density of tanks in various states of India. The figures are valid for the year 1963. Current figures are not available for all areas.
X

Though the absolute magnitudes have changed over the years, the relative values are still valid. It is seen that around 40% of the total irrigated area in the east coast states derives its water from tanks. In many other states, the contribution from tanks is significant, though not to the same extent as in the east coast states. Individual tanks have storage capacities which vary widely from one region to another. Irrigation tanks are built in Karnataka to store as little as 200 000 m^3, while in Maharashtra the minimum capacity considered for such a tank is 1.4 million m^3. There are big tanks in Tamil Nadu which store as much as 100 million m^3 of water.

The exact total volume of water collected in tanks is not available, but a rough estimate may readily be made from the area irrigated. An average of 0.8m depth of water for irrigation, 1.3m for seepage from the canals(10) and 1.8m for evaporation (§5.64) (this assumes the tank bed area to be equal to the irrigated area, cf §5.63) over the total tank - irrigated area of 4.55 million hectares gives an average storage of 351700 m^3 of water per tank. The average area irrigated per tank works out to 9 ha. The total amount of rainwater stored in the tanks of the three southern states of Andhra Pradesh, Tamil Nadu and Karnataka amounts to 9.7% of the annual rainfall over the area.

5.6 Some problems of tanks

Tanks have several advantages: they serve local communities,

Table 5.1 - Tank distribution[9] (Year 1963)

State	Population, millions	in thousand hectares		Contribution of tanks to irrigation, %	Total land area, thousand km²	Total number of tanks	Tank density per km²
		Area irrigated from all sources	Area irrigated from tanks				
Andhra Pradesh	43.5	2967	1232	41.5	276.8	56700	0.2
Assam	14.6	613	0	0	78.5	0	0
Bihar	56.4	1973	276	14.0	173.9	27800	0.16
Maharashtra	50.4	1080	191	17.7	307.8	48100	0.16
Gujarat	26.7	720	16	2.2	196.0	20400	0.10
Jammu and Kashmir	4.6	280	0	0	222.2	0	0
Kerala	21.3	336	45	13.4	38.9	1500	0.04
Madhya Pradesh	41.7	952	151	15.9	442.8	40200	0.09
Karnataka	29.3	883	355	40.2	191.8	36500	0.19
Orissa	21.9	1028	412	40.1	155.8	1700	0.01
Tamil Nadu	41.2	2460	928	37.7	130.1	31400	0.24
Punjab	13.6	3154	6	0.2	50.4	200	0.004
Rajasthan	25.8	1790	165	9.2	342.2	Not available	
Uttar Pradesh	88.3	5013	413	8.2	294.4	140000	0.48
West Bengal	44.3	1336	364	27.2	87.9	100000	1.14
Total			4554			504500	

they can be built with local material and skills and they take a short time to construct. They are however beset by several problems, important among which are silting, breaching, seepage evaporation, submergence of cultivable land and weeds. These are discussed in some detail below:

5.6.1 Silting: Silting is a serious problem with tanks. The tropical rains often consit of sharp showers, and the hot weather proceding the monsoon will have rendered the soil particles loose. Considerable erosion therefore takes place, less in forest areas and more in cultivated or uncultivated areas. Tanks are almost always in the midst of cultivated areas, since the irrigated area should be situated near the tank in order to minimise loss of water by seepage through the sides of canals. The rate of erosion of soil, as measured at large reservoirs(11), is estimated to be of the order of 600 to 900 m^3/km^2 every year. This is carried as silt by the stream, to be depositod in tanks, reservoirs or carried into the sea. For large catchments, the erosion could be as high as 2250 $m^3/km^2/$ year(12). On an average, the storage capacity of a tank decreases at the rate of about 0.5% per year due to silting. The irrigation canal intake is kept at a level which allows a 10% 'dead storage' which will ultimately be filled with silt. 20 yr approx.
The solution proposed for the silting problem is light afforestation of the catchment of the tank, banning cultivation of the foreshore lands and construction of small check dams upstream to trap the silt.

5.6.2 Breaching of the bund: This is the most serious problem with tanks. A case study(13) in Andhra Pradesh revealed that 20 tanks included in the study had suffered a total of 38 breaches; 14 times due to the bund being overtopped by flood waters, 16 times due to erosion of the bund, 5 times due to 'piping', where seepage water flowing below or through the bund took away soil particles when emerging to the surface, and 3 times due to unknown reasons.

Most cases of overtopping of the bund occur due to insufficient capacity of the waste weir. In the above case study, the committee concluded that on an average, the flood surplussing capacity of the waste weir was 23% of the estimated maximum flood. Sometimes local farmers, in order to increase the storage in the tank, raise the level of the waste weir crest before the monsoon, but do not restore it before the floods. This might result in overtopping of the bund. In the case of a 'series' of tanks, where many tanks are built across the same stream, the overflow from the upstream tank filling the one on downstream, the breaching of an upstream tank is likely to cause successive breaching of the downstream tanks. This risk can be reduced by making the downstream tanks bigger than the upstream ones, and, of course, providing adequate surplussing capacity for all tanks.

5.6.3 Submergence of cultivable land: Tanks are in general shallow, the typical depth of water being around 4m (cf § 5.5). The waterspread for a meaningful storage is therefore large when compared with big conventional reservoirs. Since tanks are built in the midst of agricultural land, the area submerged by a tank represents loss of cultivable land. The increase in agricultural output due to irrigation from the tank must therefore more than compensate the loss of crop due to submergence, if the construction of the tank is to be worthwhile.

A sample survey(9) in the states of Karnataka, Tamil Nadu and Andhra Pradesh showed that the ratio of the area irrigated by a tank to that submerged by it is, on the average, 1.2 to 1.8. In Andhra Pradesh(13), for example, the total area submerged by tanks is 1 million ha, and the area irrigated by them 1.25 million ha. In particular cases, the ratio may even be less than 1. The ratio decreases from year to year as the lake gets progressively silted up.

Under some circumstances, the submerged land is not lost for cultivation, as with the "submergence tanks" of Rajasthan (Chapter 7).

5.6.4 Evaporation: The large waterspread in relation to the storage in tanks also means a relatively large evaporation from the lake. Evaporation rate depends on the atmospheric humidity, temperature and wind speed. In India, the hottest period of the year is just before the monsoon, when most tanks are almost dry. The windiest months are the monsoon months, when the humidity is also the maximum. As a thumb rule, the year is divided into three periods of four months each, and the mean evaporation loss assumed as follows:

Winter (Nov., Dec., Jan. & Feb.) : 75mm/month
Summer (Mar., Apr., May, Jun.) : 250mm/month
Monsoon (Jul, Aug., Sept. Oct.) : 125mm/month,

totalling 1.8m per year. While the actual evaporation is close to this figure in Tamil Nadu or Andhra Pradesh, it may be as high as 3m per year in the hot arid regions of north-western India.

Despite efforts over a long period, no satisfactory method of reducing evaporation has been found. Planting of trees on the shores of the lake has been suggested to reduce the wind velocity on the lake surface. X

5.6.5 Seepage : Very scanty data is available regarding the loss of stored water by seepage through the tank bed and sides and bottom of the irrigation canals. A recent study[14] revealed that the average rate of seepage from the bed of a tank in Aurangabad district in Maharashtra is 0.3m/month. However, this rate is unlikely to be maintained as the tank grows old, since fine silt is deposited, becomes dense, and progressively cuts the rate of seepage. Another estimate[9] is that 1.2m of water percolates into the ground through the tank bed every year. It is estimated[10] that 44% to 47% of the water let out for irrigation is lost by seepage through the sides and bottom of irrigation canals, the main canals accounting for 15% to 20%, the distributaries 6% to 7%, and the small field channels 21% to 22%. 0.1 m/month half

5.7 Maintenance

Tanks need annual maintenance, just after every monsoon. Weeds and long grass growing on the top of the bund or waste weir are to be pulled out, eroded parts of the bund repaired, ratholes plugged, clogged drains cleared and the upstream revetment stones properly packed. When the tank dries up before the monsoon, accumulated silt in its bed should be cleared. This, however, is easier said than done. In the earlier days, farmers who cultivated lands adjacent to a tank used to dig out, transport the silt and spread it on their lands as manure (silt is estimated to have a nitrogen content of about 0.3%). With rising transport costs and the advent of chemical fertilisers, this practice is now abandoned, resulting in more rapid silt accumulation in tanks than before. X

Tank bunds are likely to settle during the first few years after construction. The level of the top of the bund should be maintained by periodic filling. Any cracks in the bund should be plugged with a mixture of sand and clay, especially carefully at the joint between the earth and masonry. Cracked joints in the waste weir masonry should be repaired. Any scour by the lead-off channel at the bottom of the waste weir should be filled, so that the weir foundation is not undermined.

5.8 Costs

The current cost of construction of a complete tank system, including the bund, waste weir, irrigation canals etc. is estimated, in terms of the area irrigated by it(15), at Rs.6875/ha. Assuming an average total storage requirement of 39100 m^3/ha, the cost of a tank works out to Re 0.18/m^3. 4x 100x100 = 40,000 m^3 The water is sold to farmers not on the basis of the actual volume consumed, but on the basis of the crop grown and the area irrigated. The average annual return works out to about Re 0.0062/m^3 of stored water, which is 3.5% of the initial investment. Allowing for depreciation and maintenance costs, it is obvious that there is a large element of subsidy involved in the sale of water. But this is not peculiar to tanks, and is true of all irrigation works in India, though the subsidy is smaller with conventional large reservoirs due to economies of scale.

5.9 Examples

One of the big old tanks is the Tonnur tank (Fig.5.1), situated about 140 km from Bangalore. It is said to have been built around 1100 AD by Ramanuja, a religious reformer. It irrigates at present 300 ha besides meeting domestic water needs to neighbouring villages. The bund is about 23m high and closes the gap between two hills (Fig.5.11).

The Chembarambakkam tank in Tamil Nadu is another big tank, with a storage of about 100 million m^3 and a water-spread of 23 km^2, irrigating 4000 ha. Its bund is 5 km long and the waste weir 203m. The height of the bund varies from 5m to 8.5m and the top width 3m to 8.5m. Ten irrigation canals take off from the tank. Unlike typical tank terrain, the terrain here is rather flat in the neighbourhood of this tank, which therefore does not lie across any particular stream. Instead, it collects river water and rain water flowing on slopes over a wide region through feeder channels. The tanks at Veeranam (length of bund 19 km) and Puniyari (length of bund 48 km), both in Tamil Nadu, are other examples of such tanks. The height of these bunds vary from 1.8m to 3m. These tanks resemble the Ahars of Bihar (Chapter 7) in appearance though they function like conventional tanks.

Another example of a big tank in Karnataka is the tank of Madaga, whose bund is 495 m long, with the upstream side-slope (varying from 1:2.5 to 1:3) protected by stones upto 1 m^3 in volume. The bottom width of the main bund varies from 283m to 330m and its height from 27m to 32m. The bund was built of a mixture of red clay and gravel. One saddle to the west and another to the east of this main bund were closed by smaller bunds. No waste weir was provided, and the tank was destroyed long ago by floodwaters breaching the western secondary bund.

CHAPTER 6 : RAPATS OF RAJASTHAN AND PERCOLATION TANKS OF MAHARASHTRA

6.1 Introduction

For small tanks, sometimes the loss of water by evaporation and seepage from irrigation channels as well as tank bed is large in relation to the storage. This, if combined with porous soil, makes tanks of the kind described in Chapter 5 unattractive. Under such conditions, tanks can be built with the sole purpose of recharging ground water. Sandy or rocky soil provides favourable conditions for the success of such tanks, since water can quickly percolate underground through pores in the soil or fissures in the rocks. This water is stored in an aquifer and can be pumped out of wells constructed downstream. This type of tank has evolved over a long period in Rajasthan, especially in Ajmer district, where it is called 'Rapat'. The soil here is sandy, with a clay content of 3% to 9%. Similar tanks have been built in Maharashtra also for about the past 25 years, and are known there as percolation tanks. The soil at the site of the percolation tanks is rocky. Similar tanks are being experimented with in Israel too (§10.3.4).

6.2 Components of a Rapat

A rapat or a percolation tank, has a structure to impound rain water flowing through a catchment, and a waste weir to dispose of the surplus flow in excess of the storage capacity of the lake created. If the height of the structure is small, the bund may be built of masonry, otherwise earth is used.

The Rajasthan rapats, being small, are all masonry structures. But no irrigation canals are provided, and hence there are no intake structures or sluices in the bund. Considerations which apply in selecting the site for an irrigation tank also apply for a rapat.

If the bund is a masonry structure, it will have a vertical upstream face. The downstream face has a slope of 0.7 to 0.75 horizontal to 1 vertical (Fig.6.1). The bottom part may be built of random rubble masonry and the top 0.3m thickness of size stone masonry. Since the catchments of masonry rapats are quite small, in most cases the entire length of the rapat will act as the waste weir. The relatively gradual slope of the downstream face will also dissipate the energy of the flowing surplus water.

If the bund is made of earth as in Maharashtra, the section of the bund is similar to that of an irrigation tank, except that the cut-off trench is taken to a depth equal to half the height of the bund (Fig.6.2). The purpose of the cut-off in the case of the percolation tank is just to prevent erosion of the downstream slope of the bund due to piping. The cut-off should be shallow enough to permit the percolating water to pass downstream into the aquifer. As with an irrigation tank bund, the percolation tank bund has a hearting and a casing, and is provided with stone pitching on the upstream face and turfing on the downstream slope. A masonry waste weir is also necessary to pass surplus water. Drains are provided under the bund to lead water percolating into the bund safely downstream. The percolation tanks of Maharashtra have, on an average, a larger storage capacity than the rapats of Rajasthan (§6.8).

6.3 Terrain suitable for rapats and percolation tanks

Since rapats and percolation tanks closely resemble irrigation tanks in the principle of storage, the same type of terrain is suited to all three, namely an undulating terrain with valleys which carry the rain water and hillocks which provide end points for the bund and whose ridges define the watershed. Fig.6.3 shows the LANDSAT photograph of the Ajmer region, taken in March 1975. There are numerous rapats in this region. The Aravalli hills are seen running in the middle, with dry river beds on either side. Fig.6.4 shows a LANDSAT photograph of the Nasik region in Maharashtra, where percolation tanks are built. This photograph was also taken in March 1975.

6.4 Quantities of water harvested by rapats and percolation tanks

Rajasthan being an arid region, the rainfall is low (cf Table 2.2). The quantity of water harvested by a rapat is small, and is of the order of 30 000 m^3. On the other hand, rainfall in Maharashtra is much heavier, and percolation tanks are built with storage capacities from 30000 m^3 to 600 000 m^3.

Rapats and percolation tanks do not directly irrigate land, but charge wells within a distance of 3 to 5 km downstream.

(They provide, of course, drinking water to neighbouring communities). The number of wells which are benefited may range from 3 to 100 or more, depending on the storage and permeability of the soil. The area of land irrigated by wells drawing water from a rapat or percolation tank likewise ranges from 2 to 100 hectares or more.

6.3 <u>Problems</u>

Like irrigation tanks, rapats and percolation tanks also face the problems of silting, evaporation and submergence of cultivable land. While the masonry dam of a rapat is ordinarily capable of discharging floods, the earthen bund of a percolation tank will be breached if the waste weir capacity is insufficient. The maintenance procedures for percolation tanks are the same as for irrigation tanks. The dam of a rapat also needs to be inspected annually and weeds must be pulled out and cracks repaired.

Why do rapats not clog up.

Silting is a more serious problem with the small rapats than with the big percolation tanks. The estimated life of a rapat varies from 5 to 20 years. The annual depreciation on a per hectare basis is therefore high (sometimes of the order of Rs.150 per ha). After the rapat fills up with silt, the farmers dependent on it will have to revert to the earlier cropping patterns.

A possible solution for this problem would be to equip the rapat with vents which could be closed manually with shutters immediately after the silt - laden floodwaters have passed, in a manner similar to the Kolhapur-type bundharas (Chapter 8).

6.6 Costs

The average current cost of a percolation tank in Maharashtra works out to Rs 1.0/m^3 of stored water. The cost of a rapat in Rajasthan also approximates the same figure. On the basis of figures for the Khed taluka (a taluka is the regional administration centre for a group of villages) in Maharashtra, the average number of wells which draw water from a percolation tank is 28. This figure may differ for other regions. The area irrigated per well averages 1 ha (this is a more widely applicable figure), for percolation tanks as well as rapats. However, only a part of the water for irrigation comes from the rapat, the rest coming from natural ground water recharge. Table 6.1 gives some relevant data.

Table 6.1 - Some data on rapats and percolation tanks

Name	Storage million m^3	Cost of storage per m^3 of water	Cost of storage per hectare irrigation	Volume of water supplied/ha
Indira percolation tank, Maharashtra (17)	0.566	Rs.1.02	Rs.3600	3540 m^3
Ambekar percolation tank, Maharashtra (17)	0.174	Rs 0.86	Rs.3064	3550 m^3
Sarnia rapat, Rajasthan (18)	0.0229	Rs 0.85	Rs.815	956 m^3

6.7 Efficacy of rapats and percolation tanks

While little quantitative data is available in the form of recorded increase in the yield of wells or rise in water table downstream of these tanks, qualitative assessments of their performance hold them satisfactory. A water balance study of the Pachpirwadi percolation tank[14] in Aurangabad district in Maharashtra has indicated that 0.3m depth of storage percolates into the ground every month. Some measurements of the fluctuations in water level in wells downstream have been reported, but levels before constructing the percolation tank are not available.

0,3 m/month

In the Khed and Junnar regions of Maharashtra, the number of wells has increased five to six fold after the construction of percolation tanks[17]. The cropping patterns also have changed as a consequence, farmers going in for crops like paddy and sugarcane where rain-fed crops like groundnuts or sorghum were grown earlier. Similar views are expressed about rapats[19]. Downstream of a rapat with 15000 m^3 storage, it is said that the level of water in wells rose by 3m after the rapat started working. Another rapat in Ajmer district led to a 2m rise in the level of water table downstream, and wells which were earlier used only for drinking water supply could now be used to irrigate two crops per year.

6.8 Examples

The Indira Talav at Rajgurunagar near Pune in Maharashtra (Fig.6.5) is a large percolation tank with a catchment area of 9 km^2 and a storage capacity of 566 000 m^3. It was built in 1974 at a cost of Rs.576000. It has an earthen bund, at one end (the far end in Fig.6.5) of which there is a rock outcrop. The waste weir is formed by levelling the outcrop. The percolation tank charges a number of wells which irrigate a total of 160 ha of land.

The new Sarnia rapat, under construction now in Rajasthan, has a catchment area of 3.84 km^2 and a storage capacity of 22900 m^3. It has a 44m long masonry dam, 2.5m above the stream bed at the deepest point. The estimated area of land that will be irrigated by wells charged by the rapat is 24 ha. The rapat is expected to completely silt up in not less than 16 years. The actual life of the rapat is likely to be more, since flood waters flowing to a depth of 0.6m above the dam carry away some of the silt.

CHAPTER 7 : AHARS AND PYNES OF BIHAR AND SUBMERGENCE TANKS OF RAJASTHAN

7.1 Introduction

The Indo-Gangetic Plain, as already stated (Chapter 1), is formed by the filling up of a trough with alluvium. It is in general flat land. South Bihar, parts of Rajasthan (Alwar and Bharatpur districts) and Uttar Pradesh (Agra district) have under these conditions evolved a water harvesting technology called Ahars in Bihar and Submergence tanks elsewhere. In what follows, 'Ahars' will include submergence tanks also.

Ahars are created by building earthen bunds aligned as far as possible along contour lines (Fig.7.1). Since the ground where they are built has a very mild gradient (the fall is of the order of 10cm in 1 km), the bunds are turned transverse to the contour lines where it is desired to terminate them, to meet higher ground. Since variations in ground elevation over short distances are very small, the ahar can follow local features like roads, property boundaries etc. without any problem. During the monsoon, rainwater running off the ground above the ahar is collected by it, and due to the flat nature of ground, vast areas of land are submerged. After being retained till the sowing season all the water is let out downstream through pipes embedded in the ahar or pumped to higher land for pre-harvest or pre-sowing irrigation. The soil which was earlier under

wetted

water above the ahar is then sown (usually with wheat). The soil in these regions has a high clay content, because of which its moisture retention capacity is high. The crop therefore grows well without any further irrigation. The submergence tanks of Rajasthan and Uttar Pradesh also work on the same principle. The water collected is let out by the end of September so that sowing can be done by the middle of October. In Rajasthan's desert district of Bikaner, similar structures are built, but the water benefits only the land submerged.

Ahars are often built 'in series', the water let out (or the surplus water) from one filling another downstream. Sowing operations in the beds of the downstream ahars are therefore delayed a little, but the area of land benefited by this practice is large. However, like irrigation tanks in series (§5.6.2), the breaching of an upstream ahar in a series is likely to endanger the downstream ahars.

An additional benefit resulting from ahars is that brackish ground water has become potable in the neighbourhood of ahars after they are built, since fresh water collected by the ahar can easily percolate into the ground through the soil broken up every year by ploughing. Ahars also check soil erosion by arresting the flow of rain water. Because of the numerous outlets from an ahar, there are no silting problems.

Sometimes a strain of paddy is sown in the bed of the ahar before it fills up, which can grow with standing water.

Though the yield is low, the effort is worthwhile, especially in view of the subsequent winter wheat crop.

When the catchment area of an ahar is insufficient to submerge land on a significant scale, canals known as pynes are dug from a neighbouring catchment, starting at a stream. Pynes are inundation canals (§8.4) akin to the feeder channels of irrigation tanks (§ 5.2.3), and because of the flatness of the gradient, may be upto 30km long. Pynes harvest rain water from the catchment above them in addition to conveying water from a stream. Unlike ahars, pynes have a silting problem.

7.2 Components of an ahar

An ahar consists of the bund (which is itself popularly called ahar), pynes if any, surplus disposal works (waste weir and gates) and the outlets from the ahar.

7.2.1 The bund: The bund is built of locally available soil, dug out of borrow pits a little distance upstream. Unlike the bunds of irrigation and percolation tanks, the ahar bund does not contain a hearting or a cut-off trench. The soil in the bund is the same throughout its section. The section of the bund is trapezoidal, with an upstream slope of 1:2 and a downstream slope (also usually 1:2) adjusted to keep the phreatic line within the bund. This is not expensive, since the height of the bund does not exceed 3m, and the soil, because of the high clay content, has a low permeability. The top width of the bund is normally kept at 1m. A free board of 1m is provided to allow for waves. The length of the bund may vary from 150m to 10km or more depending on local requirements. Fig.7.2 shows the bund of the Pawar ahar near Patna. It follows the curves of the road to its right, and can be seen disappearing into the distance at the far left of the photograph. The bund slopes are usually left unprotected, but in deeper portions, boulder pitching of the upstream slope is done. The top of the bund is sometimes used as a road. While building the bund, gaps are left to accommodate the masonry work involved, such as the irrigation intakes and surplus disposal works.

7.2.2 Pynes: Pynes are unlined inundation canals, i.e., their bed level at the stream from which they start is above the normal water level in the stream. This ensures that they do not draw water when there are standing crops on the bed of the ahar, and also that they do not breach by drawing large quantities of flood water. Water flows in the pyne only when the flood level in the stream rises above the bed of the pyne. Since the flood waters carry considerable quantities of silt, the initial lengths of pynes are often filled with silt after a flood, necessitating a cleaning operation every year after the monsoon. The streams which feed the pynes have catchment areas of 3 to 8 km^2. Sometimes a small weir is constructed across the stream to raise its water level, so that the length of the pyne could be reduced.

7.2.3 Surplus disposal works: Since the ahar has an earthen bund, it must be provided with a device which enables surplus water to be discharged without the water level upstream of the bund exceeding the permissible limit. This job is done by a waste weir similar to that in an irrigation or percolation tank. In addition, sluice gates set in masonry structures (Fig.7.3) are provided at one or more points to empty the ahar quickly, if required, in time for sowing. The gates may also be operated as surplus disposal devices in addition to the waste weir. The gates are made of steel plates stiffened with angle irons, and are operated by a screw. Their size is of the order of 1m x 1m. The surplus water is led to a local stream or another ahar downstream.

7.2.4 Irrigation intakes: The intake for an irrigation canal from an ahar is very simple, consisting of a pipe embedded in the bund. The bund is protected from erosion at the ends of the pipe by small masonry blocks built around the pipe (Fig.7.4). The pipe has a diameter of 150 to 300 mm and is laid at the ground level. Since the bottom width of the bund is typically of the order of 15m, the length of the pipe is of the same order. The pipe may be made of stoneware, asbestos cement, reinforced concrete or cast iron. When water is to be retained in the ahar, these pipes are plugged at the end with straw and earth.

Fig.7.4 shows an irrigation canal taking off from an ahar the bund of which is seen behind the road. Since the land irrigated is adjacent to the ahar, these canals themselves often act as field channels in which case there is no heir-archical network of main canals, distributaries and field channels as in the case of an irrigation tank. The canals are therefore of small capacity and closely spaced. The typical spacing between canals is 50 to 100 m and each canal has its individual intake. If the ahar feeds another ahar downstream, there will of course be no irrigation canals. A big ahar may have, apart from the small channels, several big canals which feed distributaries and field channels.

7.3 Terrain suitable for ahars

The main parameter indicating the utility of an ahar is the extent of the land submerged by the water stored in it, the actual volume of storage being of secondary importance. A flat terrain having a very mild slope is therefore ideal for the construction of ahars. Fig.7.5 shows a LANDSAT photograph of the region around Patna in Bihar. The meanderings of the rivers and streams (the big river in the photograph is the Ganga, also known as the Ganges) are evidence of the mild slope and flat nature of the ground. The numerous ahars in the region show up as black patches.

The soil must be moisture-retentive, since the moisture absorbed when the ahar bed is under water should suffice for the crop till it is harvested. A sufficiently high clay content ensures this.

7.4 Quantities of water harvested

No information is available on the total quantity of water harvested by ahars. Individual ahars may submerge an area of 1 ha to 500 ha. Very big submergence tanks can submerge upto 4000 ha, and in addition irrigate an equal area or more, or submerge more land downstream depending on the mode of operation of the ahar. The quantity of water stored in an ahar may range from 5000 m^3 to a million m^3, and in very big submergence tanks upto 70 million m^3. The thousands of ahars existing in Bihar irrigate a total area of about 800 000 ha[20]. Ahars are more efficient in the use of stored water than irrigation tanks, since (i) the percolation losses are small due to the low permeability of the soil as well as the absence of an extensive network of channels, (ii) Evaporation losses during storage above ground are small since the humidity in the atmosphere during the period is high and (iii) All the water required for the crop is stored in the soil, and little of it is lost by evaporation.

7.5 Problems

Ahars are free from most of the problems encountered by irrigation tanks. The only serious one to be faced is breaching of the bund. This is due either to water overtopping of the bund due to insufficient surplus disposal capacity or to breaching of an upstream ahar. The only answer to this is to provide a long enough waste weir and ensure that the sluice gates are opened in time. A less serious problem is erosion of the unprotected slopes of the bund. The slopes are left unprotected since water stands against the bund only for a few weeks. Erosion therefore occurs either by rain or by waves.

Pynes have generally a flatter slope than the stream from which they take off, and so the velocity of water in the pyne is less than that in the stream. The silt in suspension in the flood water therefore gets deposited in the initial part of the pyne.

7.6 Maintenance

The bund should be repaired every year after the monsoon, the eroded portions being filled and the levels restored where any settlement has taken place. The gate, if provided, should be painted periodically. Cracks in the maonsry should be repaired. If the ahars are fed by pynes, the pynes should be cleared of silt before the monsoon every year.

7.7 Costs

Due to the absence of large networks of canals and bund slope protection measures, the cost of an ahar is much smaller than that of an irrigation tank or percolation tank for a given storage. Another factor which accounts for the low cost of an ahar is that only the land occupied by the bund itself needs to be acquired, whereas for irrigation tanks and percolation tanks, the land submerged by the water at the full tank level must also be acquired.

Accurate cost figures for constructing an ahar are not readily available since very few new ahars are being built. The thousands of existing old ahars were built by individual landowners over centuries. A large number of these are out of use, most of them due to breaching. These ahars are now being repaired by the state government. The cost of repairing the old ahars works out in the range of Rs.10 to Rs.25 per metre length of bund, based on the figures for 1963[20]. On the basis of the area benefited by irrigation, the cost of repair is Rs.30 - Rs.45 per ha. The cost of a new ahar is only slightly more than this since the repairs on which these figures are based are quite extensive. In terms of the volume of water stored, the cost averages to Re 0.05 to Re 0.15 per m^3 depending on the size.

7.8 Examples

The sabajore ahar[20] in the district of Santhal Parganas is 655m long and has a catchment of 1.3 km^2 (rainfall in this region averages 100 cm a year). It benefits an area of about 80 ha. Its bund has an average height of 2.7m and the waste weir is 4m long, over which water flows to a depth of 1.3m during flood.

The Nagri ahar in Patna district has a catchment of 2.6 km^2. It has a 15m long waste weir, 5 hume pipe outlets for irrigation, 3 sluice gates of size 0.9 x 0.6m and one sluice gate of 1.5 x 1.2m.

The Kasap ahar in Bhojpur district of Bihar also has a catchment of area 2.6 km^2. It irrigates an area of 400 ha. The submergence tanks of Rajasthan are bigger in comparison. The Ajan bund[19] near Bharatpur built in 1895 has a bund

19 km long and 4.8m high at the deepest part. It collects 70 million m^3 of water, fed by a channel from a nearby river. It submerges 4100 ha of land and irrigates 4800 ha more. It has numerous irrigation outlets, four main canals and several waste weirs.

The neighbouring Chiksana bund has a length of 510m and is fed by a 13 km long canal from the Ajan submergence tank overflow. The canal also gathers rain water running off the Bharatpur region. The Chiksana submergence tank irrigates 1000 ha.

CHAPTER 8 : ANICUTS AND KOLHAPUR TYPE BANDHARAS

8.1 Introduction

Diversion weirs have been constructed for centuries in many parts of the world across big rivers as well as small streams. The weir consists of a masonry dam of small height (usually upto 5m). Upstream of this weir canals are taken off from the banks of the river or stream to convey water to the points of use. The dam raises the water level upstream, so that the canal can be aligned in higher ground and water from it can flow on to the fields at lower levels by gravity. The design of the weir is simple if it could be founded on rock, but large Indian streams usually have beds of sand of great depth. The technology of building weirs on sand was unique to India several centuries ago[21]. These weirs are called 'anicuits' and consist of a masonry wall with long aprons of stone or reinforced concrete both upstream and downstream of it (Fig.8.1). The aprons serve to dissipate the energy of water flowing below the weir by lengthening its path, so that particles of sand or soil would not be washed away from under the weir. Undermining of the sandy (or other permeable) foundation of the weir is thus prevented. Foundations of wells filled with concrete are nowadays provided to the weir and aprons. The Grand Anicut at Srirangam in Tamil Nadu across the river Kaveri, built in stone and clay 1800 years ago, was the biggest weir at the time[22]. It is 330m long, 12 to 18m wide and 4.6 to 5.5m high, and is the oldest weir still working in India.

It has been stated[21] that the Delta barrage on the Nile (24km north of Cairo) built by Mohammed Ali in the 1830s failed because the technology of building such structures on sandy foundations was not known to his engineers. The design of weirs in modern times has been developed by Khosla[23], who evolved a theory to explain the failure of some weirs on permeable foundations.

Both anicuts and the canals built upstream of them face the problem of silting. Scouring sluices are provided in the weir at the stream bed level in the neighbourhood of canal intakes, so that water flowing through the sluices carries away the deposited silt. However, this is effective only in the neighbourhood of the sluices, and weirs, like tanks, gradually silt up. The "Kolhapur type Bandhara" has evolved in answer to this problem and is used in Maharashtra and some other parts of India as well.

Bandhara is the Marathi term for weir, and the Kolhapur type bandhara is a weir with vents throughout its length (Fig.8.2). The vents have removable shutters held in grooves in the piers. The vents are open during the floods, which therefore pass the weir with only the piers offering obstruction. The silt is carried away by the flow. When the floods subside, the vents are shuttered up and water collects behind the bandhara. This water is pumped to the neighbouring fields for supplemental irrigation. No canals are built to convey the water, since the quantity of water stored is relatively small. The Government of Maharashtra has now standardised the dimensions of the piers, vents etc. for these bandharas.

8.2 Components of a Kolhapur bandhara

The Kolhapur bandhara consists of a series of stone masonry piers (Fig.8.2) constructed across the bed of the stream. The piers carry a thin reinforced concrete slab running from one bank of the stream to the other. The piers contain grooves to hold shutters.

8.2.1 The piers: The piers are built of stone masonry. Each pier contains two vertical grooves on either side just behind its nose (Fig.8.3). The grooves have a cross section of 100 x 100mm and have a clear spacing of 300 mm. The pier rises to a height of 4.5m above the bed in the deepest part of the stream. The width of the pier is 1m, and the clear space between adjacent piers is 2m.

8.2.2 The slab: The slab on the piers, spanning the river, is of reinforced cement concrete. It is 1.5m wide and 150mm thick. It serves primarily as a platform from which closure of the vents can be carried out. During floods, the depth of water above the slab can go upto 4m or more.

8.2.3 The shutters: The shutters being used at present are of wood (Fig.8.4) in the form of planks about 300 mm wide and 2.2m long. When the depth of water in the stream has come down to about 400 mm (after the floods have subsided), the planks are lowered into the grooves one by one and at the sametime the gap between the front and back shutters packed with a mixture of straw and mud (Fig.8.5), till the vents are blocked throughout their height. Two or three vents at either bank are left open till all other vents are closed, so that the water level does not rise too high to render the closing operation difficult. Those end vents are blocked last. The whole exercise takes one to two weeks to complete. This form of shuttering is reasonably leakproof, though not completely. A problem with it, however, is that crabs nest in the straw-and-mud packing between the planks causing progressively larger leakages and therefore constant attention and periodic plugging is necessary. Besides, the wooden planks deteriorate and are to be replaced periodically. New types of shuttering are therefore being tried, using only one line of grooves. Shutters fabricated out of steel plates and angle irons, with a width of 640mm and rubber seals at the ends (Fig.8.6) or out of reinforced cement concrete, in the form of an arch with stiffeners (Fig.8.7), with the same width, are giving satisfactory results besides shortening the time needed for closing the vents.

8.3 Quantities of water used and costs

The Kolhapur type bandharas do not use all rain water that comes in the stream, but allows the floods to go through. This is because floods occur during the rainy season when no artificial irrigation is needed. After the rains have largely subsided, when the runoff from sporadic rainfall or the subsurface runoff from the earlier rains finds its way into the stream, storage in the bandhara begins. Pumping of the stored water takes place even as storage continues, and it is estimated that the amount of water ultimately applied on the fields by pumping is twice the storage capacity of the bandhara.

The average cost of construction of the Kolhapur type of bandhara amounts to Re 0,90/m^3 of water stored, or Re 0.45/m^3 of water used, since twice the storage is actually used.

8.4 Inundation canals

Inundation canals were used for long in the arid regions of Northwest India and Pakistan to gather water from the rivers and streams fed by rain and melting snow in their upper reaches. Practically the entire state of Sind in Pakistan was dependent on such canals for its water. The inundation canals is the simplest of all canals, and is just excavated from the bank of a river without any headworks across the river such as a dam or an anicut. Its bed is at a much higher level than the river bed, at about the normal low level of water in the river in the winter. During flood, water rises above the canal bed and the canal starts conveying water, when the flood subsides, the canal dries up. Irrigation in many parts of Sind is even now done with inundation canals drawing water from the Indus and its tributaries. They flow from April or May to September each year. The canals are from 3m to 100m wide, and from 1m to 3m deep.

The slope of the canals is less than that of the river, so that cultivable land between the canal and the river can be supplied by gravity. As a result, the velocity of water in the canal is less than in the river, and silt in the flood water gets deposited in the initial length of the canal. It is not uncommon that the bed level of the canal at the end of the rainy season is about 1.5m higher than at the beginning[25]. The canal regulator (a gate) necessary to control the flow in the canal is therefore provided about 5-6 km from the river[25], and silt removal is an annual necessity.

An interesting application of inundation canals was in vogue till about two centuries ago in Bengal and in the Thanjavur delta in Tamil Nadu[26]. The flood water with its silt was carried by the inundation canals to the fields in these regions, which had simultaneously a good rainfall too unlike the arid northwestern part of the country. The silt fertilised the fields, the fish eggs which came via these canals into local lakes and tanks hatched there, the young fish fed on the larvae of mosquitoes and thus the incidence of malaria was reduced. The water itself in the inundation canal was superfluous, and the canal almost flowed full till its tail end where it received surplus water flowing off the fields. However, during the Afghan-Maratha war in the 18th century and the subsequent British conquest of India, these irrigation systems were destroyed, never to be revived afterwards.

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8.5 Other sources of water

Big reservoirs formed by dams of earth, masonry or concrete built using modern construction methods are to be found all over India, and account for the major part of power generation and irrigation. These technologies are not discussed here as they are very well documented in text books.

Ground water is another large source being exploted. The open dug well, used for drinking water as well as irrigation water is a common sight in any village. More recently, tube-wells are being drilled, virtually at the rate of one per village in many states, to provide perennial drinking water. Hand operated reciprocating pumps are installed in these wells, but problems have arisen due to the frequent breakdown of these pumps. Efforts by many organisations are under way to improve the reliability of these pumps. Tubewells with power driven pumps are also being used for irrigation in northern India increasingly, though they have not been used on any significant scale in the south, which is a hard rock area. An irrigation tubewell lasts 20 years on an average, after which it has to be deepened. The average area irrigated per tubewell is 80 ha, if it belongs to the 'deep' category. There are also 'shallow' tubewells, which irrigate 3 to 4 ha. The cost of a tubewell irrigation system varies from Rs.25000 to Rs.150 000 depending on its depth and the area to be irrigated.

In the Himalayas, from Kashmir at one end to West Bengal at the other, canals aligned roughly along contours are dug to draw water from hill streams or springs. These canals are known as 'Kuhls'. The length of the kuhls varies from 1km to 15km[27]. They have a trapezoidal cross section 0.1 to 0.2 m^2 in area and carry a discharge of 15 to 100 litres/sec. Many kuhls collect rain water and snow melt running off the slopes above them, and occasionally one finds that the discharge increases along the length of a kuhl as a result. The discharge also varies with the season. A single kuhl irrigates an area of 80 to 400 ha through distributaries or by flooding. The irrigated land, being situated in hill slopes, is terraced. The system is prevalent at altitudes from 350 to 3000m, i.e., in the Outer and Middle Himalayas (Ch.1). Where there is a significant drop in elevation in the path of a kuhl, the fall is utilised to drive machinery like flour mills. The cost of construction of a kuhl varies from Rs.3000 to Rs.5000 per km. Fig.3.8 shows the typical Himalayan terrain, photographed by the LANDSAT, where the Kuhl system of irrigation is practiced. During the monsoon, many landslides occur in this region, and a number of kuhls get damaged. Annual repairs must therefore be effected, at a cost which averages Rs.60 per hectare of area irrigated.

CHAPTER 9 : OCCUPATION OF PEOPLE, STANDARD OF LIVING AND SOCIAL SYSTEMS

9.1 Introduction

In the Indian subcontinent, it is estimated that about 80% of the people live in rural areas, depending almost wholly on agriculture. With a population density of 178 (based on a 1971 survey) per km^2, there is pressure on agricultural land to such an extent that both sociologists and the government classify the rural population into landowners and landless labourers. Most of the cultivation is done using human and animal power. The average area of land owned by a family varies from place to place in the range of 1 to 2 ha. The family members usually all work in the field, and during crucial periods of activity like transplanting seedlings or harvesting the crop, hire the landless labourers. Thus, while the land-owning class is assured of work throughout the year, the landless labourers have to look for work in the urban areas for a part of the year.

The use of electricity in Indian villages is limited. About 10% of the rural houses use electric power, and that too only for lighting. Heating energy (mainly for cooking) is mainly provided by firewood, gathered over 2 to 3 man-hours every day. Some kerosene is also used for cooking.

9.2 Standard of living

With this background information as far as India is concerned, the standard of living is best indicated in terms

TABLE 9.1 STANDARD OF LIVING INDICATORS (YEAR 1970)

Country	Infant mortality per 1000 live births	Life Expectation at birth	Inhabitants per physician	Inhabitants per Hospital Bed	Calories, Apparent consumption per capita per day	Protein, Apparent consumption per capita per day	Literate as % of total population 15 and over	Vocational Education Enrolment as % of population 15-19	Pupil/Teacher Ratio in primary education	Average Number of Persons per Room
Iran	x	48.6	3262	756	2080	52.6	27.2	1.0	33	x
Iraq	104.0	51.5	3266	517	2250	62.4	28.8	1.0	22	x
Israel	22.9	71.3	406	174	2970	91.5	84.2*	20.2	17	1.8*
Jordan	x	x	3600*	570*	2310	60.0	x	x	34*	x
Lebanon	67.3	64.1	1197	212	2380	69.5	x	10.4	23*	x
Saudi Arabia	x	x	10058	1141	2080	56.2	x	0.3*	24	x
Syria	x	52.8	3849	1005	2530	70.2	60.0	1.6	37	2.3*
Yemen(AR)	x	x	x	3300*	x	x	x	x	50	x
Yemen(PDR)	x	x	x	x	x	x	x	x	31	x
Afghanistan	x	x	40000*	8100*	x	x	3.0*	x	41	x
India	140.2	48.3	4820	2022	2060	52.6	33.3	4.4	46*	2.8
Pakistan	128.4	x	9350*	3910*	2090*	47.7*	x	0.1*	39*	3.1*
Sri Lanka	53.0	66.8	6477	331	2240	49.6	81.1	x	x	2.5
World minimum	11.0	38.1	406	67	1700	32.7	12.1	0.1	17	0.6
World maximum	200.0	74.9	92827	5538	3420	108.7	99.0	55.5	75	3.1

*1960 data

x Data not available

TABLE 9.1 (Contd.)

Country	% of Dwellings with Piped Water	% of Dwellings with Electricity	Telephones per 100000 population	Radio and Television Receivers per 1000 population	Railway Passenger kilometres per capita	Passenger cars per 1000 population	Productivity of Male Agricultural Worker in US $ at 1970 Prices	% of Adult Male Labour Engaged in Agriculture	Per Capita Consumption of Electricity in KWH	Per Capita Consumption of Steel in kg
Iran	X	X	1082	244	63.5	9.8	630	X	248	44
Iraq	X	X	1271	217	39.1	7.1	X	X	291	48
Israel	96.5	96.5	17613	310	121.0	51.1	5700	9.1	2312	221
Jordan	36.2*	17.0*	1341	180	X	6.7	X	35.5*	71	23
Lebanon	X	X	8435	377	3.1	59.7	1580	18.1	540	121
Saudi Arabia	X	X	1000	13	4.4	8.4	X	X	137	30
Syria	41.9*	38.0*	1776	237	13.8	4.8	570	46.0	152	43
Yemen(AR)	X	X	69	X	X	X	X	X	3	X
Yemen(PDR)	X	X	625	426	X	7.1	X	X	133	X
Afghanistan	X	X	X	X	X	X	X	X	9*	X
India	X	X	217	22	219.1	1.1	250	69.8	110	12
Pakistan	X	X	161	14	89.1	1.6	210*	73.5*	61	5
Sri Lanka	14.0	9.0	479	X	238.5	7.0	600	40.5	65	8
World Minimum	0.3	6.1	53	3	3.1	0.9	150	3.3	3	1
World Maximum	100.0	100.0	58677	1828	2761.7	433.6	11490	96.0	14643	734

*1960 data

X Data not available

Table 9.1 (Contd.)

Country	Per Capita Consumption of Energy in kg of Coal Equivalent	GDP from Industry as % of Total GDP	% of Economically Active Population in Manufacturing Industries	GNP Per Capita in US $ at 1970 Prices	10-Year Average Annual Investment per Economically Active Person in US $
Iran	904	38	X	385	160
Iraq	617	42	X	335	X
Israel	2483	27	23.3	1800	930
Jordan	295	12	X	270	X
Lebanon	881	16	17.6	675	460
Saudi Arabia	826	66	X	395	X
Syria	457	20	12.1	270	125
Yemen(AR)	13	X	X	X	X
Yemen(PDR)	589	X	X	X	X
Afghanistan	14*	X	X	X	X
India	182	16	9.5	100	40
Pakistan	84	19	8.1*	145	X
Sri Lanka	149	11	7.9	170	65
World Minimum	8	4	1.1	55	10
World Maximum	11123	66	45.5	5095	1760

*1960 data

X Data not available

Source: Ref.27

of selected statistical parameters. Table 9.1 gives 25 parameters for India and the middle eastern countries for the year 1970, as compiled by the United Nations(27). The world minimum and maximum values of these parameters have also been given for a relative appreciation. Most of the countries listed have large rural populations (80% in India). Since 1970, changes are likely to have occurred, especially in the petroleum exporting countries, but the table will still serve as an indicator of the relative standards of living.

9.3 Social Systems relevant for the Technologies

The water harvesting technologies discussed so far are very widely applied in the respective regions of India for which they are suited. The density of tanks (table 5.1) in Peninsular India illustrates this. Proper maintenance and operation of the systems will therefore be ensured only if the beneficiaries themselves organise it. Unfortunately, however, local training in technical skills has not kept pace with the application of the technologies, with the result that the maintenance and operation has to be shouldered by the centralised agencies of the government.

A case where the lack of local effort in maintenance has been acutely felt is that of tanks, which face the problem of silting (§5.6.1). Fig.5.12 shows the cumulative frequency distribution of the loss of storage capacity of tanks due to silting, as prepared using data obtained during a study sponsored by the Planning Commission of India.(9)

It is based on a survey of 121 tanks in Tamil Nadu, and shows that 10% of the tanks were silted up more than half, and 50% of the tanks had lost about a fourth of their storage capacity. If Fig.5.12 is a typical representation of the situation at any given time, it is reasonable to assume that it also represents an equilibrium situation, old tanks at the left end nearing 100% silting getting out, new tanks coming in at the right end and the rest of the tanks gradually moving left. Since tank sites have almost all been used up in the peninsula , very little addition is taking place to the tank population. A time will therefore come when the right end of the graph starts disappearing and the number of tanks in use decreases progressively.

Reference has already been made to the fact that silt was being removed from the tank beds earlier by the beneficiaries (§ 5.7). This used to be done under a feudal system known as 'Zamindari', where large areas of land were owned by a 'Zamindar' (landlord), but cultivated by local villagers (tenants) on the basis of sharing the crop. When the tank bed dried in summer, the tenants were all required to remove the silt and spread it on the fields as part of their duties. This was more or less slave labour, and the system of Zamindari was abolished soon after India gained independence. No alternative system, however, was introduced for desilting the tanks(9). With the advent of chemical fertilisers and the increasing cost of transporting the silt, the latter soon lost its attraction as manure. Loss of storage capacity due to silt accumulation has therefore now become a serious problem.

Another instance where social cooperation is essential is the operation of feeder channels from tanks (§ 5.2.3). It has been stated that divide walls are constructed in streams to divert flood water into the feeder channels. These walls are to be built before the stream starts rising. The beneficiary cultivators have worked out a system in which one of them stands watch at the site and gives a call as soon as the proper moment comes. The farmers then assemble and quickly put up the wall. Those who absent themselves would be fined.

CHAPTER 10 : THE MIDDLE EAST

10.1 Physiography of the Middle East

For the purpose of this Report, the term 'Middle East' covers the territories of Pakistan, Afghanistan, Iran, Iraq, Syria, Lebanon, Israel, Jordan and the Arabian Peninsula. Table 10.1 gives the geographical area and population of these countries, together with those of India and Sri Lanka.

The middle eastern countries lie in one of the great desert belts of the world stretching from the Sahara in Africa to the Great Indian Desert in the East. Vast areas of land are occupied by the Rub al Khali and the Nafud deserts of Saudi Arabia and the Syrian and Jordanian deserts. A 'fertile crescent' exists alongside the desert in the regions watered by the Tigris, Euphrates and the Jordan Rivers (Fig.10.1a, b and c).

The landscape in Pakistan presents sharp contrasts, from the perpetually snow-clad great Himalayan and Karakoram mountains in the north to the hot and dry Sind desert in the South. The Hindu Kush mountain range in the north runs along the border with Afghanistan for some distance before turning west, stretching upto Kabul (Fig.10.1b). These mountains cut Afghanistan off from the monsoon. Further to the west, the Zagros and Elburz mountain ranges in northern Iran play an important part in determining the climate and formation of soil in Iran. Eastern Iran is again a desert region.

Table 10.1 : Area, Population and surface flow of water - India, Sri Lanka and Middle East

(Source: Partly, ref.32)

Country	Area, 000 km^2	Arable land 000 km^2	Population, millions (1971)	Density of Population, per km^2	Estimated total surface flow per year, million m^3	Surface flow per capita per year, m^3
India	3276	1946	548	167	1 810 000	3303
Sri Lanka	65.6	16	13	198	432 000	33231
Pakistan	803.9	303.5	64.9	80.7	175 000	2696
Afghanistan	650	90	15.9	24.5	50 000	3145
Iran	1648	315	28.39	17.2	96 000	3381
Kuwait	15	x	0.73	48.7	- Not available -	
Iraq	438.4	120	9.47	21.6	77 000	8131
Syria	185.2	88.3	6.79	36.7	29 500	4345
Lebanon	10.4	5.3	2.7	260	3 500	1296
Israel	20.7	x	3.2	155	590	184
Jordan	94.6	11.3	2.42	25.6	2 100	868
Saudi Arabia	2201	3.73	6	2.73	- Not available -	
United Arab Emirates	82.9	x	0.193	2.33		
Yemen (AR)	194	x	5.73	29.5		
Yemen (PDR)	464	x	1.5	3.23		

The northern area of Iraq has its mountain ranges which continue into its neighbour Iran to the east. Its southern and western regions lie in a desert, which continues across the border in the west into Jordan and southern Israel (the Negev). The mountain ranges of Iraq continue into western Syria on the north upto Turkey.

A narrow coastal plain, with the Red Sea or the Mediterranean Sea to the left and mountains to the right, is characteristic of Yemen, Saudi Arabia, Israel and Syria. The width of this plain ranges from 5 to 75 km. A feature of the topography of Israel and Jordan is the Rift Valley, consisting of a rift in the earth's crust which extends from northern Syria across the Red Sea to further south. The river Jordan flows in this valley, emptying itself into the Dead Sea whose bottom is 792 m below mean sea level. The water level at the Dead Sea itself is 392 m below mean sea level, bordering the lowest places on earth. The rift continues southwards and forms the bed of the Gulf of Eilat in the Red Sea. The Jordan valley is the most fertile part of Jordan, and is about 100 km long and 5 to 15 km wide. To the south lies the Arabian Peninsula with the highest mountain peaks near the southwestern coast and sloping towards the north and east. The El Jebel mountains in Yemen (AR) rise 3600 m to the highest point in the Peninsula. East of the mountains are hilly regions which gradually merge into the plantless Rub al Khali ('Empty Quarter') desert. No water is to be seen in this region for a stretch of about 700 km. Northwest of the Rub al Khali is the Nafud, a land of sand dunes. Most of the rivers in Saudi Arabia, as in other desert regions of the Middle East, run for short distances and disappear in the sand.

10.2 Climate and Rainfall

At the right end of the Middle East, Pakistan is an arid to semi-arid region. The mean annual rainfall in Pakistan ranges from 889 mm in the northern submontane region to about 125 mm in Sind to the south. Rain falls in summer (June to September) as well as in winter (December to March). The summers are very hot, with average maximum temperatures of 40°C over a large part of the Indus Plain of the country. One of the world's highest temperatures was recorded at Jacobabad in Sind (53°C). The ocean has a moderating influence on the climate in the coastal region. The mountainous western region has a cooler climate, and as one passes into Afghanistan, the extremes of temperature typical of a continental climate are observed. The mountain ranges of the Hindu Kush limit the influence of the monsoon to a line from Kandahar to Kabul. Rainfall in Afghanistan usually occurs from January to May. Considerable snowfall occurs in the Hindu Kush region in the winter. The mean annual rainfall is 254 mm in the Helmand Valley, 508 mm near Kabul and falls to 125 mm in the lower reaches of the desert area. Afghanistan's neighbour Iran also has a hot dry summer (mean maximum temperatures from 34°C to 50°C)and a cold winter (subzero temperatures) over most of the country except near the persian gulf. The major part of Iran is semiarid, but north of Elburz mountains, the rainfall averages between 1000 & 2000 mm. Rainfall occurs in the winter months. Further to Iran's west, Iraq is a little warmer and rainfall occurs between November and April. It varies from about 150 mm in southern Iraq to 406 mm in the north. There is virtually no runoff from the area. In the mountains, however, rainfall varies from 400 to 1829 mm, a large part of it occurring in the form of snow. In Syria, the winter is again rainy, but a mediterranean climate prevails. Rainfall in the coast and mountains exceeds 1000 mm and is very small in the desert. In the interior. fluctuations in temperature over a day may sometimes exceed 25°C. The maximum in summer is 48°C and the mean in winter 0°C. The Jordan Valley, situated in close proximity to the sea as well as the desert, enjoys Mediterranean climate in the western highlands and desert climate in the east. The mean maximum temperature is 45°C and the minimum 5°C. Rainfalls from December to March, and averages annually about 550 mm in the highlands to virtually nil in the desert. Israel, likewise situated near the sea as well as the desert, enjoys a heavy night dewfall, especially in the coastal areas where an annual maximum of 60 mm has been recorded. The average annual rainfall in Israel varies from about 700 mm near Haifa to 50 mm at the southern tip near Eilat. In the Negev, where an intricate rain water harvesting system was practised during the times of the Roman Empire, mean annual rainfall varies from 400 mm in the north to 50 mm in the south. In the Arabian Peninsula, the highlands of Yemen in the southwest interrupt the monsoon currents, resulting in a mean annual rainfall of 500 mm in the mountain regions. The coastal plains receive 100 to 130 mm of rain. Rainfalls throughout the year, most of it between March and November. Towards the Rub al Khali, rainfall is negligible. The peninsula has extremes of temperature, the mean maximum going upto 48°C, the minimum 0°C. The average rainfall is 125 mm. There are no perennial rivers in the region.

The estimated mean annual total surface flow of water in various countries is given in Table 10.1, as also the per capita availability of water per year.

10.3 Water Harvesting Technologies of the Middle East

Since a large part of the Middle East receives very little rainfall, efforts to utilise all water available have been made for centuries. The technologies evolved as a result are represented by the run-off farming in the Negev desert and Yemen, collection of the flood waters in the wadis (dried up river beds) either for groundwater recharging or for spreading on the fields in Israel, the tanks and diversion weirs in different countries, the subsurface dams in Algeria, the inundation canals in Egypt, in addition to the Iranian technique of harvesting ground water by means of qanats. Devices like tanks, diversion weirs and inundation canals have been described in the chapters on India and only a brief mention will be made of them in this chapter.

10.3.1 <u>Runoff farming</u>: Run-off farming had flourished in the Negev desert in the days of the Roman empire(30), when the Roman trade route to the East passed through it. Conditions in the Negev favourable to run-off farming are: a reasonable rainfall (mean annual value about 200 mm in the part of the Negev considered), a moisture-retentive soil (known as loess, a loamy soil) and availability of a catchment large compared to the cultivated area. Evenari and others(30) have reconstructed some of these ancient farms and proved the possibility of successful cultivation. Water for the farms was collected by long canals cut on hillslopes, in addition to the run-off from the catchment of the farm itself. These canals, which functioned more or less like the feeder channels (§ 5.2.3) and pynes (§ 7.2.2) of India, had an average cross sectional area of 0.1 m^2. The biggest canal had a cross section of 0.4 m^2. The catchment area of a canal was on an average 0.1 to 0.3 ha. The bigger canals drained an area of 1 to 1.5 ha above them. The biggest farm had an area of 5 ha, and the farm received rain water from a catchment 17 to 30 times its own area. In the case of a very large catchment, a diversion weir was built across the stream which drained it, and the water diverted to the farm by a canal. It is estimated that about 2% of the rainfall over a large catchment was utilised, whereas the figure was 10% for small catchments. The Bedouins in the Negev still use these water harvesting techniques. Fig.10.2 shows a typical run-off farming system. The Negev is probably the only area where the catchment was prepared in olden days in order to increase the run-off. In some regions, particularly where the slope was steep, the ground was stony. The stones broke the velocity of runoff, aiding percolation of water into the ground. There are many places where the stones were gathered into small heaps (Fig.10.3), so that the water could flow faster and a larger quantity could reach the farm before percolating.

10.3.2 Drinking water in the Negev: The drinking water supply to houses and public places in the Negev during the time when towns flourished there was also met by rain water harvesting. The houses got their water by collecting rain water running off the rooftops and streets. This water was first collected in a settling tank where the silt got deposited. The clear water was allowed into underground cisterns built in the house. These cisterns were normally bottle-shaped (Fig.10.4). The capacity of each cistern was in the range of 5 to 10 m^3 (against the average annual water requirement of 1.5 m^3 per man, 1 m^3 per camel etc). The cisterns were lined with stone to protect the walls. Public places like churches and forts had open cisterns of larger capacity, and they were supplied by canals 1 to 4 km in length, often cut in hill slopes. These cisterns had stone walls about 1m high at their periphery to keep strangers and animals out. Settling tanks were also provided to remove the silt. At some places, depressions in the ground with capacities of 50 to 100 m^3 were also used to store rain water. Rain water collection from rooftops is even today widely practised in Israel (as also in parts of

Rajasthan in India), which has one of the least per capita surface water flows (cf Table 10.1).

10.3.3 <u>Terracing of fields</u>: A technique for conserving rain water used all over the world is terracing of slopes. The slopes are levelled over short widths at different elevations, a low mud or stone wall separating the terraces (Fig.10.5). Such terracing is found on hillslopes everywhere (§ 8.5) as well as in smaller wadis in the Negev[30]. The spacing between the walls (i.e, the width of the terraces) is 12 to 15 m in the Negev farms, the walls 60 to 80 cm high, and the difference of level between terraces 50 to 60 cm. Water flows from one terrace to another negoitating the drop in between gently. On large slopes, the drop will be higher, and a drop structure has to be provided to dissipate the energy of falling water and avoid erosion of the field. In the Negev, this structure takes the form of a series of short stone steps. The technique of terracing wadi beds in order to cultivate them is also practised in South Yemen, where besides the rain water, dew and mist during the nights also provide substantial amounts of moisture[31]. The nearness of South Yemen to the sea as well as to the desert (Rub al Khali) promotes substantial dew formation, as in Israel.. The hill slopes of North Yemen (in the region around whose capital San'a, the famed Mocca coffee is grown) are also cultivated by terracing. Water for these fields is harvested from the runoff on neighbouring uncultivated land. This is said to be so thoroughly done that no rain falling on the hill slopes escapes out of the cultivated land, and no soil is eroded[32].

10.3.4 Percolation reservoirs of Israel: It is interesting to note that the technique of using percolation tanks and rapats (Chapter 6) was accidentally rediscovered in Israel when an attempt was made in 1958 to create a storage reservoir by building a dam across the Shiqma wadi near the Gaza strip border[33] in the southern coastal plain at Karmiya. The area is characterised by coarse, pervious sand dunes. The reservoir failed to function satisfactorily as the storage it was intended to be, since the water percolated rapidly into the ground. It was, however, noticed that wells downstream of the dam showed a rise in the water level. It is estimated that this dam replenishes the ground water to the extent of 3.5 million m^3 per year. Two more experimental percolation reservoirs at En Kerem and Bet Netofa have been subsequently built.

10.3.5 Artificial storage in Israel: Small artificial temporary lakes are created outside river beds at many places in Israel by pumping, later to be spread on the fields[32]. Thus, 12 million m^3 of water flowing in the Menashe during the rains is pumped each year to a lake outside. 6 million m^3 of water are similarly pumped from the Rubin per year.

The reservoirs, however, are in general smaller, with a capacity of 300 000 to 600 000 m^3. Experiments in catchment preparation such as treatment with sodium chloride and phosphates and compacting of soil are being conducted in order to increase the runoff. Rainfall in the region varies from 200 mm to 700 mm. The total quantity of water harvested in this fashion amounts to about 60 million m^3, and is stated to be never sufficient(34). The water thus harvested is used in conjunction with sewage effluent from rural community treatment plants for irrigating summer crops and for industrial cooling. The cost involved amounts to US $ 0.20 - 0.30 per m^3 of water stored in the root zone of crops.

10.3.6 Village tanks in Iran: Small village tanks, formed by building an embankment or by digging, are used widely in the Middle East, to collect rain water. The typical storage capacity of such tanks in Iran(35) is 5000 to 10 000 m^3 per village. These tanks work in a manner similar to the Indian irrigation tanks and face the same problems.

10.4 Other sources of water

10.4.1 Qanats: 'Qanat' is a semetic word, used in Iran to denote a device to tap ground water and bring it to the surface without the use of pumps. It is called Karez in Afghanistan and Baluchistan and Foggara in the Arab countries.

A Qanat consists of a series of vertical shafts in sloping ground, inter-connected at the bottom by a tunnel whose gradient is flatter than that of the ground (Fig.10.6). The first shaft is usually sunk in a hill slope to a level below the water table, and is called the mother well. The direction of the groundwater flow is determined by evidence provided by the presence of springs, vegetation and swamps in low ground. Shafts are sunk at intervals of 20 to 30 m in a line along the direction so determined. The shafts are rectangular in plan, the typical size being 0.7 x 1 m. Fig.10.7 shows a photograph of a shaft of the Chintala Karez near Kabul. The shaft is lined with stone for a depth of about 1 m from the ground level to prevent the edges falling in.

Fig.10.6 also shows the technique of construction of qanats. A man excavates the shaft, and another man lifts the excavated soil to the ground with the help of a windlass. The soil is dumped around the opening of the shaft to form a small mound, so that runoff from the surrounding land does not enter the shaft bringing silt with it. After the shafts are sunk, they are interconnected by a tunnel whose height is of the order of 1 to 1.5 m and width 0.4 to 0.8 m, just enough for a man to work. The excavated soil is again transported through the nearest shaft. The man working the tunnel carries a lamp with him. If the soil is firm, no lining is provided to the tunnel. In loose soil reinforcing rings must be installed at intervals in the tunnel to prevent its collapse. These rings are usually made of burnt clay. The slope of the tunnel is adjusted to keep the depth of flowing water constant[36]. When the qanat is in operation, the shafts serve to provide aeration to the flowing water as well as for maintenance work.

Qanats are found not only in Iran and Afghanistan, but in China, Pakistan, the Syrian desert, the Arab Peninsula, Palestine, North Africa (Sahara), Spain, Chile, Peru and Mexico[30]. Megasthenes, the Greek travelled to India, has recorded in the year 300 BC the existence of qanats in Baluchistan, now a province of Pakistan. In the Middle East, qanat building is a skill in which some families specialise and which provides them their livelihood. Qanats are built, as a rule, in winter when the demand for oxygen by the men working in the tunnel is smaller than in summer[37] (the oil lamp also needs oxygen, though nowadays battery operated lamps might be used in many places). Building a qanat is also somewhat dangerous, since there is always the risk of a cave-in, and asphyxiation can result in the narrow tunnel. In the light of these considerations, most qanats are built by young people[28].

Fig.10.8 shows the outlet of a qanat near Kabul. The water flows in a channel to irrigate lower land. When the water is meant for consumption in a village, an enclosure is erected to cover a ground level cistern into which the qanat discharges, so that pollution is avoided. Water is taken in pots from the cistern. It is said that the city of Tehran got its water till 1933 from qanats excavated from the Elburz mountains. A qanat may take 2 to 3 years to build, and costs about US $ 2250 per km length. The maximum discharge from a qanat is of the order of 30 litres/sec.

10.4.2 Snow for drinking water: In a few villages around Sheritala in the Takhar Province of Afghanistan, snow falling in the winter is stored underground, to be used as drinking water in the dry summer(37). The snow is collected in bags, laden on donkeys and dumped in a pit in the village. The pit is 6 to 8 m in diameter and about 10 m deep. It is not lined, since the loess soil in the area is firm. The snow is compacted and the pit filled to within 2 to 3 m from the ground (Fig.10.9). The remaining space is filled with earth, which acts as an insulator. A ramp or a series of steps is constructed from the ground level to the bottom of the pit. A small bamboo tube is driven through the wall of the pit into the snow some 50 cm above its bottom. The snow melts slowly around the tube, and water trickles down to a pot placed underneath. It is said that the storage in one such pit supplies the village (10 families) its drinking water for two years. In this technique, losses due to evaporation and percolation occurring in the case of water storage are avoided. However, if snowfall is bad for two consecutive years, the entire village has to shift to the neighbourhood of a stream, 40 km away, in search of water.

CHAPTER 11 : RECOMMENDATIONS

The technologies discussed in the previous chapters have all evolved over centuries, which is an indication that they are capable of replication in the respective conditions of terrain, climate and rainfall, soil types and agricultural practices. They also have the considerable advantage that the constructions involved can be completed quickly, local materials and labour can be used; and finally, they can be applied in areas where large projects are uneconomic to undertake.

It is a fact, however, that large numbers of structures erected to collect the water are in a poor state of repair. The main reason for this is that there are thousands of them, and maintenance is done by centralised government departments which are unable to cope with the volume of work. Training of local people in maintenance is therefore necessary to ensure greater success of these technologies.

Catchment preparation to induce a larger runoff is not practised in India, except on a minor scale in parts of Rajasthan, partly because the annual rainfall is good. In an area like Israel, where the per capita surface flow is less than 6% of that of India, catchment preparation is imperative.

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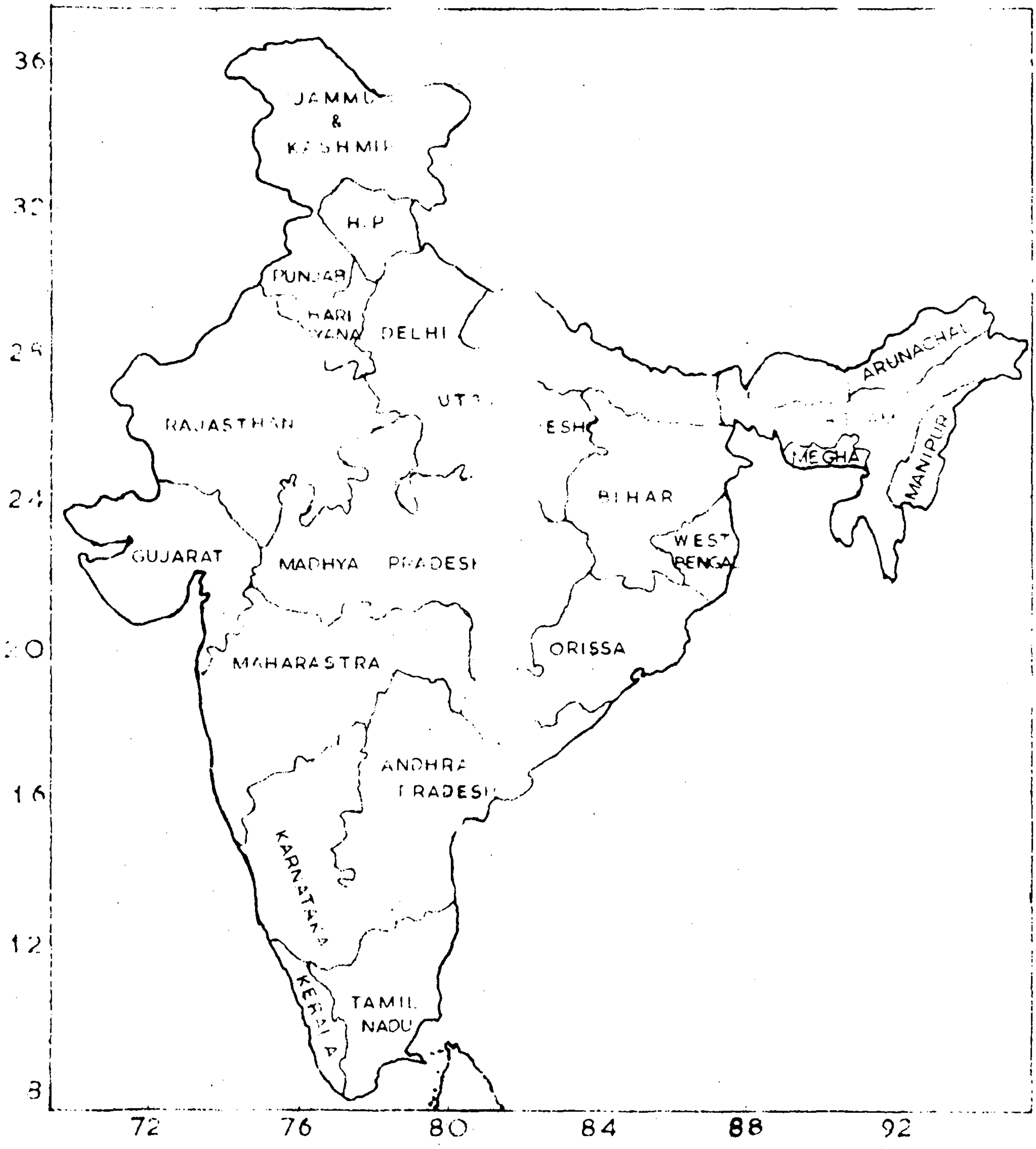


FIG. 1.1 - POLITICAL MAP OF INDIA

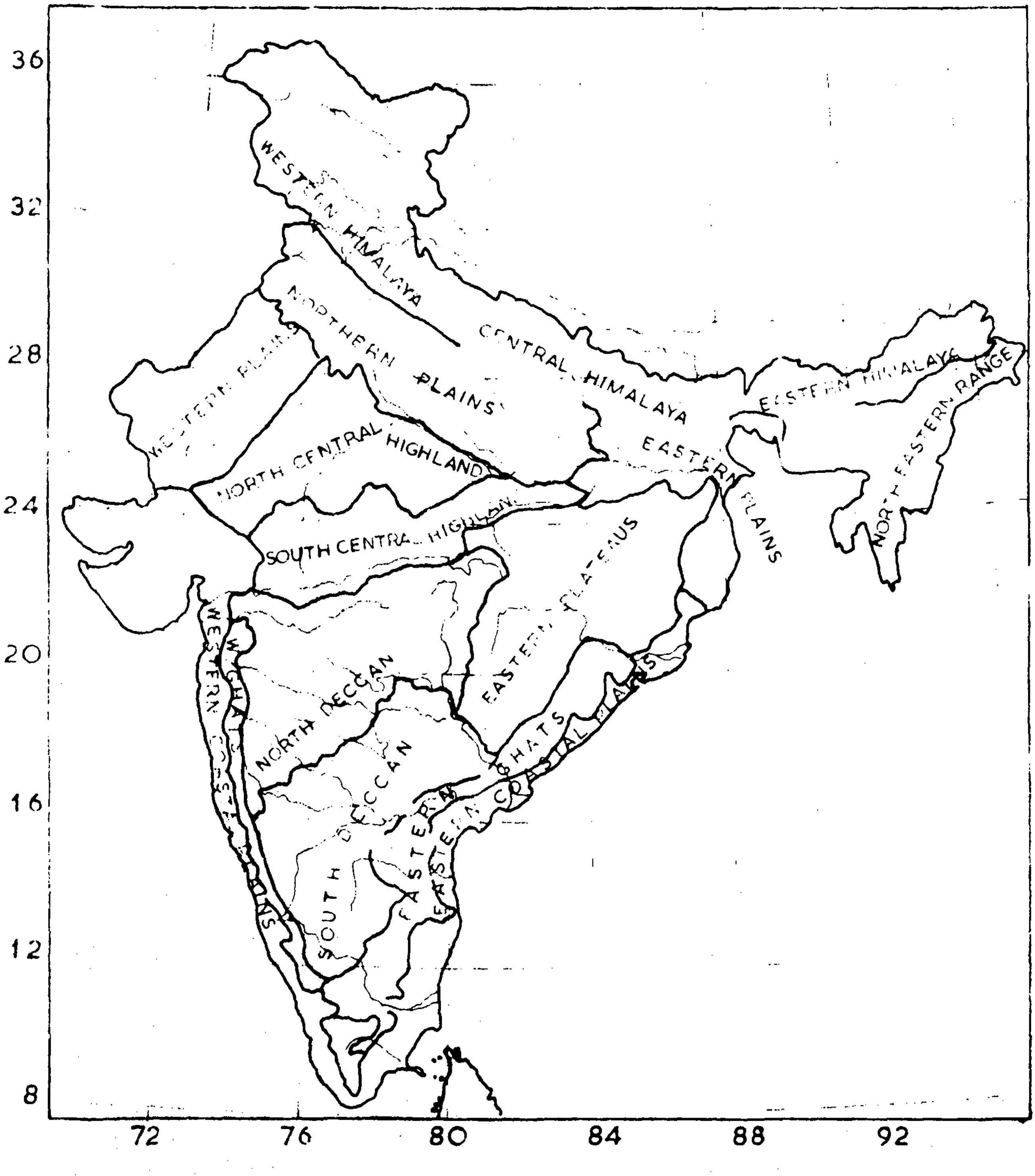


FIG. 1·2 - PHYSIOGRAPHIC DIVISIONS OF INDIA

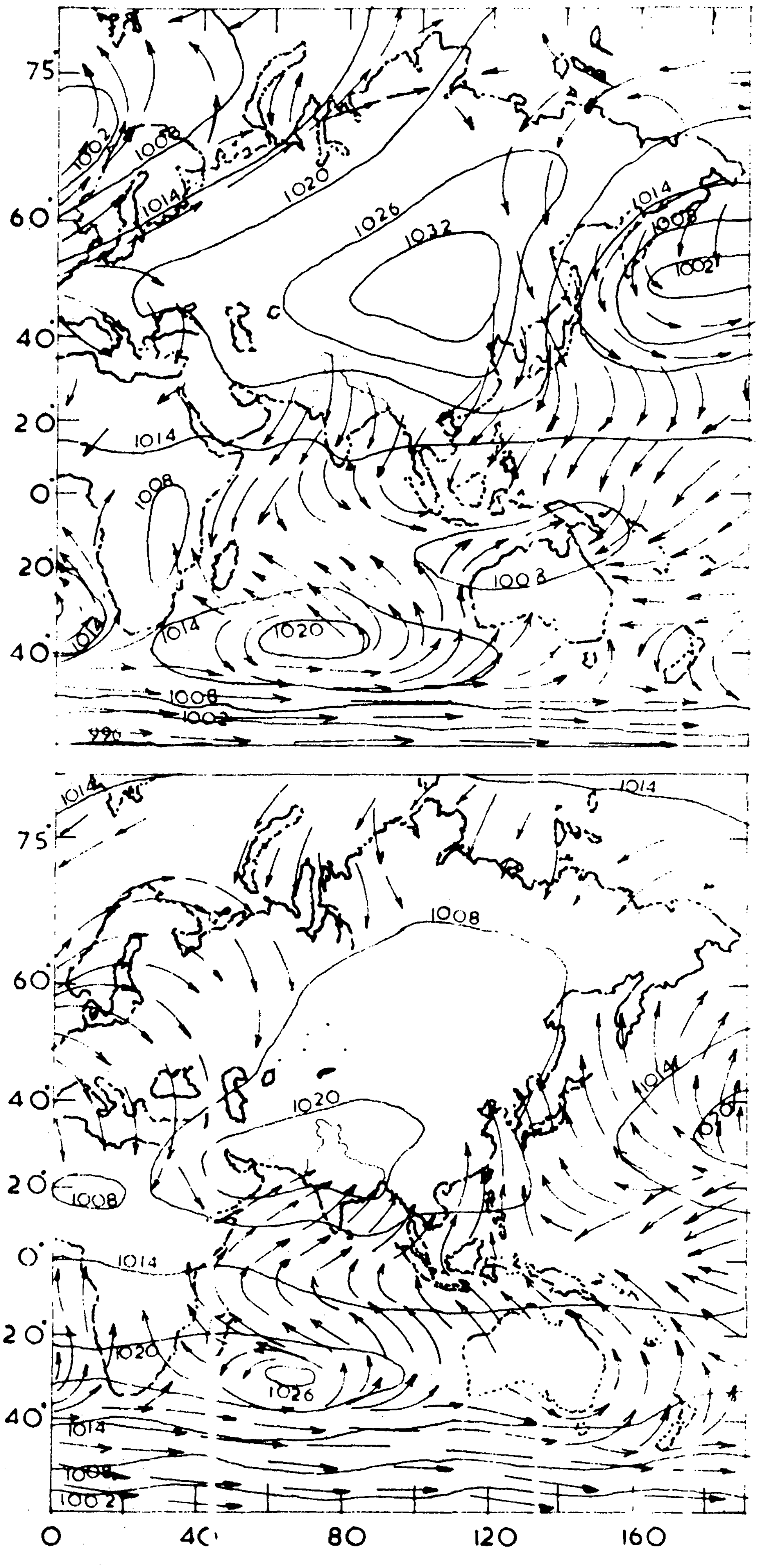


FIG. 1.3 WORLD SOBARS IN JANUARY & JULY

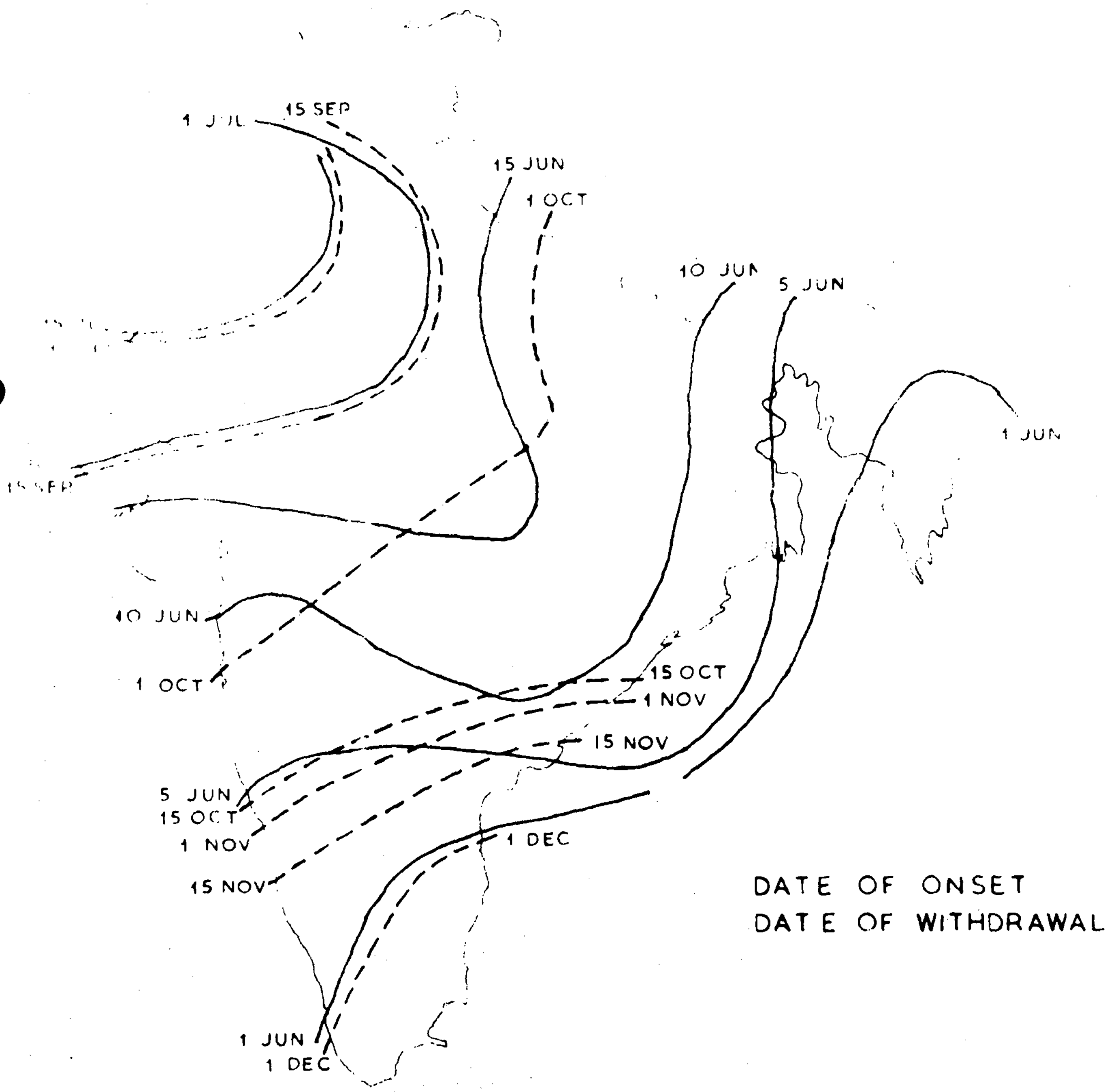


FIG 1.4 MONSOON DURATION IN INDIA

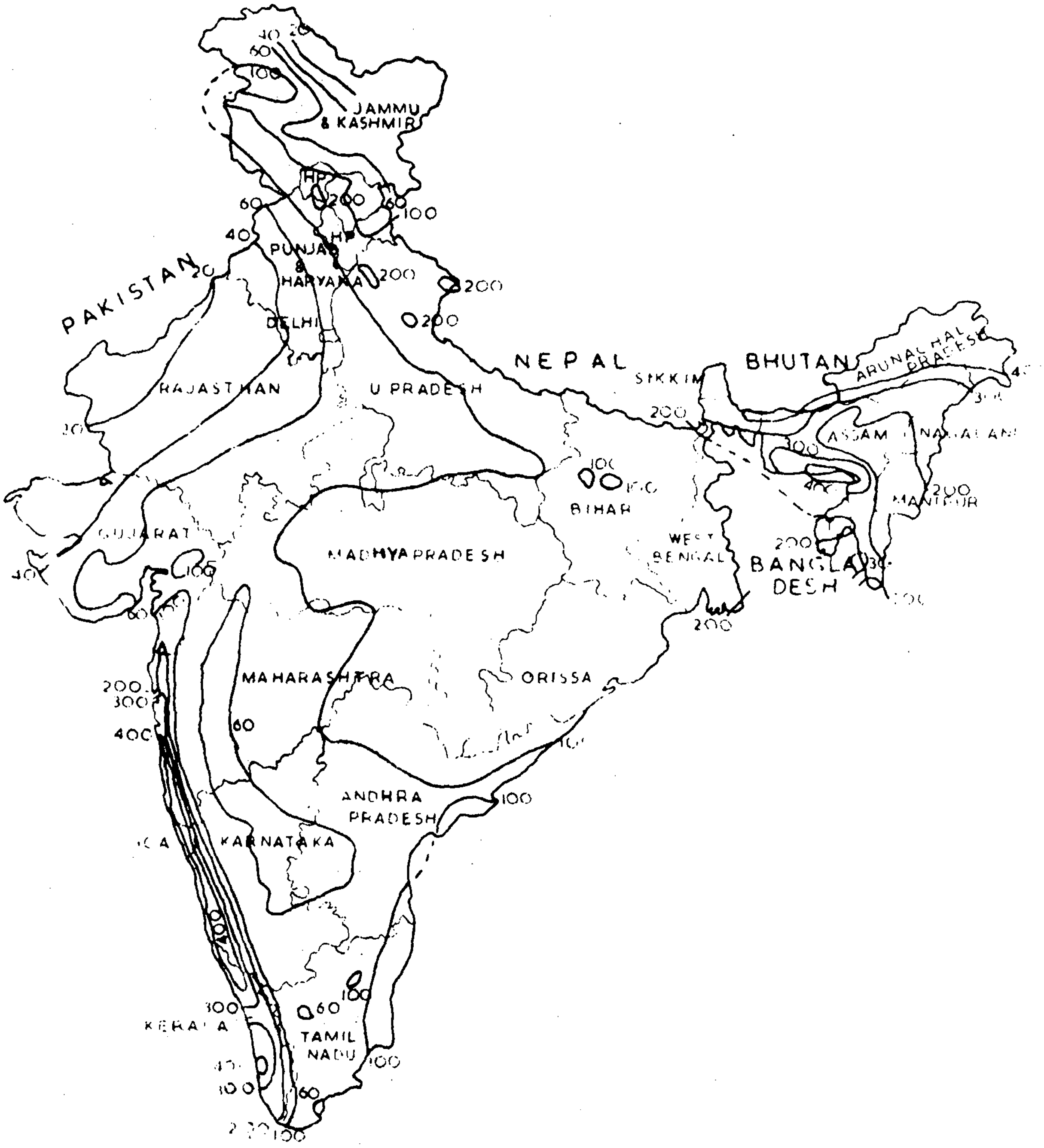


FIG 1.5 ANNUAL AVERAGE RAINFALL IN INDIA, IN CM

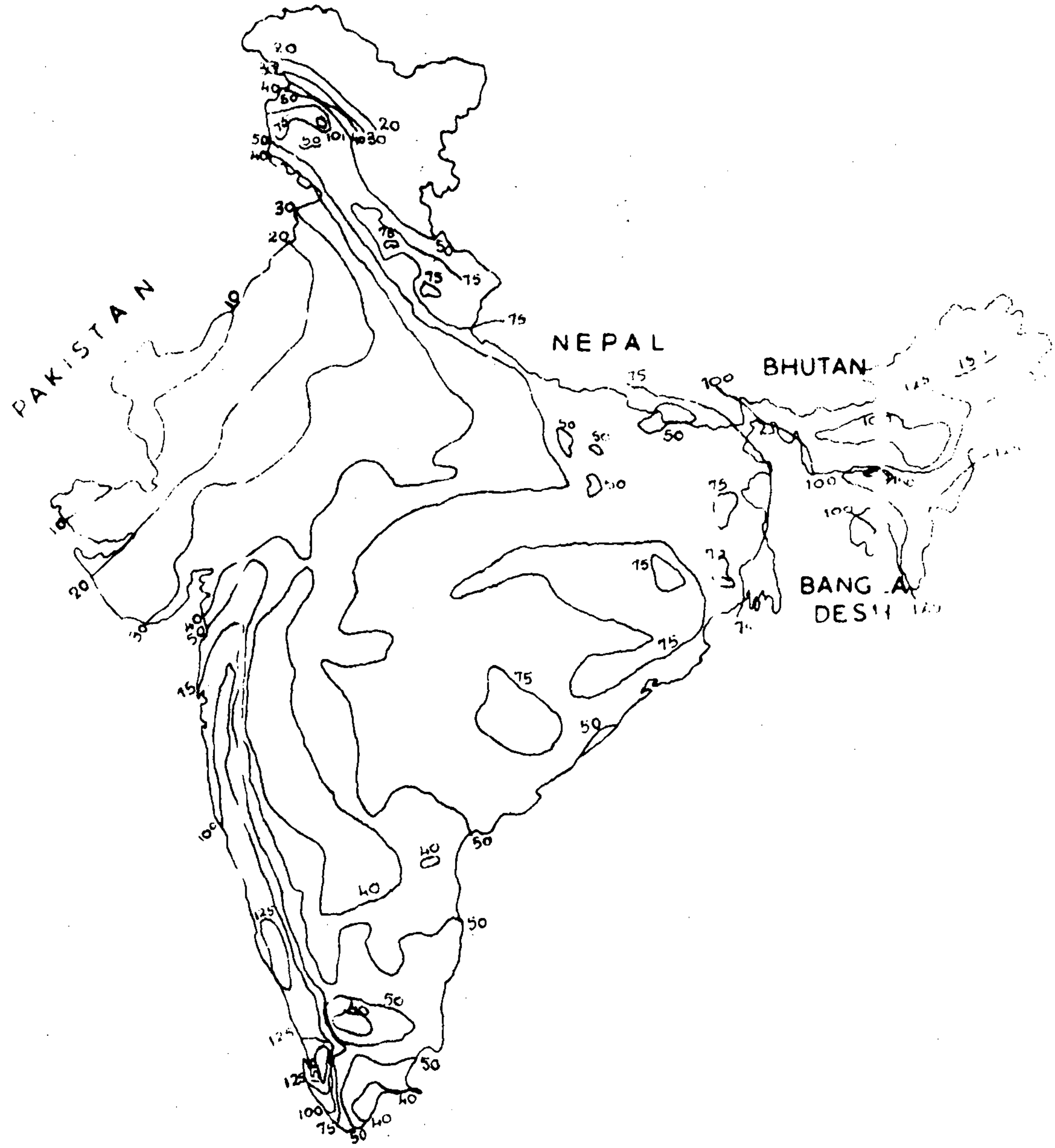


FIG. 1.6. NUMBER OF RAINY DAYS IN INDIA

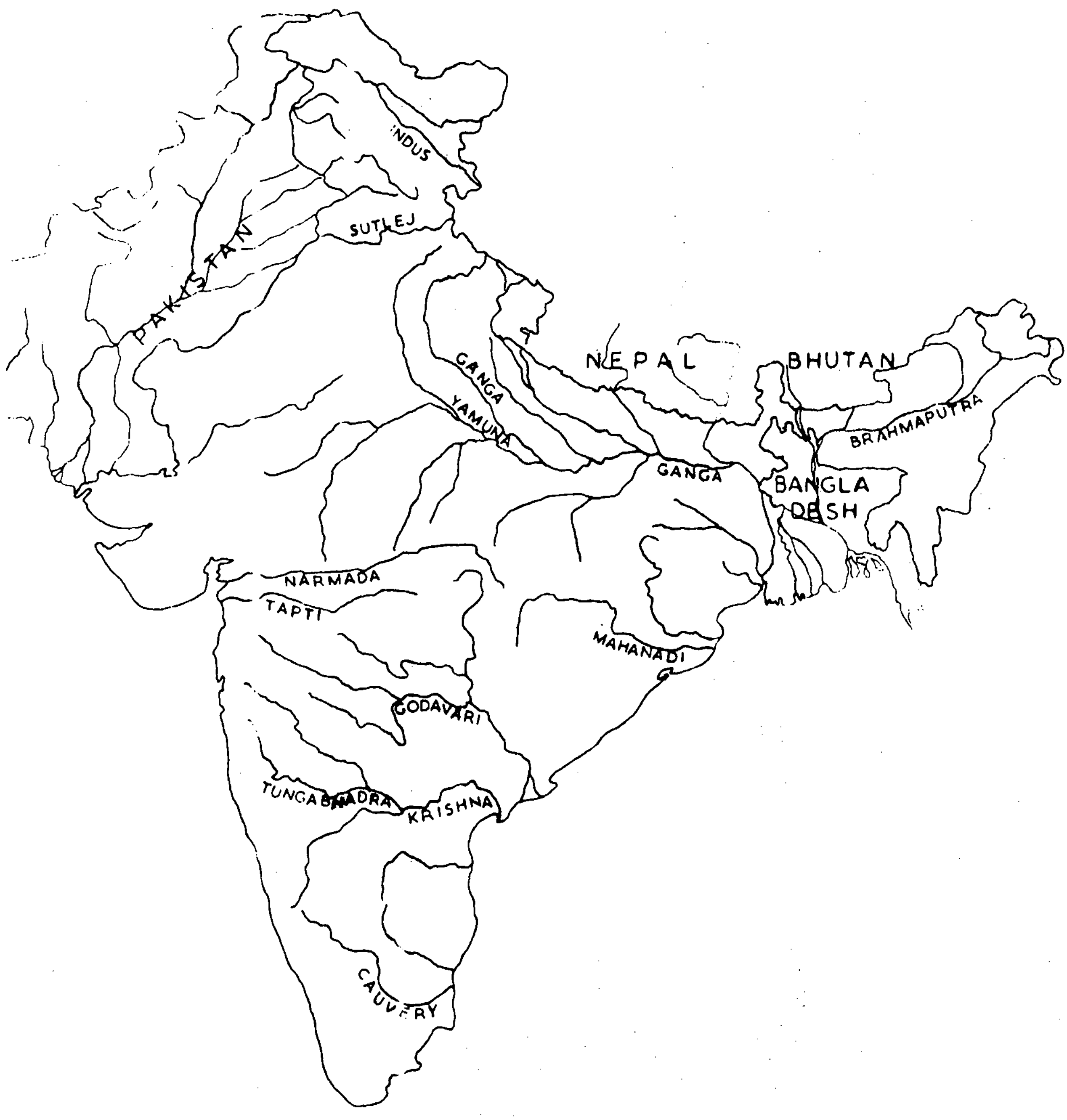


FIG. 3.1. RIVERS OF THE INDIAN SUBCONTINENT

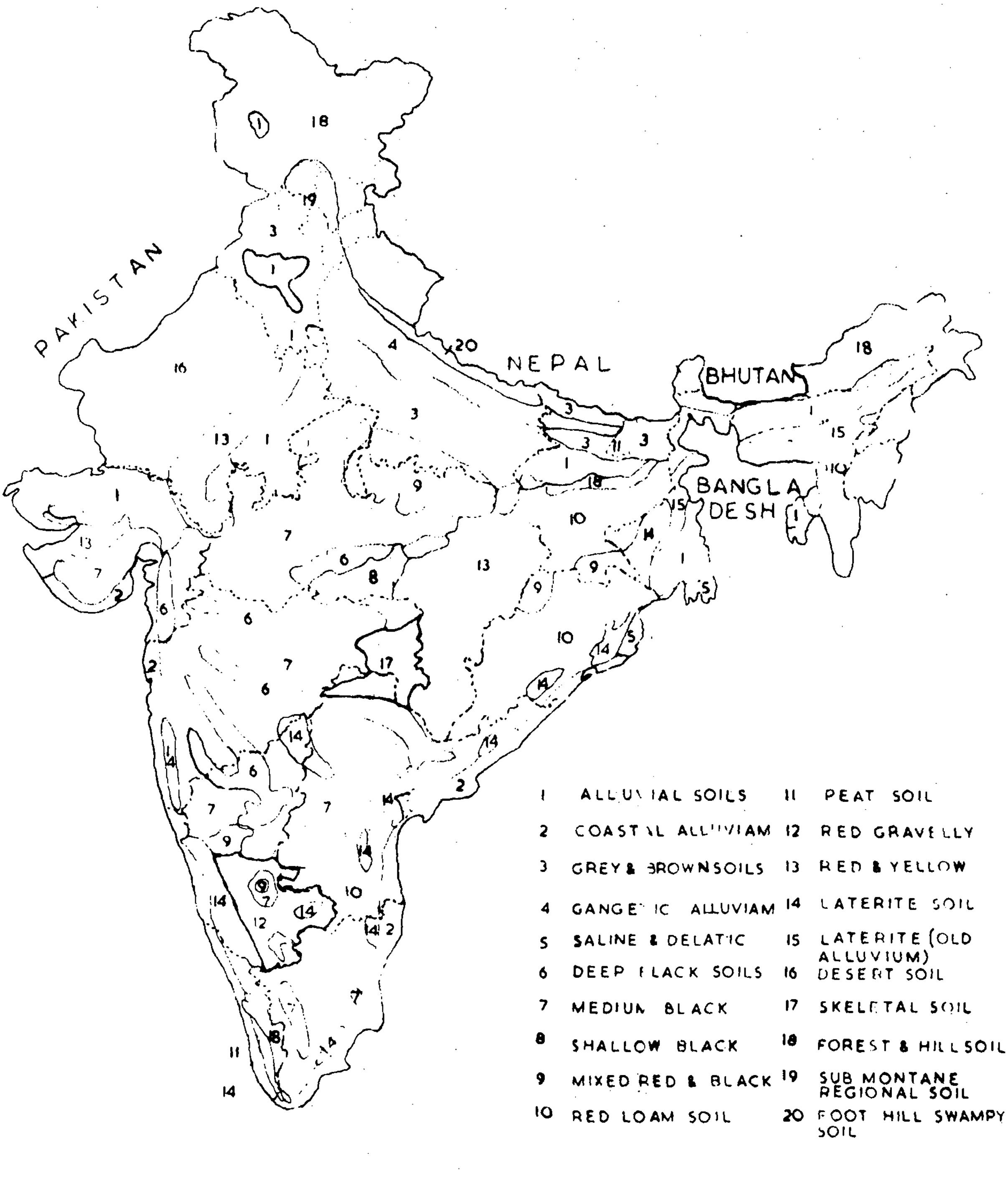


FIG 4.1 SOIL MAP OF INDIA

FIG. 5.1 Tonnur tank bund--Upstream slope

FIG. 5.3(contd) Tank outlet

FIG. 5.4a Stream intake to feeder channel

FIG. 5.4b Feeder channel control

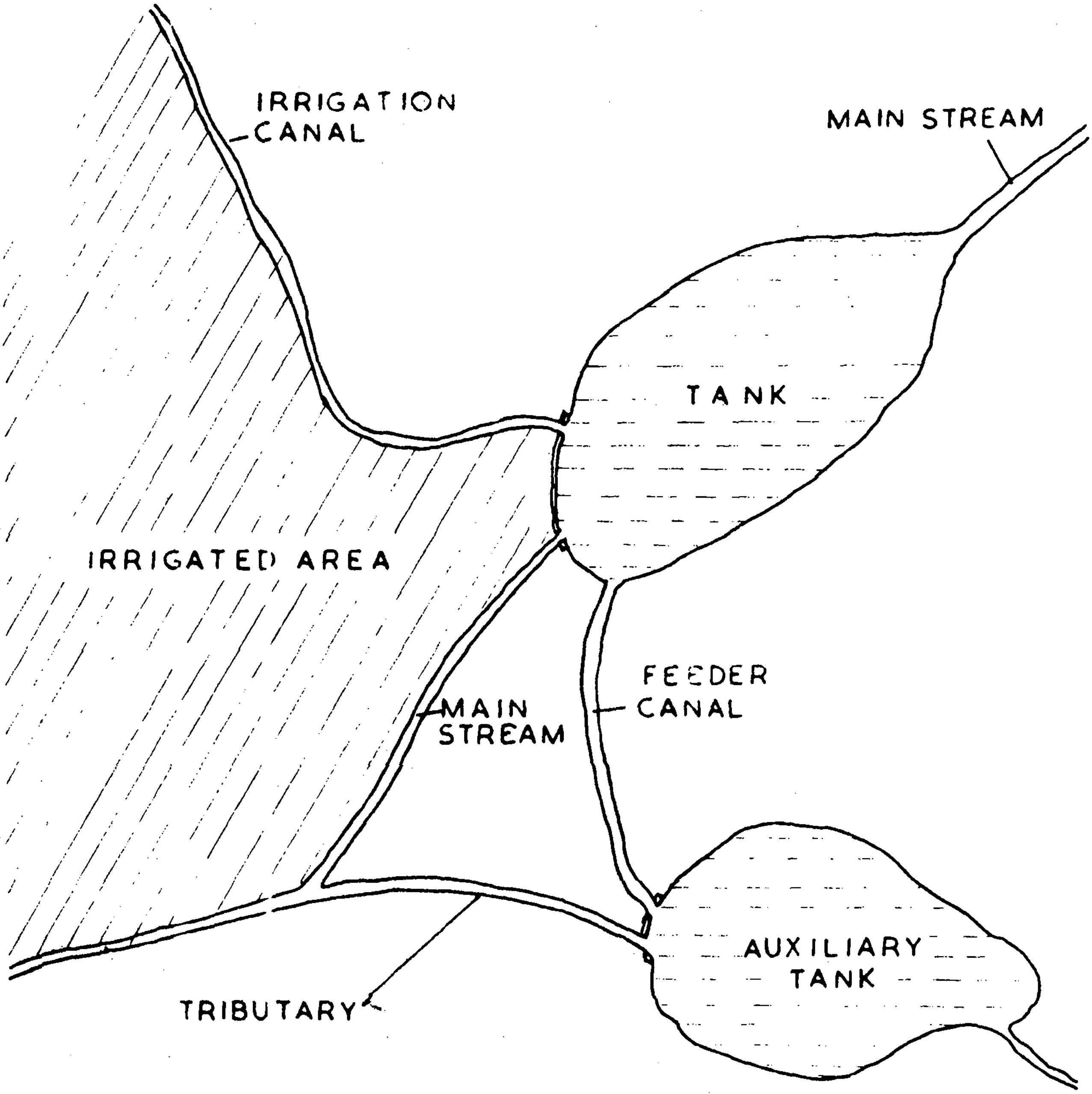


FIG 5.5. FEEDER CHANNELS FOR TANKS

FIG. 5.6 Waste weir in rock

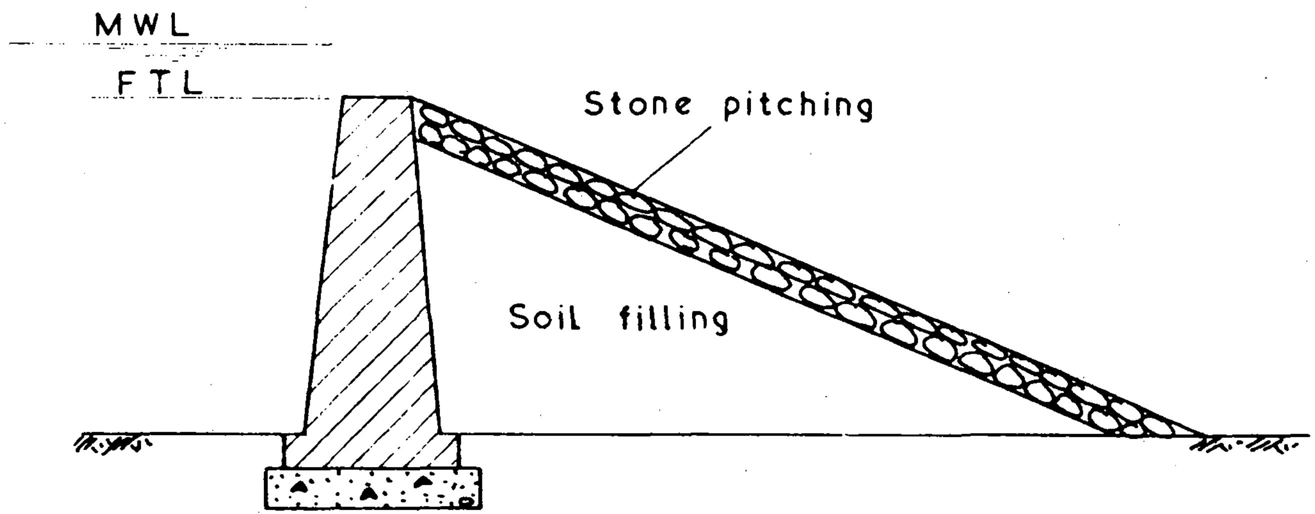


FIG. 5·7 - SECTION OF A WASTE WEIR

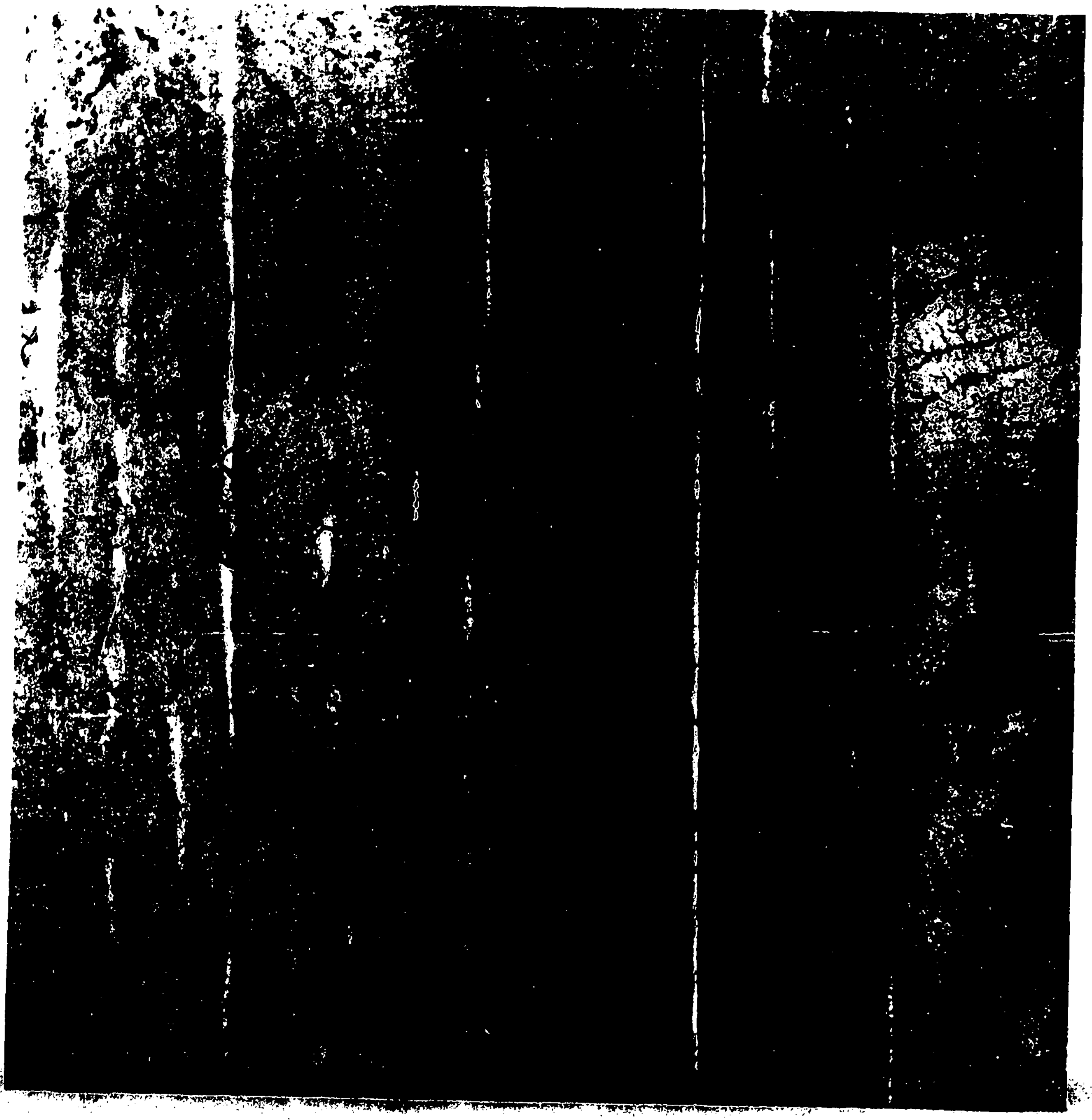


FIG. 5.8 Tank terrain

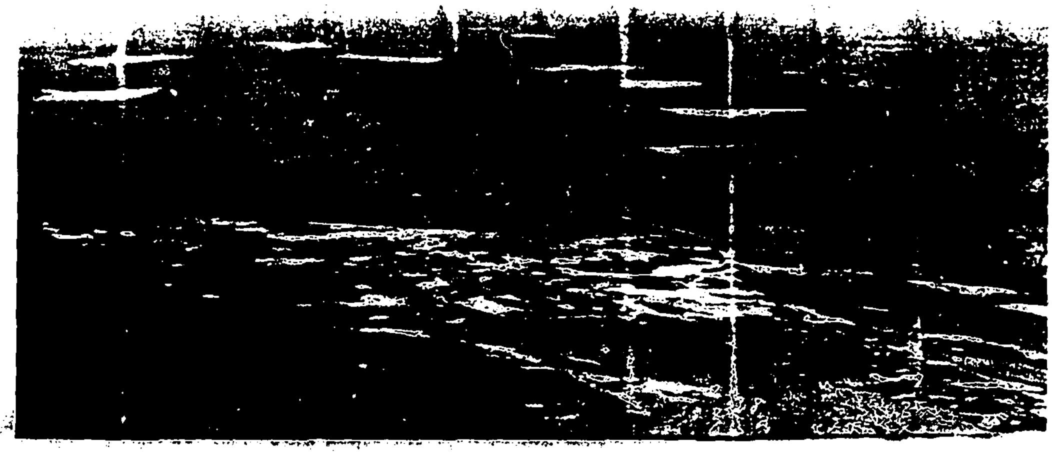


FIG. 5.9 Tanks near Bangalore

FIG. 5.10 Dug tank for fish cultivation in Bihar

FIG. 5.11 Downstream view of the Tennur tank

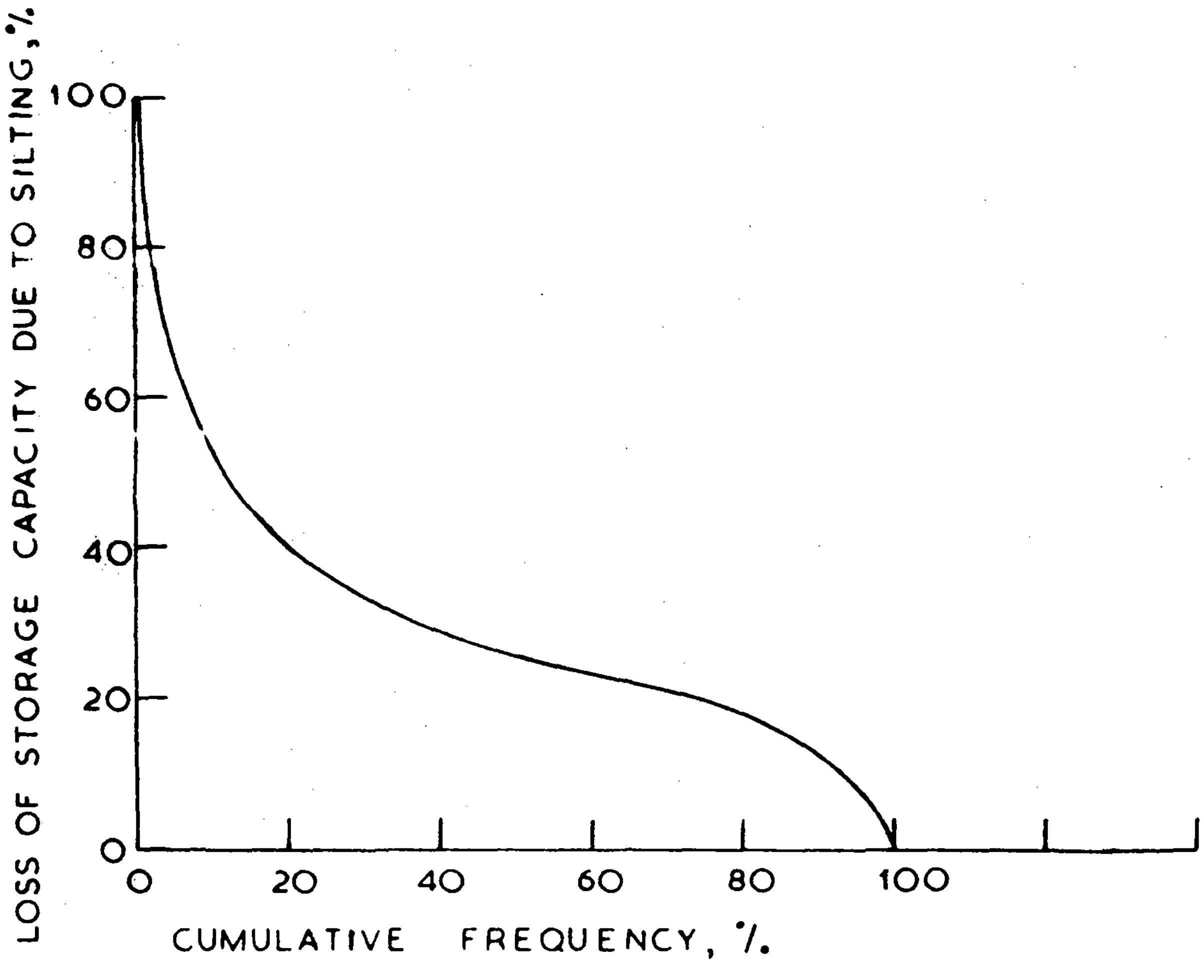


FIG.5.12. CUMULATIVE FREQUENCY DISTRIBUTION OF SILTING OF TANKS IN TAMILNADU

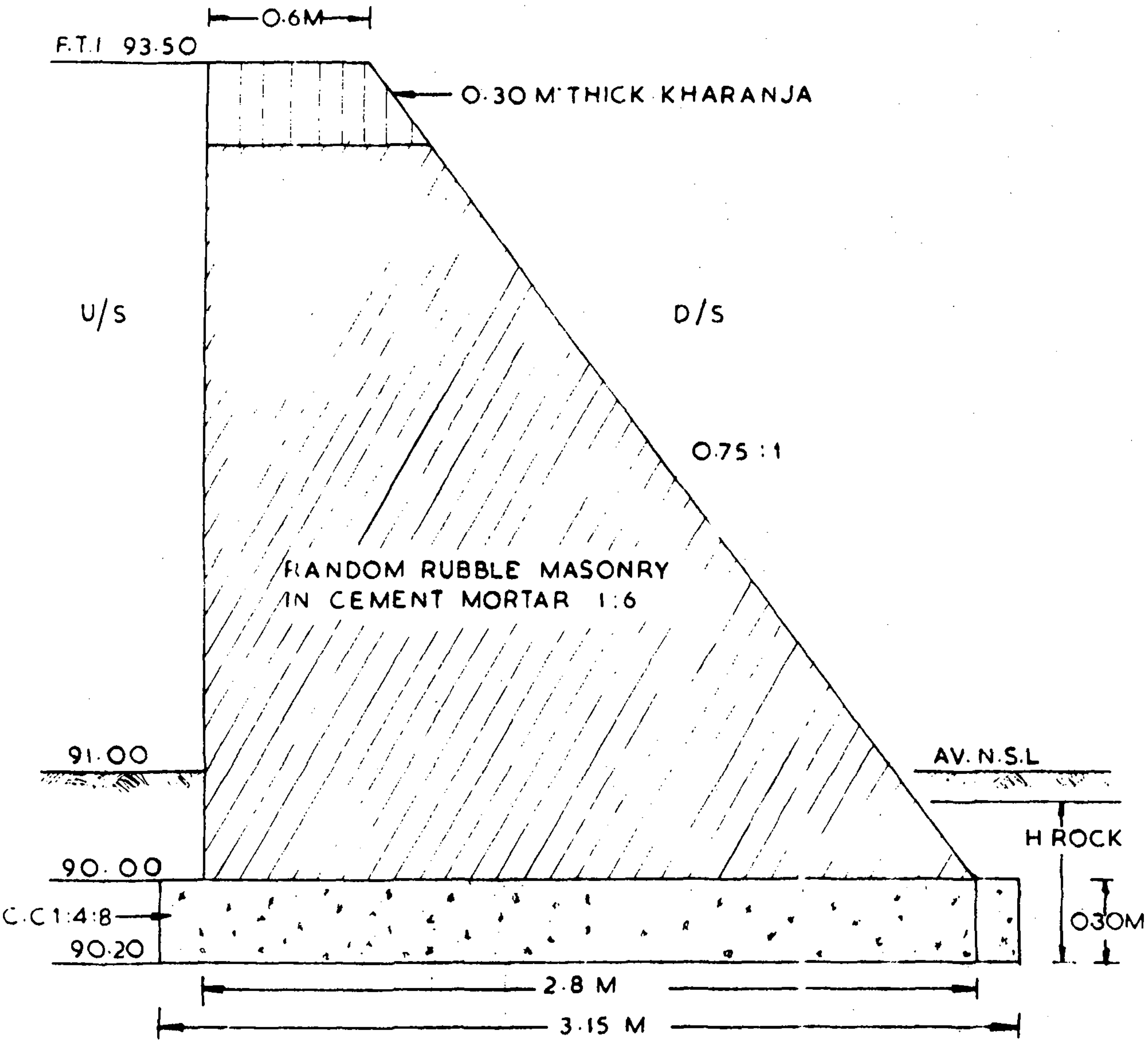


FIG. 6.1 SECTION OF A RAPAT

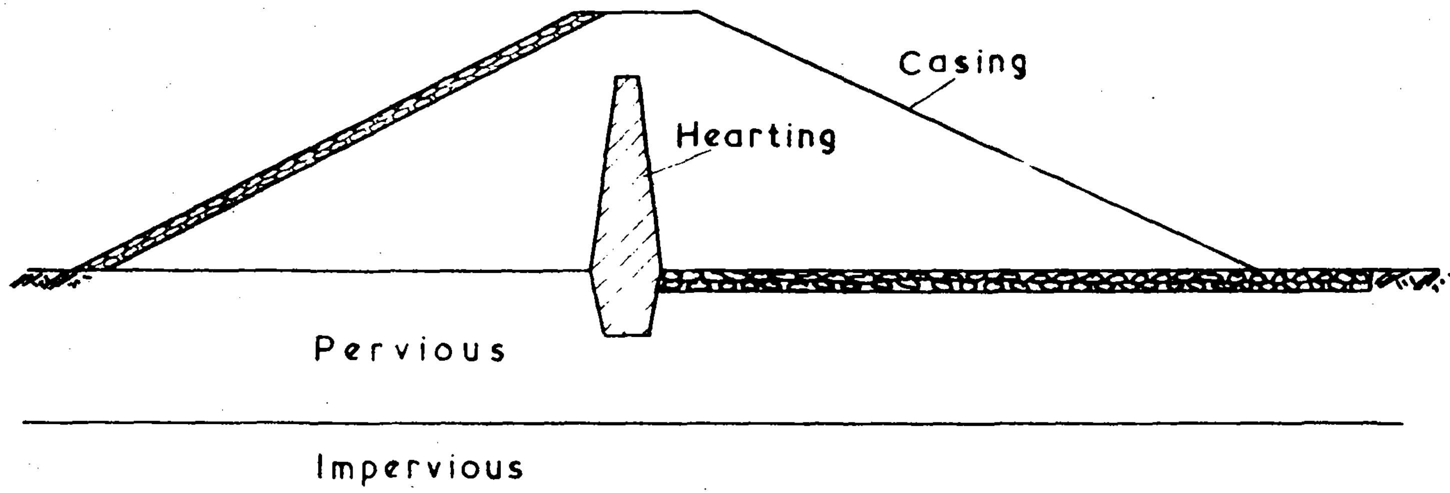


FIG. 6·2 – CROSS SECTION OF A PERCOLATION TANK BUND

FIG. 6.3 Rapat terrain

FIG. 6.4 Percolation tank terrain

FIG. 6.5 Percolation tank near Pume

FIG. 7.2 Pawar ahar near Patna

FIG. 7.3 Gate of an ahar

FIG. 7.4 Irrigation outlet from an ahar

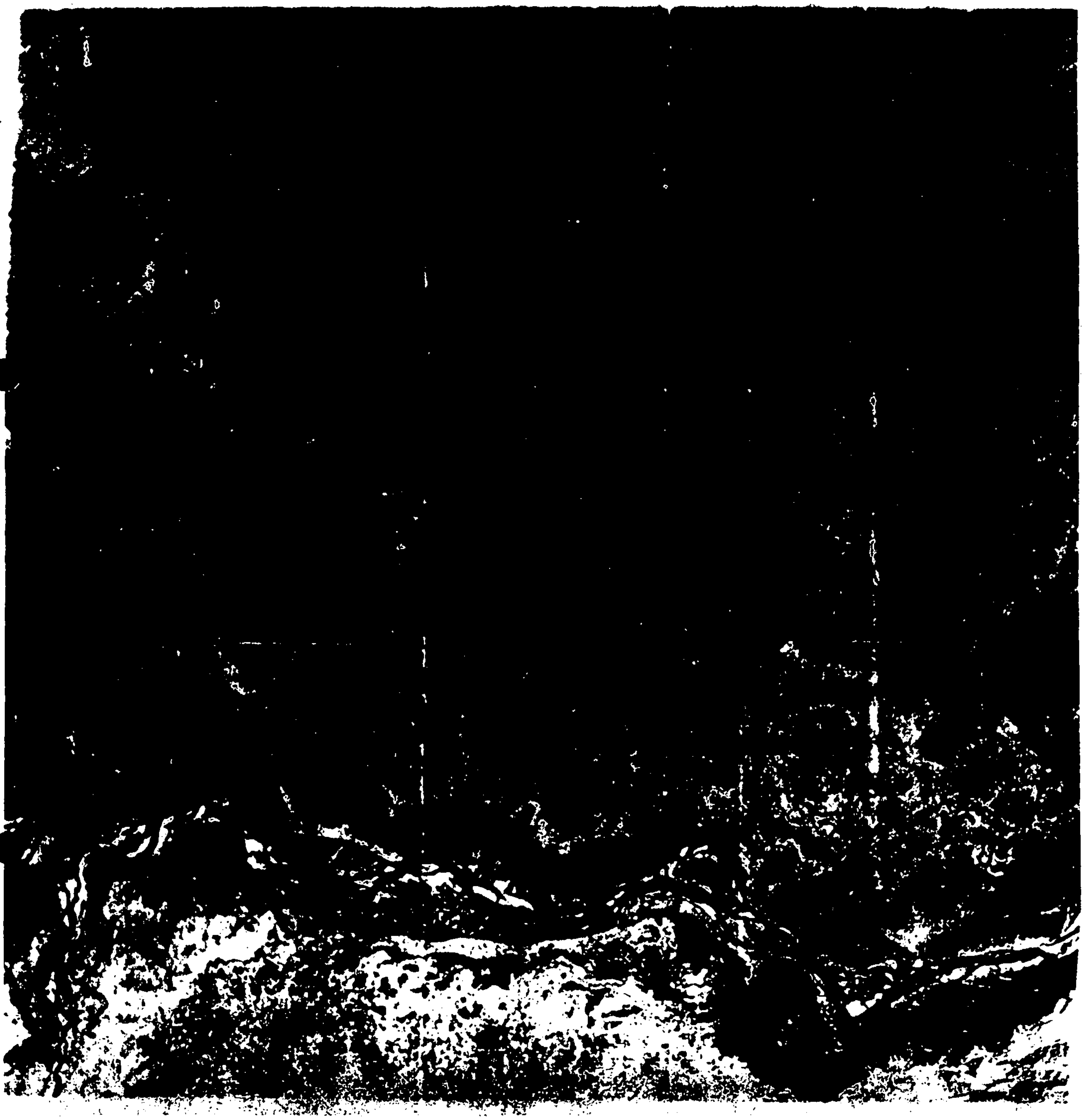
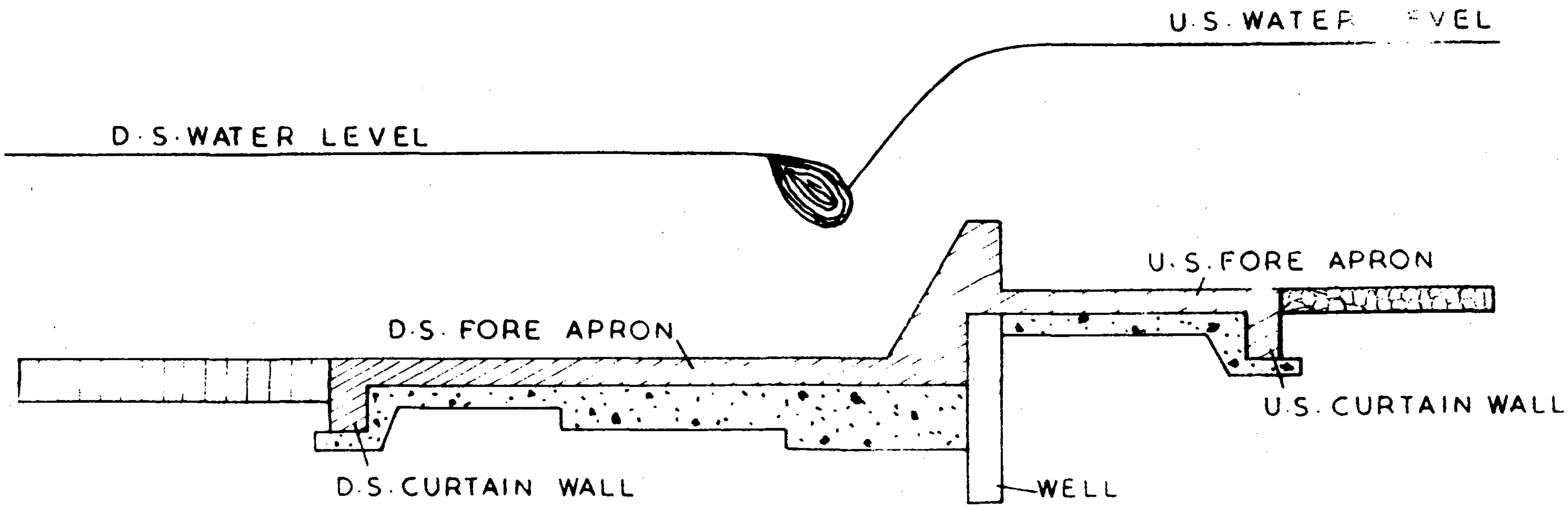


FIG. 7.5 Ahar terrain



FIG·8·1·SECTION OF AN ANICUT (DIVERSION WEIR) ON SAND FOUNDATION

FIG. 8.2 Kolhapur type bandhara

FIG. 8.3 Piers of the Kolhapur bandhara

FIG. 8.4 Wooden shutters for Kolhapur bandharas

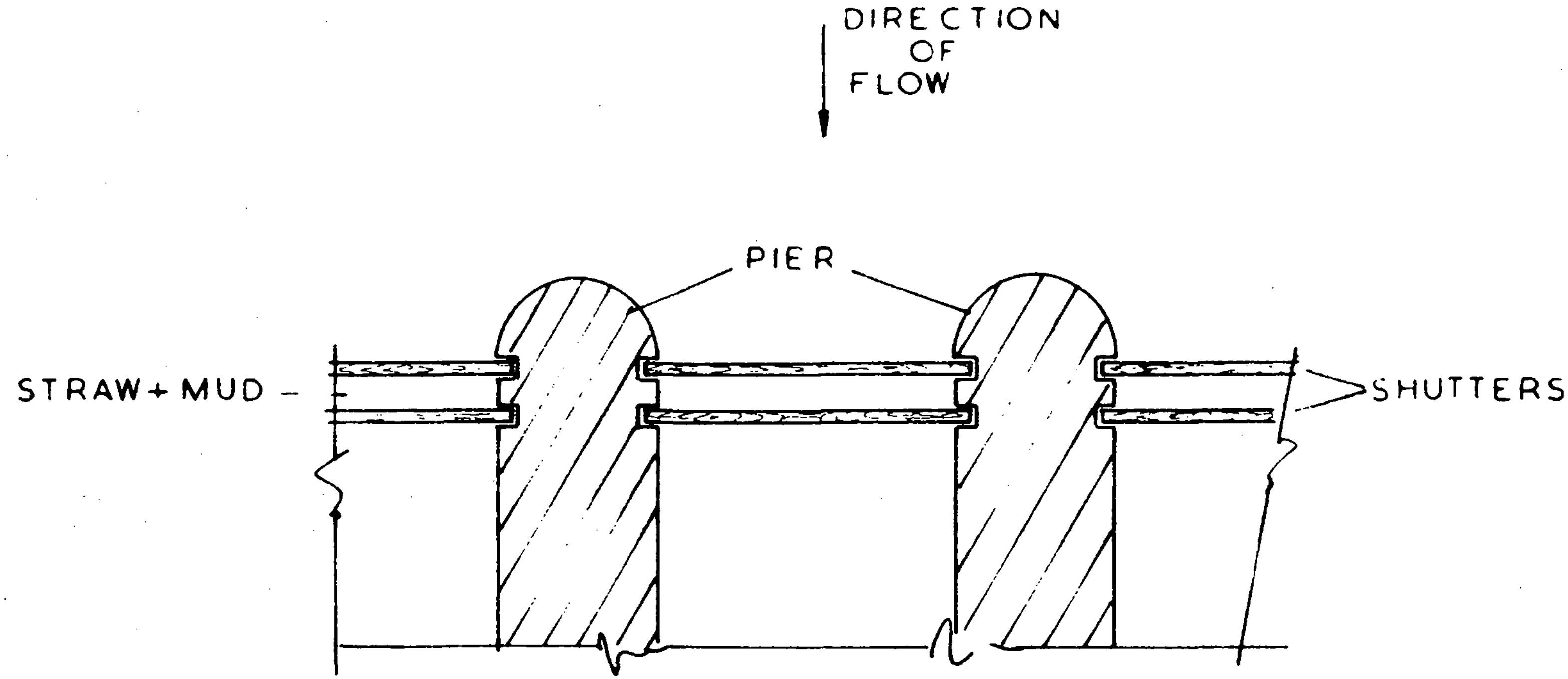


FIG 8.5 SECTIONAL PLAN OF PIERS AND SHUTTERS OF A KOLHAPUR TYPE BANDHARA

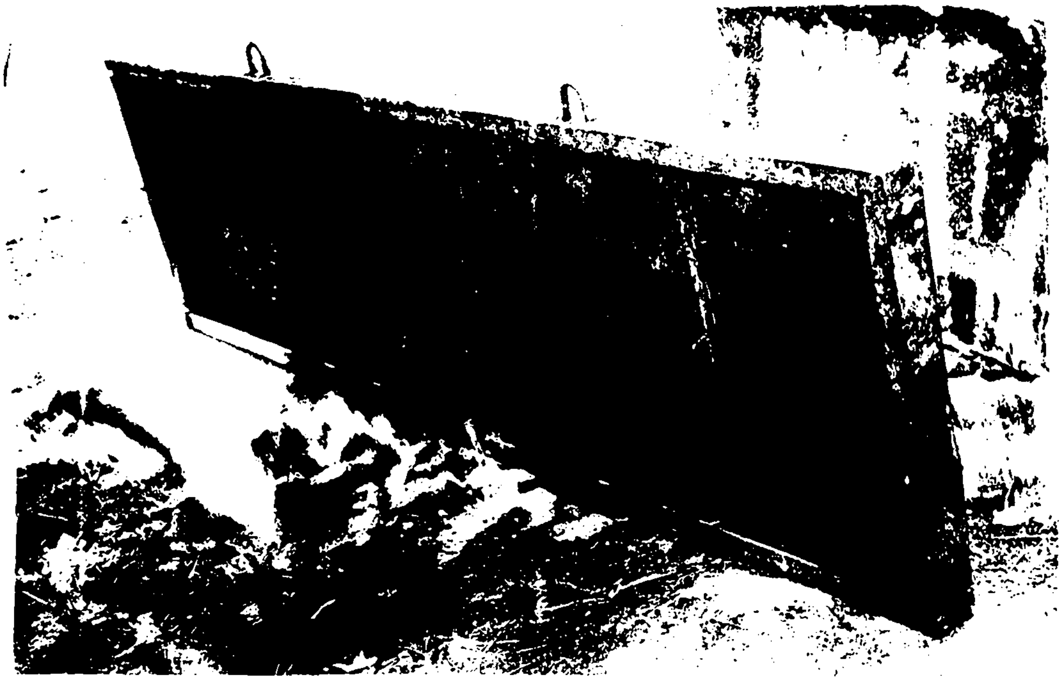


FIG. 8.6 Steel shutters for bandharas

FIG. 8.7 R C C Shutters for bandharas

FIG. 8.8 Kuhl terrain

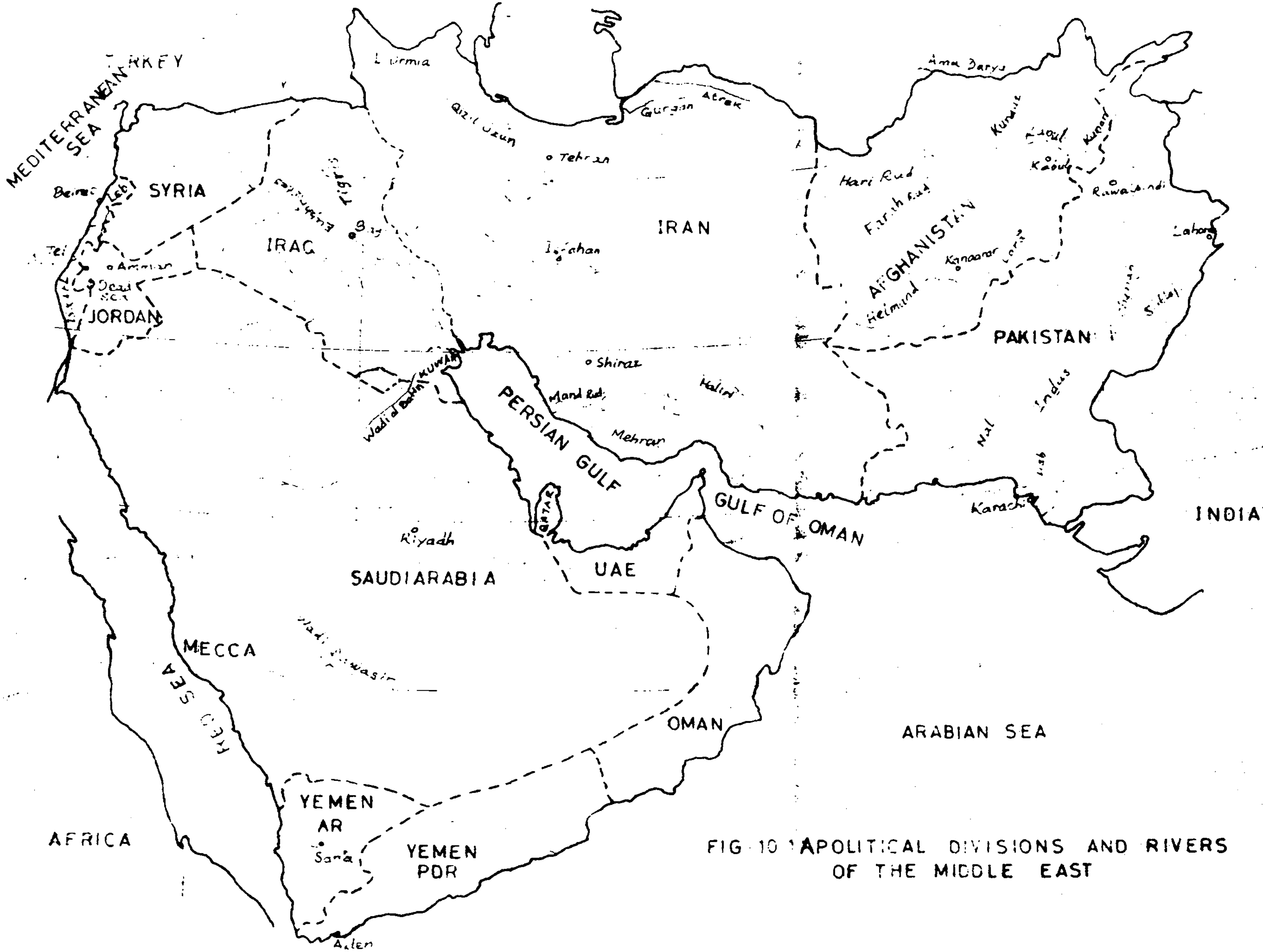


FIG 10 APOLITICAL DIVISIONS AND RIVERS OF THE MIDDLE EAST

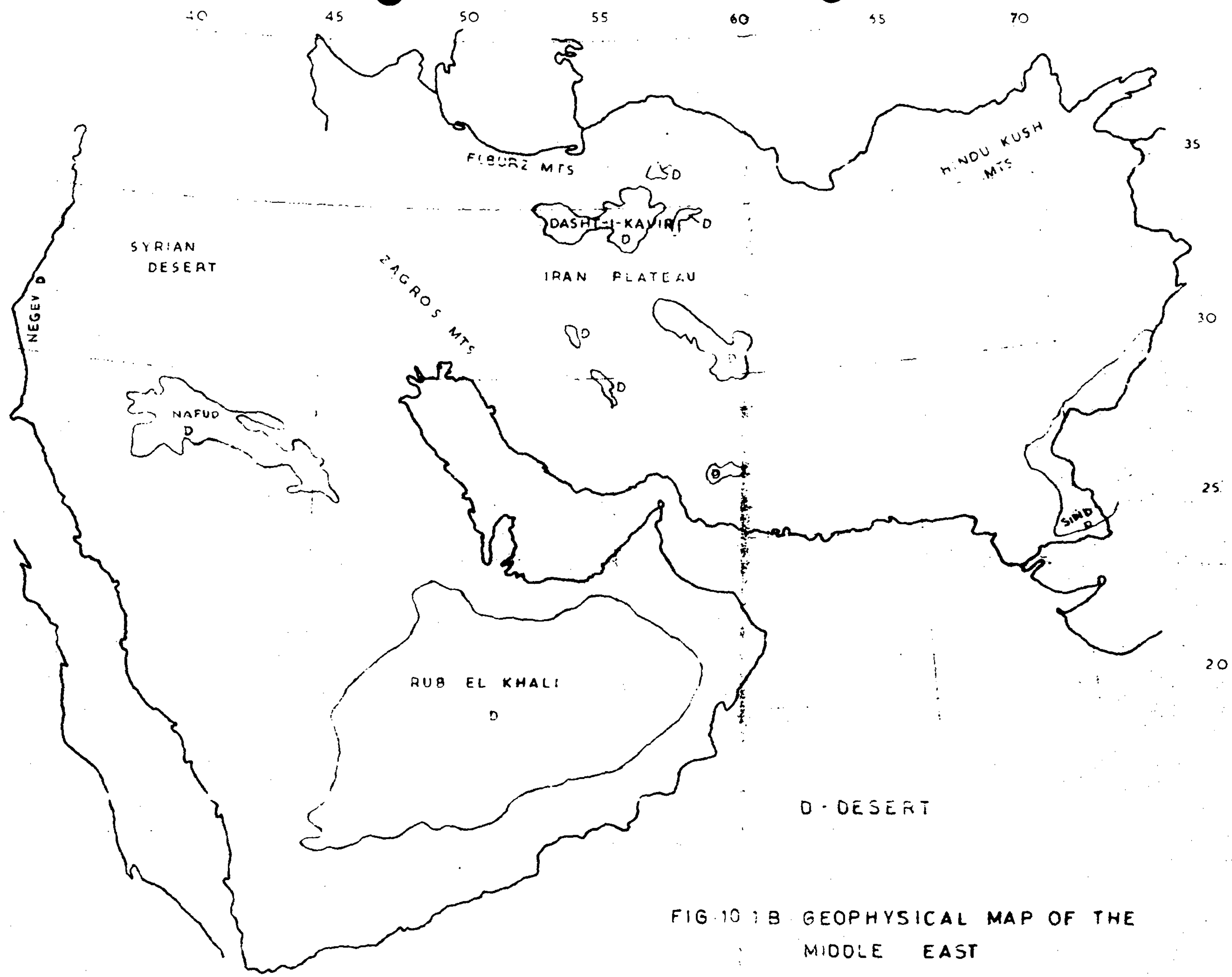
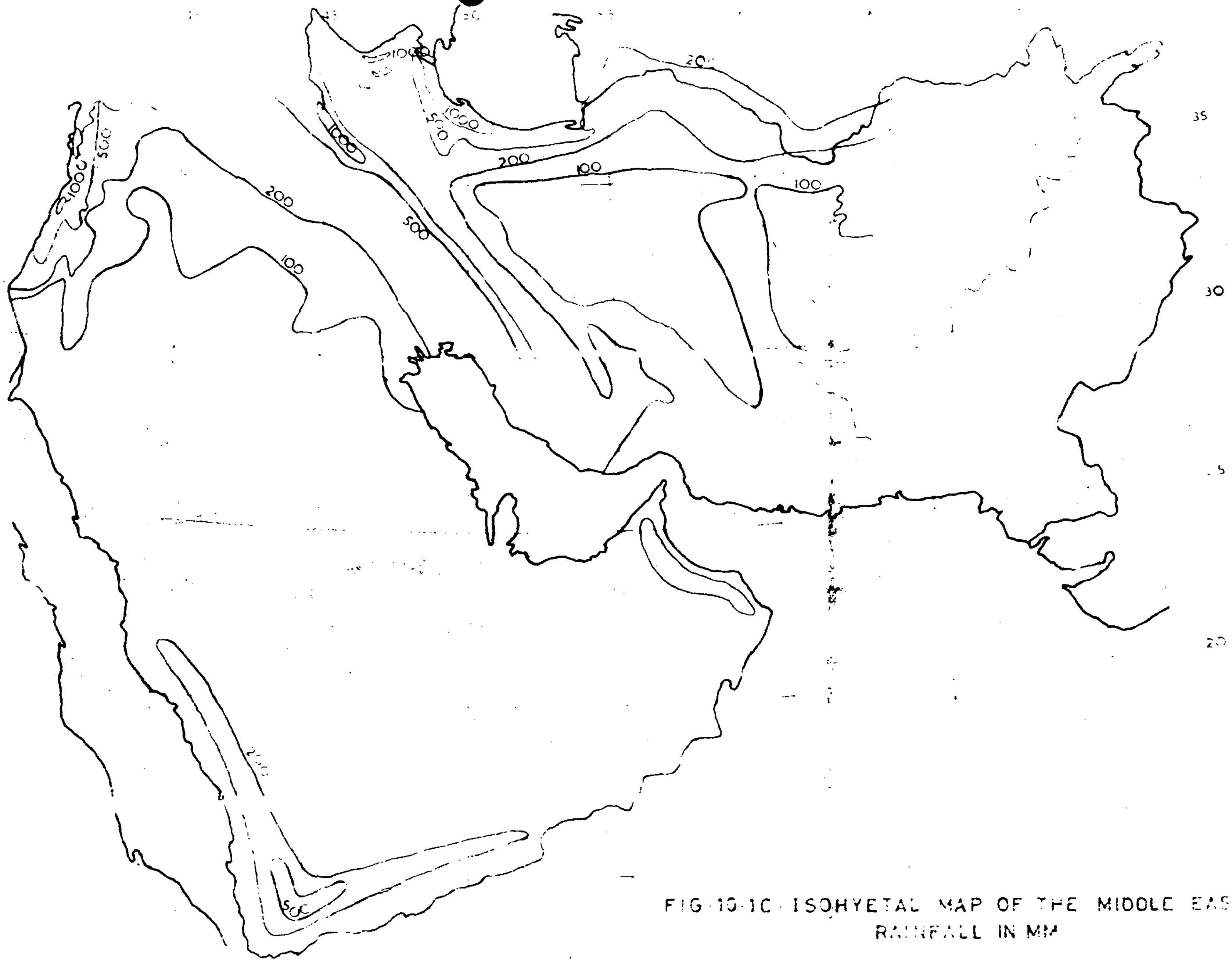


FIG 10 1 B GEOPHYSICAL MAP OF THE MIDDLE EAST



FIG·10·10· ISOHYETAL MAP OF THE MIDDLE EAST
RAINFALL IN MM

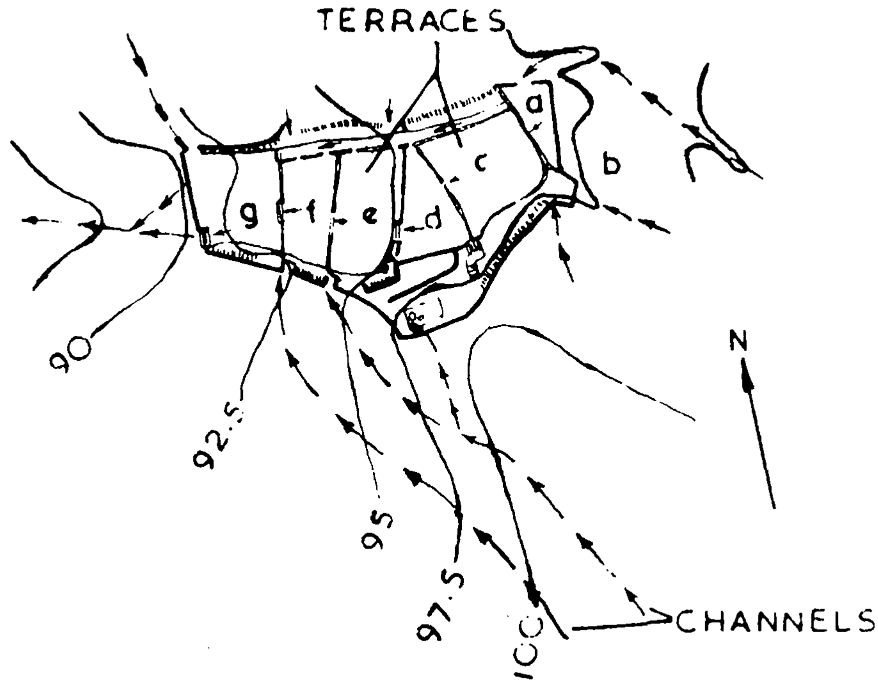


FIG.10.2. ANCIENT FARM IN THE NEGEV

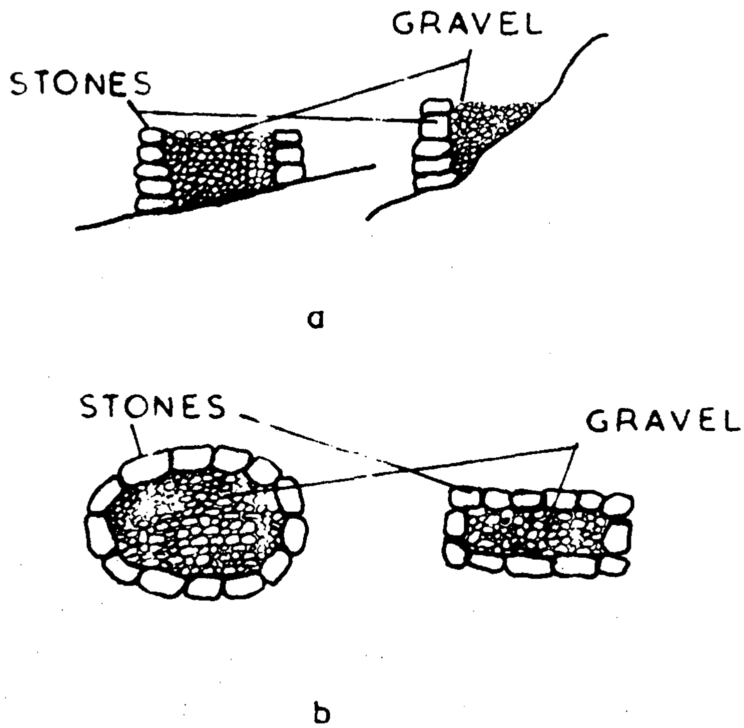


FIG.10.3. MOUNDS INTO WHICH LOOSE STONES IN NEGEV CATCHMENTS ARE GATHERED TO INCREASE RUNOFF (a) SECTION (b) PLAN (AFTER EVENARI)

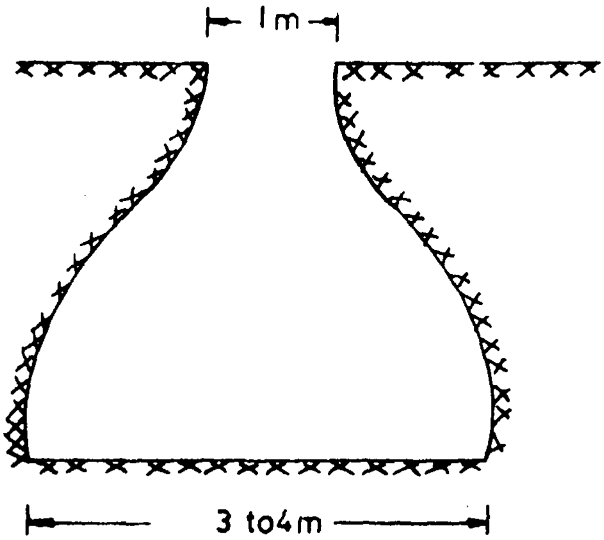


FIG. 10.4. UNDERGROUND CISTERN FOR DRINKING WATER IN THE NEGEV

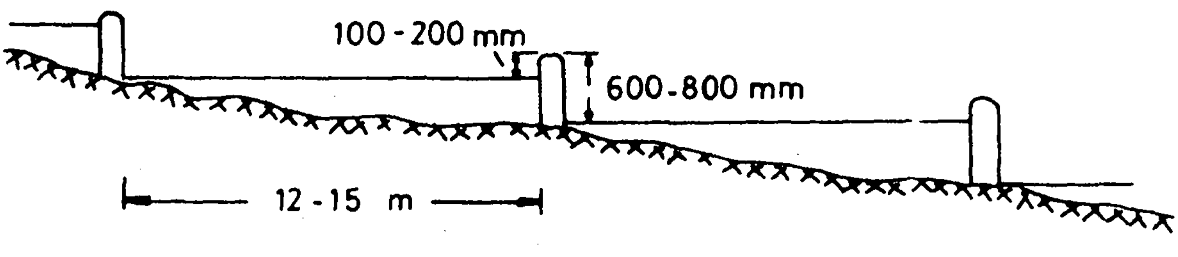


FIG. 10.5. TERRACES IN THE NEGEV WADIS

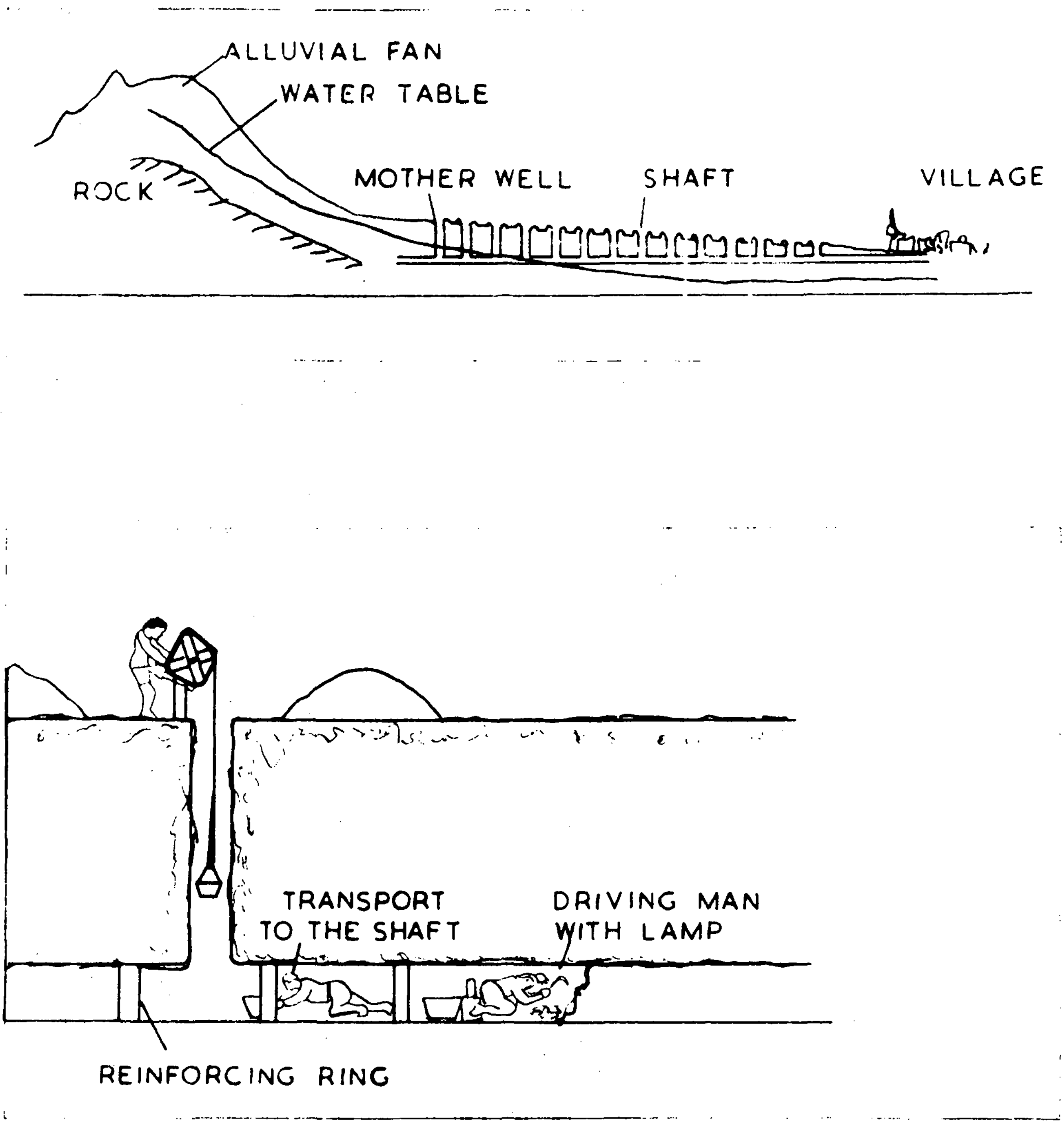


FIG. 10.6. A QANAT AND ITS CONSTRUCTION (Ref. 36)

FIG. 10.7 Shaft of qanat near Kabul

FIG. 10.8 Outlet of qanat near Kabul

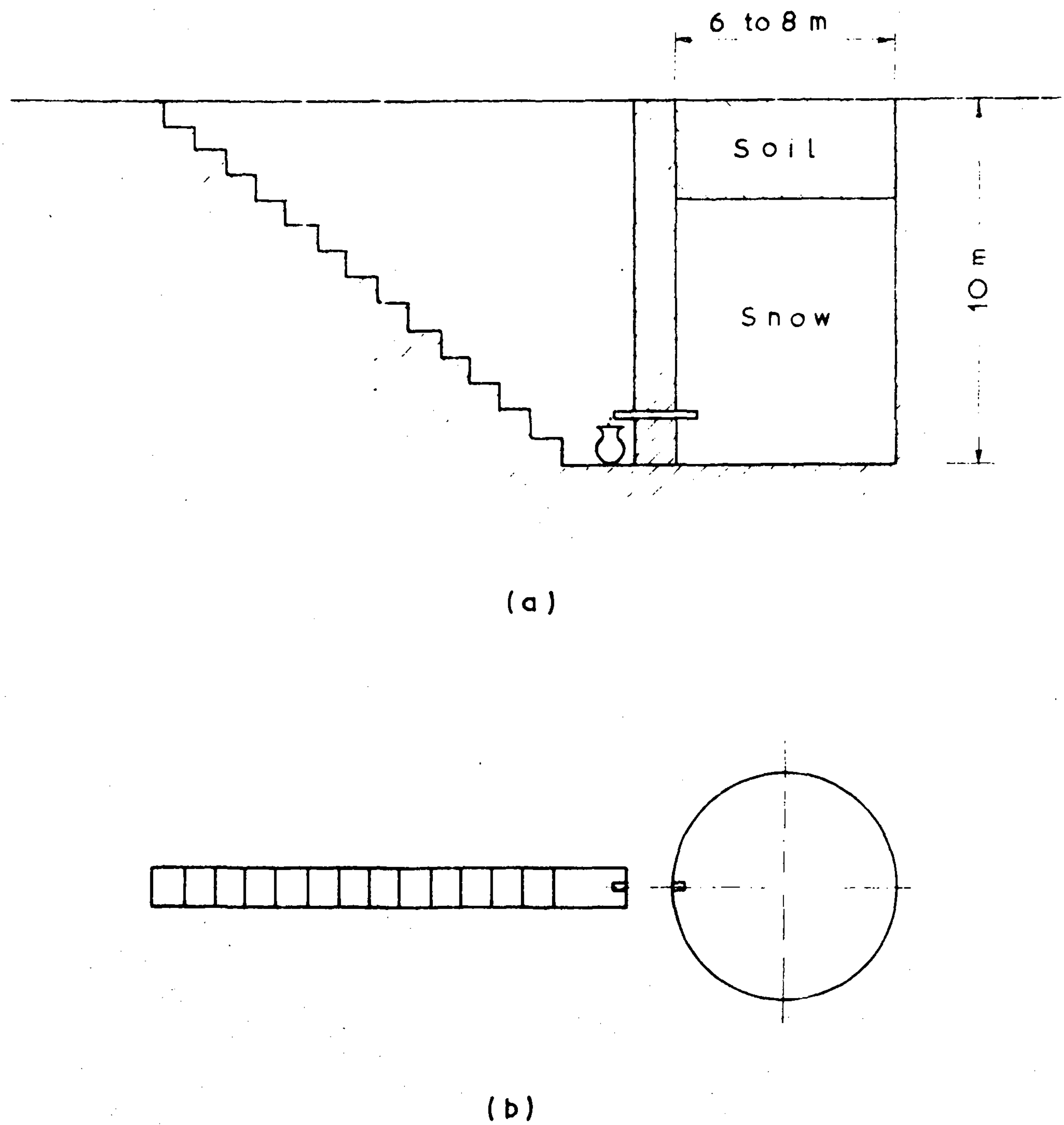


FIG. 10·9 - SNOW STORAGE IN AFGHANISTAN