Chapter 8

Discussions, Conclusions and Recommendations
Discussions, Conclusions and Recommendations

Resource Management

The resource management is basically an activity involving the assessment of two aspects such as the availability of resources and the requirement of the same. Hence, it is necessary to have a complete understanding of the resources, with respect to its occurrence, quality, and its nature (either renewable or non-renewable); in case it is renewable, then the factors governing the renewability as well as factors which may spoil the mechanism responsible for the renewability have also to be thoroughly understood. The resources, which are non-renewable, are generally finite in nature. The quality and quantity of such resources can be easily ascertained. Being finite in nature they have a definite time span up to which they can be used. Hence, its overall management and the conservation can be attempted relatively easily and that is through minimizing the utilization, recycling the materials or finding the substitutes. As against this the conservation of renewable resources appears to be more difficult. This is not simply because of low or high quantity of resources. Almost all the renewable resources are product of some natural process, which is operating within a relatively short span of period. Hence, it is not only the resource per se that needs to be managed but care needs to be taken to see that the processes which are responsible for the renewability of resource are not put to stress. Or for that matter the activities which may not directly and essentially related to the utilization but may hamper or cause intervention in the process of renewability. Understanding of the processes becomes the essential part of the management practices in case of renewable resources. The very fact that the resource becomes available through a definite process makes it necessary to monitor the processes, assess the manner in which the processes operate, variability in the processes and its effect on the final
outcome. Such and many other aspects of the processes have to be understood if one is required to manage renewable resources.

The water, which is the main subject matter of the present work, is one such ubiquitously available renewable resource that is most widely used. The processes, that are responsible for the renewability of water, are not only complex but are operating on varied scales from global to local. Hence they make the problem of water resource management all the more complicated and difficult. Being renewable in nature, availability of water is at times taken for granted and the users tend to ignore its importance. Most of the non-renewable or finite resources are generally being managed by some agencies, most often the State. Moreover people in general are not the first users of such a resource. The resource reaches the user mostly in the form of a finished product of some controlled process. Hence its availability, distribution and such aspects are well taken care of by different agencies. The management and utilization of ubiquitously available resources is always more complex because these are quite often being managed by individuals without much of the control by any agency. Such resources (like water, land or soil), though may theoretically own by society or State, are being managed by the end users who may not have adequate knowledge regarding the processes causing degradation of such resources and hence in the process of utilization, which may not be scientific, there exist inherent threat of resource degradation. Amongst the non-renewable resources, which are ubiquitously available but not necessarily renewable one can take an example of ‘soils’. The practices leading to lowering of quality due to unchecked application of chemical fertilizers, excessive irrigation, unscientific tillage practices etc. are bound to have adverse effect on the state of soil and it will keep on getting aggravated over period of time till finally soils become infertile. Therefore it is more than necessary that the end users are made aware of the dangers involved in the pattern of utilization.
Managing Water Resources

The water resource management cannot simply confine itself to the quantification available resources and assessment of the demands. While it is true that these two are the basic inputs for any such exercise, it may be clearly mentioned that it is not a simple question of meeting the two ends. It is a multifaceted problem involving dimensions from socio-economic aspect to engineering solutions. The problem becomes more acute when it is to be worked out in the areas with high variability of rainfall coupled with meagre quantities.

The surface water is definitely renewable, however, within the limits of its inherent variability. In order to mange the surface water resources. It is essential to take into account the nature of rainfall occurrences, its spatio-temporal variability and amount of water that becomes available. The water received in the form of rainfall is subjected to a variety of factors related to the land and soil conditions, before it becomes available for utilization. Therefore details of land conditions, particularly those related to slope and relief become an invariable component of the study of water resources management. Considering this certain details of physiography particularly related to lithology, relief, drainage and slope are covered in Chapter V. The availability of water in the form of rainfall and its volume as well as runoff has been worked out in Chapter VI. The runoff estimates attempted in Chapter VI appear to be on higher side as compared to earlier estimates available in the literature. For the basin as a whole the estimated values consider 5% yield levels. However if the estimates are obtained on the local level and rainwater is harvested within reasonable distances it is more than likely to have higher yield can be realised.

WATERSHED MANAGEMENT

The ground water component, in many areas in Yemen, due to over exploitation, is becoming more and more non-renewable and finite
resource and day-by-day the costs of its extraction are becoming exorbitant. Hence dependence on ground water for the agriculture or municipal water requirement has to be reduced by increasing the utilization of surface water that is renewable within the time span of annual climatic cycles. The researcher believes that integrated watershed management programmes can achieve this. Whatever be the amount of rainfall that is received, the effort should be made to harvest maximum out of it and this can be achieved only if the water is harvested in the immediate vicinity of the area where it is received. For this purpose different scholars, have suggested a number of measures and plans for different environmental conditions. However, the strategies to be adopted and plan to be implemented will depend largely on the nature of the region and problems the particular region is facing.

So far as Wadi Zabid is concerned, or for that matter, Yemen as a whole, following problems have been listed, which will have to be taken into consideration for any kind of water resources development and management programmes. These problems can be grouped into two classes such as problem related to rainfall and those related to the land conditions, which is the first recipient of the meteoric waters. Some of the problems are listed below.

1. Problems related to rainfall:
   - The rainfall amount is too inadequate in large part of the basin.
   - The nature of rainfall is such that, it suffers from high variability conditions.
   - The occurrences of rainfall are sporadic and resulting into flash flood conditions.
   - The low rainfall is the root cause of meagre percentage of area under cultivation.

2. Problems related to land:
   - The west, which has flat lands, suffers from low availability of rainfall.
   - The east, which receives sufficient rainfall, suffers from poor availability of land due to high relief and rugged topographic conditions.
The central zone suffers from both the low rainfall conditions as well as rugged topography.

The slopes are too steep and the rocks are too hard particularly in the central zone, which limit the scope of extension of agricultural land through terraced cultivation.

In the east, however, terraced cultivation is practiced particularly along the high altitude plateau and their marginal slopes.

It is only in the wadi areas, that some flat lands along the flood plains and lower terraces are available for cultivation.

The tectonics, the area has undergone has been responsible for quick movement of the groundwater arrested to greater depths and hence, the extraction of this becomes costlier and at times beyond the reach of individual farmers.

Due to high relief and steep slopes soil erosion is a serious problem. Tremendous amount of the material are moved into the wadi depressions.

The watershed development programmes have to take into account the problems of the area and the resources available at hand. The watershed programme is generally centred on (1) Water conservation, (2) Soil conservation and (3) Conservation of natural vegetation. All these three components are quite interconnected.

For water conservations certain measures are required to be taken along the lines of flow. Therefore, these are quite often termed as line treatment measures. These include construction of various types of bunds and barriers across the flow lines, which basically aim at making water available at the place of its requirement and also reduce the velocity of the flow in order to check the erosive action by the streams. The work of water conservation also needs to be taken up in the areas away from the flow lines. Controlling the losses of available water in the form of runoff and promoting greater amount of percolation and through that enhancing the scope of groundwater recharge is another aspect of water conservation methods. A good deal of methods / techniques have been recommended by engineers and environmentalists for such work. These are termed as measures of area treatment. Depending on the ground condition one has to make a choice of particular method or technique suited for the region.
Both line treatment and area treatment measures for water conservation also serve the purpose of soil conservation by reducing the losses through soil erosion.

MANAGING AGRICULTURAL WATER REQUIREMENTS

Apart from the problems listed above there are several other problems, which can be considered as area specific problems. These problems have to be taken into consideration particularly when watershed management programmes are to be worked out on micro level. In the watershed development micro-level the participation of people in the entire programme is essential. At this stage these details normally required at local level are not been taken into consideration. Instead, certain details of general guidelines at a regional level are being discussed here.

As mentioned earlier, the Zabid basin area can be divided into three components such as Tihama Plain, Transitional Zone and Eastern Zone. For each of these the nature of the programme can differ significantly, though the basic principles could be common. The main principle is to make use of rainwater within reasonably short distances from the place of their occurrences. It has already mentioned in the last chapter that the total area under cultivation in Yemen as a whole is less than 10% and this also varies from year to year. Even if one considers the total cultivable area that can be brought under cultivation it amounts to 10% of the total geographical area. As far as Wadi Zabid is concerned the facts are somewhat different. The cultivable area amounts around 45%. The actual area cultivated may vary considerably depending on the rainfall condition in a particular year. It may drop drastically to even half of the cultivable area in bad rainfall years and considering the level of variability one can clearly see that frequencies of low rainfall are much higher than that of high rainfall. Vast areas in different physiographical units are barren for one reason or the other. Most of the agricultural activity is confined to the regions, which have some prospects of getting water; either in the form of
groundwater or through water irrigation (flood irrigation). Some of the characteristics of region related to the problems pertaining to the water harvesting and utilization are discussed below.

**Tihama Plain Area**

Though a region of flat and fertile land with very high potentials of agriculture, the Tihama plains basically suffers from low rainfall amounts and high variability. However, it is fortunate to have ground water resources to depend on for the agrarian activity. Yemen Government has already undertaken a good deal of efforts for the development of Tihama Plain. The increasing demand of food grains and other agricultural products is causing tremendous stress on the groundwater resources. The level of groundwater is lowering at an alarming rate. The area has the advantage of flood irrigation, particularly for the lands close to wadi courses. The areas away from the wadi courses and between the divergent channels have to depend only on ground water. Moreover, due to the peculiar arrangement of water rights of riparian population, the farmers in the far downstream areas generally suffer from insufficient water availability particularly in the years of low rainfall. The land being full of alluvium, it should not be difficult for the farmers to attempt collection of rain water individually into the pits and use it during the time of moisture stresses faced by the crops. It has already been argued that the high variability of rainfall does not mean absence of rainfall. Hence, if proper care were taken to collect and store rainwater in the pits of sizeable dimension it would reduce the threat crop failure simply because of the non-availability of the water. Considering the high water requirement of the Tihama, the researcher is aware of the fact that such waters will not prove to be adequate to fulfil the entire irrigation needs of the given crops. The areas which are not put to use for agriculture in Tihama include: (1) Areas of the pediments along the western slopes of high rising mountain front separating the Tihama from the eastern zone, (2) Areas
between wadi deltas- the interfluvent areas where the flood waters from wadi areas do not reach. This is because (1) The elevation of interfluvent areas is slightly higher and (2) Moreover the availability of groundwater is questionable, (3) The flood discharges do not reach these areas and (4) Frequent sand storms in pediment

Another problem regarding agricultures in Tihama relates to high proportion of salinity in the soil. Therefore while considering the water requirement of crops Muharram (1997) has made provision for leaching water requirement.

The migrating sands in this area spread into the agricultural land and surrounding region leading to extension of desert conditions. TDA has recommended the plantation programme for such areas so as to arrest or disallow the sand to spread into surrounding regions.

An extract of the aerial photograph has been given in the fig.(8.1). It covers the area south of Zabid Town. It clearly shows patches of cultivated and uncultivated farmlands between the flow lines. It also marks a part of desert land in NW direction of Zabid Town. It is evident from the photograph that agricultural activity is confined to the flow lines.

The Transitional Zone

The central or Transitional Zone is rather the most difficult zone so far as the problems of water resource availability and management are concerned. By and large it can be described as a semi-arid zone. Al- Jerbah and Al Har Polygons basically represent this. A sizeable part of this region also is covered in Al Udain polygon. Though the average annual rainfall increases from 180 to 350 mm, it suffers from all the adverse aspects of high variability and sporadic nature of rain occurrences. Coupled with this is the problem of non-availability of flat lands. The low rainfall with high intensity has been responsible for intense soil erosion and as a result most of the mountainous tract of this area bears a barren look and its sterile appearance. It is also the area of high degree of
Fig. 8.1

No. 0091
Toposheet No. 1444 C4

Location: Wadi Zabid
at Zabid district
(Govt. of Hoeidah)
lithological variability and intense tectonic activities. The absence of
topsoil or weathered mantle, steep to very steep slopes and the hard rock
do not permit terraced cultivation are some of the obvious problem in the
region. Along the wadi bed and basal portion of valley flat land in the
form of flood plains terraces and pediments are the only areas where some
amount of agriculture is possible.

The sketches based on the air photograph form the different parts of
the central zone are included here to give the idea about the terrain (Fig.
8.2). These are extracts of air photographs from the area of confluence of
Wadi Aqaqah and Annah. It may be seen from the sketch that even close
to Wadi Zabid there exists sufficient relief, and the density of drainage is
reasonably high. A number of 1\textsuperscript{st} and 2\textsuperscript{nd} order streams with sizeable
lengths enter Wadi Zabid. The area to the south of Wadi Zabid indicates
the existence of flat lands, which are already under cultivation. The
purpose of giving this sketch is to show that there are sufficient potentials
to take up watershed development programmes. The second sketch
represents the northern parts of Central Zone (Fig. 8.3). Administratively
this area belongs to district Al Qafr and it falls within the basin of Wadi
Wajis. The area marked as dissected pediment along Wadi Wajis is
crisscrossed by a number of the tributaries having their sources in Jabal
Naqid range. Because of high amplitude of relief in the south, though the
elevations are not exceeding 1000 m the availability of land is becoming a
problem. Whereas in case of the area exemplified by part of Al Qafr
district, it is both the elevation as well as relief, which are proving as
factors limiting the scope for over all developmental activities. The
average elevation of Jabal Naqid is around 2000 m, with a few plateaus
rising over 2400m. The valley flats mentioned above as portions of
dissected pediment have elevations of 11,00 to 1200 m.
No. 0011
Toposheet No. 1443 D\textregistered\textsuperscript{246}

Location: Wadi Al Zabidi & Wadi Aqaqah
Far al Udain (Govt. of Ibb) and
Jabal Rás (Govt. of Hodeiah) distirct
Fig. 8.3
Location: Wadi Wajis
Area between Al Qafr (Govt. of Ibb) and Wusub Al Ali (Govt. Of Dhamar)

Sketch from Aerial Photo

Plateau zone

Disturbed pediment slopes
Areas having
Potential for terraced
The Eastern Zone

The eastern zone of wadi Zabid is identified with isohyets of 800mm. Basically the area is covered by polygons like Yarim, Al Dalil, Rihab, Ibb and Al Udain. Of these Ibb has maximum annual rainfall of 1900 mm and Al Dalil has annual rainfall of 500 mm. The elevations in these areas reached by mountain peaks are in the range of 2500-3000 m, with valley flats around 1800-2000 m. It forms the source region of rivers like Annah, Al Fanaj, Al Sahwal and Hamd. Three different sketches extracts based on air photographs represent three sets of landscape of the region (fig 8.4). These represent three different sets of conditions as observed in the areas of Eastern Zone. The first of these is a portion of Al Sahwal basin. The peculiarity of the eastern part is the fact that people in this area have utilized every possible flat land as well as sloping areas for agricultural activities. Terraced farms cover the slopes wherever possible and high-level plateau areas are intensively cultivated for a variety of crops. However, the area is not free from problems. The practice of terracing, an age-old phenomenon, can be considered as an indigenous form of water harvesting efforts. The land available for terracing is relatively limited as has been rightly pointed out in HWC report there is hardly any scope for farther extension of terracing activity. The terminal slopes of the plateau areas are very steep, almost near vertical. The rock formations in this area predominantly include Yemen volcanic, comprising of tuffaceous and felsic materials. They have relatively higher erodibility, which in a way allows terracing but in case of near vertical slopes these highly erodible materials remain always unstable and hence in such areas the scope of utilization of slopes for agricultural activity becomes difficult. The sketch of Al Sahwal valley area shows existence of flat lands at the top represented by multi-storied or multi-levelled plateau zone and certain benches utilized for terracing. Besides these high level flat lands, at lower altitude getting the land for agriculture is difficult. These are narrow valleys with slopes almost intersecting at the channel.
Steep slopes

Dissected Plateau

Terrace field

Steep slopes (not suitable for terrace field)

Potentials for Terrace field

No. 0059
Toposheet No. 1444 C3

Location: Wadi Al Sahwal
at Ibb and Badan district
(Govt. of Ibb)
giving appearances to perfect ‘V’ shaped profiles. The valley side slopes are generally steep, forbidding any kind of agricultural activity.

The area depicted in the extract of air photo C079 (fig 8.5) belongs to Ans district of Dhamar Governorate. The purpose of including this photograph for describing the landscape is the fact that it represents a peculiar set of landform assemblage, which is quite well spread in the eastern zone. These are the portions of isolated, detached portions of plateau that can be considered as the residuals of the extensive plateau surface existing in the farther East. It is this area that gives us some idea of the famous terraced cultivation of eastern Yemen. However the terraced fields in this part of the area are confined to the tops of residual plateaux and their marginal slopes. Agricultural activity in the entire area is quite restricted in the area and vast lands are found to be just barren. The beds of major wadis are the only regions appearing as ribbons of cultivated land. These areas extend in the upstream direction. Their extension across the wadi course is quite limited. The hill slope materials show the signs of intense slope wash processes. The feeble lines of flows in the form of rills and gullies along the slopes and the granular nature of the texture clearly indicate high erodibility of the materials. The high erodibility coupled with steep inclination has rendered the sloping areas to be unsuitable for any kind of utilization for agricultural purpose. Except for the patches of the plateaus and the beds of major wadi courses the entire area has a barren look. In the south particularly in the southeastern parts of the area one can easily observe the effect of structural details on the slope morphology. Mostly these appear like strike ridges with bed inclination towards northwest. Though the drainage density is relatively low in this part of the area, slopes are quite steep. The texture of the image in this part of the area particularly along the hill side slopes where the rock outcrops are well expressed is much less granular than that observed in the northern section. This is suggestive of the resistance of the rock to erosion. This clearly indicates that the terracing or any other form of
Fig. 8.5

No. 079
Toposheet No. 1444 C2
250 a.

Location: Wadi Al Har
at Ans district
(Govt. of Dhamar)
agriculture is not possible in the area. What the researcher would like to
emphasis that whole the area under cultivation is considerably limited in
this part. The vacant land with good natural slopes can be utilized for
rainwater harvesting in such areas by introducing the hill slope runoff
divergence channel. At the base of hill slopes the runoff can be
channelized to flow in desired direction and the same can be collected to
at the point closer to wadi channel – flood plains. This will ensure water
supply for the crops.

The next photograph (C-16) selected from further east, through the
actual area depicted in the photograph lies little east of the eastern divide
(Fig.8.6). The region particularly defines an altogether different set of
landscape. This represents the high-level plateau region, which so far as
the agriculture is considered is most intensively cultivated region. The
region of the plateau is spotted with a number of round top hills
particularly in the south almost every ‘inch’ of the top of the plateau is
brought under cultivation and the some has successfully moved upslope
along the hills leaving only the top most portions unploughed.

From the topographical maps of the area existence of a large
number of ‘water holes’ can be noticed indicating some amount of
groundwater availability in the region. The agricultural field in the
southern portion of the photo area are separated from the rest in the north
by a chain of hills marking the southern boundary of the plateau. The
density of terracing in this area is greatly reduced and we may find that in
the extreme southern-western part the hills are totally devoid of terraces,
as against this in the southeastern zone the intensity of terracing has
reached its peak. Northeastern portion of the area is covered in Zabid
basin and the steep and sharp plateau margin forms the boundary of the
plateau in this part. So far as the agriculture is concerned one may find
that this area the escarpment that marks the boundary does not give any
scope either for normal agricultural practices or for terrace cultivation.

In this area the major problem that can be taken up under watershed
Extract of Aerial Photo

Fig. 8.6 No. 016
Toposheet No. 1444 C2

Location: Ans district
(Govt. of Dhamar)
management programme relates to reducing the soil erosion and ensuring better flow along the wadis through diverting the hill slope runoff to wadis after it has been utilized for agrarian activity.

**Broad outline for Watershed Management Programme**

In the preceding paragraphs the problems faced by different parts of Wadi Zabid area have been highlighted. The researcher firmly believes that though the problems are serious and complex in nature they are not insurmountable. With serious and committed efforts and through the participation of local people some remedial measures can be thought of, so as to initiate developmental efforts. Broad plans for different areas are outlined in the following pages on the basis of three watersheds selected from different parts of the wadi region. These are the fourth order basins, which were selected for drainage basin analysis. In all 59 such basins have been analysed for their drainage network characteristics.

The three selected basins represent eastern and central regions. On the map (Fig. 8.7) showing the distribution of 4th order drainage basins the location of these 3 have been shown separately along with other 59 basins. The one selected in the east is in the district of Al Qafr, which has a catchment area of 5177 ha. The basin No. 49, having an area of 2187 ha, represents the central region and it belongs to Al Hazm catchment in Al Udain district. The western part of the transitional zone is represented by basin No. 55, and it is located in the district of Jabal Ras. It has a catchment area of 1836 ha. Tihama, being a region of absorbing runoff, does not promote any major watershed. Hence programme for the water conservation or other related work shall be discussed separately.
These three basins though have different areal dimensions can be considered as representatives of the zones that they belong to. Before going into the details of plans certain morphometric information of these 3 representatives catchments have been given in the table below

Table 8.1: Drainage network lengths in Wadi Zabid area

<table>
<thead>
<tr>
<th>Basin</th>
<th>Order</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>ΣL</th>
<th>Σa</th>
<th>DD</th>
</tr>
</thead>
<tbody>
<tr>
<td>26</td>
<td>1</td>
<td>63.42</td>
<td>17.85</td>
<td>4.82</td>
<td>5.57</td>
<td>91.66</td>
<td>51</td>
<td>1.77</td>
</tr>
<tr>
<td>49</td>
<td>1</td>
<td>33.71</td>
<td>10.64</td>
<td>3.28</td>
<td>3.85</td>
<td>56.48</td>
<td>21.67</td>
<td>2.60</td>
</tr>
<tr>
<td>55</td>
<td>1</td>
<td>18.99</td>
<td>9.21</td>
<td>1.36</td>
<td>2.71</td>
<td>33.35</td>
<td>18.36</td>
<td>1.76</td>
</tr>
</tbody>
</table>

Watershed programmes are essentially to be considered as peoples programme if it has to achieve any success. So the first step in watershed programme should be participatory resource appraisal and problem identification of the region. The next step in programme planning has to be in the form of the proper resource appraisal carried out by a team of technical experts who would understand the problem of the villagers and will also be in the position to recommend strategies with minimum level of external inputs. These should be kept at minimal level and that too in the form of financial subsidies for the programmes as well technical knowledge that may not be locally available. People who are likely to be the beneficiaries of the programme shall take interest in the programme if are also the planners and implements of the same. The absence of their participation not only hampers the progress but the whole programme may get stalled at times. Hence making people aware about the need of such programme and encouraging them to participate in the same is the first task. This can be performed by non-government organizations (NGOs).

The planning of the programme needs to be done with the help of some technical assistance has to be sought and therefore role of NGOs project implementing agency becomes quite vital. With the participation
of NGOs and people the issue like “what needs to be done” and “what can be done”, preferably with local inputs can be sorted out.

**Basin 1**

The total length of the streams of all the orders is 91.6 km. The basin spreads into Al Qafr and Yarim district. The basin can be subdivided into 8 zones as shown in the map (fig 8.8). These zones need to be considered separately for the treatments as their slope characteristics as well as land use-land cover conditions differ considerably. These zones are shown in figure 8.9. Of these most difficult parts for the treatment is the zone of valley side slopes. As it is barren due to high inclination and is subjected to intense soil erosion processes. Hence, it is discussed with the first priority. It separates plateau zone in the east and zone of valley flats in the west.

These streams are mostly in the form of gullies, either occupying hill slopes or the pediment areas at the base. The slopes are having an inclination, at times, more than 45°. These streams cannot generally be treated with the conventional methods of constructing temporary dams or bunds. The high gradient generates tremendous velocities and therefore such structures become unstable and hence unadvisable. The area receives sufficient rainfall, which is of the order of over 800 mm annually. During pre monsoon and early monsoon the rainfall intensities are very high and the flash floods are not uncommon. Instead of constructing the loose boulder structures it would be desirable to have these streams being treated with riparian plantations of various varieties of *Qobab* (*Aloe sabaea schweinf*) as well as *Al Sabar* (*Aloe Vera*) and similar plants. A few plants of *Sant* (*Zinjy*) - *Talh* (*Acacia negrii*) as well as *Dhabah – Sumar – Kattar* (*Acacia Mellifera*) can also be planted along the banks of the streams. The advantage of such riparian vegetation would be that, whatever the material is removed from the hill slope areas would get
Watershed Development and Management
IV\textsuperscript{a} order Basin (No. 26) Land Characteristics

Fig. 8.8 For Treatment see Table 8.1
W - E Profile across IVth Order Basin No. 26

- Wadi Terraces / Pediment
- Occasional wadi courses
- Wadi Rawdah
- Pediment
- Valley side slopes
- Terrace cultivation
- Mid slope Bench
- Plateau
- Severe soil erosion
  Area is not suitable for Agriculture
- Wadi Khayran
- Escarpment
- High Level Plateau

Fig. 8.9
arrested as well as the discharges would move without much of impounding but at the same time with reduced velocities. The density of these plantations should be sufficiently high and the fast growing varieties should be preferred. Such an effort of vegetal protection to the streams and the reciprocal support to the plants by the streams would go a long way in checking the erosion.

The gullies along the hillside slopes have inclination less than $20^\circ$ and their thalwegs are fragmented with a series of drops accounting for the total relief. These steps (nicks) separate segments of low gradient. The line treatment in the form of lose boulder structures can be recommended under such conditions. The number of loose boulder structures to be constructed across the streams will depend on amount of inclination of low gradient segments and the total length available. Most of the pediments in these areas are highly dissected but are of limited extent. They immediately merge with the terraces and wadi beds. This is mainly because of the fact that the relief along the slope owes more to tectonics than sub areal processes. However, the flat lands at the base have potentials of being cultivated. Hence, the construction of loose boulder and diversion of water from these temporary structures in to the agricultural lands is being practiced in the region by local people. It is at this place the farm ponds can be recommended, which can have sizable dimension. The size of the pond can vary depending on the catchment of the stream as well as annual rainfall. Generally recommended size in plan can be:

$$\text{Mean annual rainfall} \times \text{Catchment area in hectares}$$

10

Dimension like $10 \times 10 \times 5$, to $50 \times 50 \times 5$ have been recommended by many hydrologists (Ghare, 2000)
A series of such farm ponds at the transition between the lower hill slopes and flat pediment lands particularly at the locations where the streams enter into the pediment area can be recommended. It would serve two different purposes. Firstly: it would provide large space for water, which can be utilized by the farmers during the periods of moisture stresses. These pits are not to be lined up and percolation from them should be allowed. Secondly: as this area also suffers from sporadic rain occurrences (though not as much as Central and Western Zone) a tremendous amount of material coupled with large boulders gets moved from the hill slope areas and at times spreading into the farm lands, causing degradation of the same. The pits at the transition of pediments and lower hill slopes would act as the shock absorbers and protect the fields from the spread of such excessive silt.

The next extensive zone comprising of high plateaus is the most productive area of the region and almost every possible piece of land, which could be brought under cultivation, appears to have been terraced. A number of publications particularly indicate that in the recent past the terrace cultivation has been revived and there is hardly any land now available for further extension of the cultivation. Terracing itself is a valid, and one of the ancient, forms of rainwater harvesting. What is now required to be done in terms of watershed treatment in this area is to ensure that the terrace bunds are properly and regularly repaired and maintained. There are reports that these being ancient structures at places they are in a bad shape. So the major expenditure in this area will have to be incurred on terrace bunds repairs. These streams, which are by and large already regulated in terms of their paths through the process of terrace building, need to be treated only for some amount of velocity decelerations by constructing a few structures. The areas of the plateau margins are the most vulnerable regions and therefore special efforts have to be taken for strengthening the terraces in these areas. In the upslope direction of the terraces pits can be recommended, which could be treated
more as percolation pits that can ensure greater discharges in the springs at the points of break of slope. The spring irrigation is one of the popular sources of irrigation in the areas of Ibb Governorate. It has already been pointed out that as much as 16% of the irrigated area in Ibb Governorate has spring as a source of irrigation.

The third important zone can be identified as the zone of valley flats, where the altitude is less than 1400m. It is a relatively flat area and the relief is of the order of 100-150m. It is in this area the main wadis as well as its tributaries have broad flood plains and these support good deal of agricultural activity (zone 1 in map). The discharges coming from upslope direction and particularly from the areas of steep slopes are product of high runoff. Moreover, it is in these low lying areas that the base flows in the streams are fairly dependable. The treatment in this region needs to be considered on the basis of the terrain characteristics as well as keeping in mind that these are the areas of high potential for agriculture. Though presently the agricultural land is highly restricted only to the wadis, there is sufficient scope for rainwater harvesting, as the area left uncultivated is sufficiently large from which the runoff can be collected and made available to the farmlands in the wadi areas. Considering the water requirements for different crops it is obvious that the water received in form of rainfall is far too less. As mentioned earlier, the total area under agriculture is quite low. Even for making the water available to these areas is a serious problem. Unlike the terrace-cultivated areas of the plateau region the farms in this part of the basin do not have any traditional rain harvesting system. Hence, it would become necessary to think of collecting the waters from those areas, which are in immediate vicinity of agricultural lands but presently are not under cultivation. If the runoff from those areas can be collected and stored at suitable locations and in sufficient quantities it would become available to the farmers to be used in the period of need. Unlike the pits mentioned in the preceding paragraphs, which were meant for reducing the velocities as well as
minimizing the effect of flash floods the farm ponds should be considered as the ones which are meant particularly for agricultural activity. The water requirement and irrigation schedule for different crops clearly indicate that the water to be supplied to the farm at given point of time would be of the order of 1/10 or 1/12 of the total irrigation needs. It is in the Eastern Zone that the annual rainfall is of the order of 800 to 1000mm. During the Monsoon, the amount received and its dependable components are fairly high (40-50 %). Moreover, in the eastern region the nature of occurrence of rainfall is such that, at least in Monsoon season it is well distributed in terms of temporal aspect. Hence, there is every possibility of receiving fresh rainfall in the periods of interval between successive irrigation cycles. However, it may not necessarily be always possible to receive total required amount but considering that it is to be meant for rain fed crops like Dhurah (Jowar), which normally needs only 3 flood cycles. It appears that the quantity of water, which will get collected, will be at least sufficient for survival of the crop. It may be observed that the water requirement of Sorghum in eastern part of the region during winter is 471 mm (Tables 7. 10 a to h). As against this the water requirement of the Monsoon (summer) period is of the order of 675 mm. It is suggested that for agricultural land one hectare, runoff from equal area should be collected in pits of one are size with a depth of 10m. Thus it will accommodate 1000 m$^3$ of water. The water such collected can then be made available for the crop. This form of irrigation being suggested is just to supplement the rain fed agriculture and not necessarily to promote any kind of change in cropping pattern. It is true that water thus collected will be subject to the processes of direct evaporation as well as percolation. However, sealing the percolation losses may become expensive and hence, it is not being recommend. Providing a cover to the pit made up of locally available material can reduce the evaporation losses to some extent.

Thus in three zones of the basin under consideration from eastern zone, three different sets of treatment can be recommended. The areas
which have slope less than 20% can further be taken into consideration for line treatment in the form of introducing 'refill trenches' along the ephemeral streams. Such trenches are to be taken along the line of flow. The streams, which have width more than 10m and up to 50m, may be selected for such trenches. For a length of 15-30m the bed of the channel is to be dug out for a depth of about 5m. Part of the material removed should be re-utilized during the process of re-filling. The filling should be done with first layer of large boulders with a diameter of 50-60cm. Such boulders can be collected from the surrounding regions. This should form a layer of at least 50-70cm. While filling, care should be taken that, it covers the entire area and at the same time provides for inter boulder spaces. Next successive layers should be of continuously lowering sizes. The total depth of 3-4 m (out of 5 m) should thus be filled in by materials with regular gradation and for the last layer the material removed initially may be utilized. Such within channel re-fill trenches can be introduced at sufficient intervals all along the streams. However, the choice of location and details of dimensions could vary from place to place. The discharges flowing through such streams, after the rain activity would automatically percolate into such re-filled trenches and the escaping runoff from the catchment would get greatly reduced and sufficiently arrested. The water thus held in the re-filled trenches, may not be available for direct extraction or consumption. However, due to the thick layers of soil at the top it would be protected from evaporation losses and its final destination would be definitely directed to the ground water recharge. A large number of such re-fill trenches would ensure sufficient amount of additional ground water in the region. The wells in the vicinity of the streams would be the first beneficiaries of these trenches. The constructions of loose boulder bunds as well as the gully plugs along with re-filled trenches would not only enhance the availability of surface water but also will greatly reduce the soil losses. The method suggested here are labour intensive methods and do not warrant much of technical know how.
Moreover, by avoiding the construction of weirs and dams, the dependence of the local population on the funding agencies is reduced. Thus it may be realized that most of the work can be accomplished with the help of the labour contributed by local people. It would also promote the employment generation for some period of time, during which the project is being implemented. After completion of the work it would also need some amount of maintenance personnel and therefore the work will generate job opportunities even on long term basis for at least fewer people for a longer period.

Basin 2 and 3 (Fig. 8.10 a & b)
These two basins represent the eastern and western part of the transitional zone. The transitional zone has high degree of variability in terms of climatic as well as topographical conditions and therefore it was thought necessary to take up two independent basins. The basin number two is located in Hazm al Udain district, whereas basin three belongs to district Jabal Ras. The catchment area of basin number 2 from Hazm al Udain is 21.87 sq. km and the one from district Jabal Ras covers 18.36 sq km.

Wadi Hijar occupies basin number 2, which is one of the tributaries of Wadi Zabid in its central reaches. This catchment is mainly covered by low-lying areas with an altitude ranging between 900 – 1100 m. The heights along the water divide are as high as 1400 m, in case of Jabal al Mija'dar. If one assumes a profile from this mountain across the basin, reaching the eastern slopes of Jabal al Qal’ah it would become clear that for greater part of the profile lies below 1100 m, with only marginal areas having steeper rises. A number of rivers following the average regional slope direction move from south from north. It is these low-lying areas that have good potentials for agricultural development. Towards the west the area is characterized by a few lineaments, running in northsouth direction. In its lower reaches wadi Hijar has developed its own flood plain, width of which is only around 200-250 m. This is the most prime
Watershed Development and Management
IVth order Basin Land Characteristics

Basin No. 49

- Wadi Beds Valley Flat
- Wadi Beds (upper reaches >1,000m)
- Floodplain Terrace / Pediment
- Valleyside Slopes
- Escarpments

Fig. 8.10

Proposed Loose Boulder Structure/ Gully Plugs
land of the basin, which is intensively cultivated. However, though the relief is relatively low and availability of land is fairly good, the area under cultivation is restricted to the lower reaches of the wadi – mainly the flood plain area. The lower percentage of the area under cultivation can only be attributed to the non-availability of sufficient rainfall. If the water can be made available sizeable proportion of these areas can support agrarian activity. Out of 2100 ha of the land almost 3/4 of the area has good potentials of supporting agricultural activities. There are large numbers of such basins in this part of Wadi Zabid, which have similar situations. These are the low level regions within a distance of about 10 km or so, from main Wadi Zabid. One comes across extensive flat lands, which are unfortunately left unattended so far as agriculture is concerned. With little efforts large part of such areas can be brought under cultivation.

The type of treatment that can be recommended in this area may be quite similar to that which is recommended for the valley flat zone of the first basin. It is in this area of the basin 2 and 3 the treatment of loose boulders; re-filled trenches as well as construction of farm ponds may be recommended. The size of the ponds would depend on the area for which it is supposed to provide water during emergency. It is quite possible that, large ponds may be required to be constructed. It is for the simple reason that the rain activity in this part gets greatly reduced and the collection of water will have to be done from larger areas. The base of the farm ponds should be sealed with a layer of about 10cm of clayey soils. If the clayey soils are not available, the local soils such as loams and silty loams can be mixed with the cattle excreta and grass and layer of such material may be introduced at the base of the ponds. The sides of the ponds should be sloping or terraced. They should not be vertical. The water from such ponds is to be used for the period of moisture stresses. The ponds should be constructed along the stream channels of lower order streams. These streams normally have very high discharges for short duration resulting
### Table 8.2: Watershed Management: Land Characteristics and Treatment Recommended

<table>
<thead>
<tr>
<th>Basin</th>
<th>Land Unit</th>
<th>Land Characteristics</th>
<th>Processes operating and the Problems identified</th>
<th>Present Land Use</th>
<th>Treatment Recommended</th>
</tr>
</thead>
</table>
| 1, 2, and 3 | 1 | **Wadi bed**: Flood Plain  
Good water conditions during rainy season, Moisture retained in winter | Flash Floods, Bank failures  
Mobile nature of channel causing shifts and swings  
Occasional spread of erratic boulders.  
Variability of rainfall | Agriculture: During Kharif and Rabi.  
Many areas remain un or under utilized. | For major channel (width > 50)  
Construction of concealed dykes across the channel  
For Minor Channel (width > 50)  
Refill Trenches. |
| 1, 2, and 3 | 2 | **Valley Flats**: Terraces  
Good alluvial soil. Ground water available.  
Pediment. Soils sandy. Ground water deep located | Discharges of Flash floods not available. Moisture retention by soil is poor. Heavy dependence on ground water. | Partially agriculture if water is available or else barren. Severe erosion by pediment gullies.  
Dissection common feature. | **Line Treatment**: Loose boulder structures, Gully Plugs. Farm Ponds, Ponds at the base of hill slopes to arrest flash flood sediment discharge  
**Area Treatment**: Continuous Contour Trenches, Farm bund repairs, Plantations: pasture & Horticulture development |
| 1, 2, and 3 | 3 | **Valley side slopes**: Very steep – almost vertical slopes  
**Highly erodible materials** | slope wash, intensive mass movement, land slides, rock falls common. No scope for agriculture | Largely barren. Some scrub present in different parts. Even pasture / grass land is not available | Along relatively gentler slopes staggered trenches should be attempted and plantation be promoted. The stream beds in the valley floor areas can be treated with loose boulder structures. Percolation trenches and Refill trenches. Along wadi courses riparian vegetation can be attempted |
| 1 | 4 | **Plateaux (low level)**: Height range between 2000 to 2100 m.  
Old planated surfaces good soil cover. | Generally no serious problem most of the problems are related to terrace bund maintenance and repairs. The terminal slope areas have serious threat of erosion. Mostly by the head ward extension of gullies along the lower slope segment. | Most of the area is under terrace cultivation. | Terrace bund repairs and maintenance. Some farm ponds are recommended in the upslope direction to collect rain waters and make it available for the crops in the periods of moisture stresses. |
In case of areas where the slope length are sufficient and the gradient are moderate the area should be treated with gully plugs to check the soil erosion. For short length and steep slopes at the base of the slope percolation trenches can be taken. The loose boulder structures and gully plugs or even Gabion (wire mesh) type of bunds can be recommended for areas having serious problems.

Generally barren, Un-utilized land. The steepness of land gives rise to gully erosion and this eventually causes severe problem for the farm lands.

Plateau scarps: Terminal Slopes of pediments / Terraces

These units generally cover very small areas but are considered as separate units as they demand special treatment.

In case of areas where the slope length are sufficient and the gradient are moderate the area should be treated with gully plugs to check the soil erosion. For short length and steep slopes at the base of the slope percolation trenches can be taken. The loose boulder structures and gully plugs or even Gabion (wire mesh) type of bunds can be recommended for areas having serious problems.

Mid Slope Benches: These are the relatively flat lands along the Hillside slopes.

Being at higher altitude and surrounded by steep slope promoting high runoff the ground water potentials are poor.

The percolation tanks along the upslope margins of such benches should be constructed to ensure water supply. The flat lands normally have good covers of the regoliths and at times soils. With water being made available it will have better prospects of agriculture.

Plateaux (High level)

Generally no serious problem most of the problems are related to terrace bund maintenance and repairs. The terminal slope areas have serious threat of erosion. Mostly by the head ward extension of gullies along the lower slope segment.

Most of the area is under terrace cultivation.

Terrace bund repairs and maintenance. Some farm ponds are recommended in the upslope direction to collect rain waters and make it available for the crops in the periods of moisture stresses.

Escarments

These are the narrow areas mostly barren with little soil cover. At times rocky cliffs dominate the landscape. These are more or less separators between different land units.

Barren un utilized lands

No specific treatment can be recommended for such areas due to steep inclination and poor soil cover. However at the base percolation tanks and trenches either continuous or staggered are recommended as the gullies have tremendous erosive power.

<table>
<thead>
<tr>
<th>No.</th>
<th>Plateau scarps: Terminal Slopes of pediments / Terraces</th>
<th>Mid Slope Benches: These are the relatively flat lands along the Hillside slopes.</th>
<th>Plateaux (High level)</th>
<th>Escarpments</th>
</tr>
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<tbody>
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<td>1,2 and 3</td>
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</tr>
</tbody>
</table>
out of flash floods. So, there is every possibility that the ponds will get filled at least for 3-4 times, during the period of the rainy season. The distribution of daily rainfall in the area is full of long dry spells, separating short periods of wet spells. Thus the water collected during wet spells can be stored at a number of places along the streams at convenient locations, so as to serve as support systems for the rain-fed agriculture.

So far as the area treatment is concerned, in basin 2 and 3, where the areas of moderate slope are confined to the divide lines, continuous contour trenches can be recommended. At relatively high inclination regions (20-30% slopes) instead of continuous contour trenches, long staggered trenches can be recommended. Along the sides of these trenches, horticulture plants may be planted, which can survive with the help of water collected in the trenches and moisture retained in the soils. Wadi Zabid also have a large population of livestock and hence, most of the moderately sloping land should be reserved for and preserved as pasture lands. This can be in the form of horti-pasture lands. The pasture development can be achieved by introducing high yielding grass varieties. For various units identified from the basins selected their characteristics, problem and treatments recommended are summarized in table no. 8.2.

**Managing the Municipal Water Requirement**

In the preceding chapter, the requirement of water for municipal and agricultural need have been quantified. The spatial patterns of the need on the basis of Ozlas for water requirement have been depicted in different maps. From the discussions included in the last chapter it is clear that for the water requirement no single source can prove to be adequate to fulfil the total need. Moreover, some of the sources such as spring or flood irrigation are available in specific areas and hence cannot be thought of as dependable means in all the areas. The only two sources are by and large commonly available and they are the rainwater and the ground water. With all its inherent variability either spatial or temporal, rainfall is the only source, which is renewable within the limits of variation.
It is clear from the discussion in Chapter IV and as well as Chapter VII that the annual rainfall are fairly dependable with the value of coefficient of variation ranging between 31.5 and 55.7%. The amount of monthly rainfall may vary considerably but the level variability of the annual mean rainfall is well within the acceptable limits. For most of the variables related to time, the variability of the long duration observations is always lower than short-term observations. This is evident from the fact that the variability values of the individual months reach as high as 313% as against 34% in case annual rainfall at Al Jerbah. Whether for agriculture or domestic needs water requirement have specific time restrictions. Though the sum total of availability may not be of questionable nature, the availability of the resource at the time of need is something, which has to be taken care of. The problem of management of resources basically centres on this issue, and that is more acute in case of resources like water, which are meant for fulfilling the basic needs of living forms. Its non-availability or availability with inadequate quantity and unacceptable quality will have adverse effect on the very existence of life form. Therefore the gross availability of the resource does not assure its adequacy. It is at this juncture the role of resources management becomes crucial. In the preceding two chapters the availability and need of the water as a resource have been analysed.

As for as the municipal water requirement is concerned, which has been estimated to be 552 MCM for Yemen as a whole, it may be stated that the water in adequate quantity is available provided that it is collected and utilized at places when it is received or in its immediate vicinity. One of the major problems of most of the irrigation dams is that, they have large distances between storage location, areas of collection and the actual areas of utilization. In Wadi Zabid though the dam and canal system are not a common feature, the divergent channels, particularly in Tihama plains also have the same problem. There are heavy losses of water during the transit. It has been mentioned in HWC report (1992) that the transit
losses are of the order of 1.5% per km. length. Therefore, if the water is collected at a place and utilized at different locations it is not going to be either economic or sometimes even feasible. Moreover, if the water is collected and utilized within reasonably short distances, the yield of water collected, out of which is received in the form of rainfall can be as high as 80-90%. Certainly it may depend on a number of factors such as topography, lithology, and climate. Hence, it is recommended that the water should be used in the areas where it is received and if it cannot be used immediately it should at least be made to contribute to ground water storage more in quantity than letting it get lost in the form of runoff. It is the ground water, which is a natural and most economic way of storing the rainwater.

In the previous chapter while quantifying the water requirement for municipal needs the area requirement for collecting the amount of water necessary for fulfilling the annual requirement of the population have been computed and are recorded in appendix (3A). However, as the data were related to ozlas the requirement for each and every village could not be computed. Hence, the area requirement values for villages are given as average area required per village for a given ozla. It may be noted from Appendix 3D, that the mean of area required in different years are of the order of 2.16 ha, 5.80 ha, 3.88 ha and 11.37 ha respectively. It is obvious that this value will be greater for villages with greater population and also those located in the areas where the rainfall is low.

Nonetheless, it may be observed that in case of as many as 224 numbers of Ozlas the mean area requirement for average villages is less than 5 ha in 1994. Getting 5 ha of an area, exclusively for municipal water requirement in a village should not be a problem. The following can be recommended for the rainwater harvesting for municipal water needs:

1. The area selected for this activity should be exclusively used for the same.
2. The area should be rimmed around by a trench of sufficient depth (over 1m) so that discharge from the surrounding areas, which are used for other purposes, do not enter the areas of water collection.

3. The total area of 1ha may be divided into 10 strips each of 10 m wide and 100 m long.

4. At the down slope end of such strips a grass bed may be maintained of 2-3 m in width with sufficient density to arrest silt in water. This should act as a natural sieve.

5. At the down slope end of this grass bed a shallow trench, preferably lined one or covered with PVC material should be provided for total length of 100 m, which should be at its terminal end, connected to a closed pipe having sufficient gradient for easy movement of water.

6. These pipes should move in the direction of slope of the land and terminate into a siltation tank.

7. The siltation tank can be of 9m$^3$ dimension, with a single outlet at height between 1m.

8. The outlet should be connected to storage tank of 5x5x5m.

The showers occurring in different parts of the basin have varied intensities. The maximum daily rainfall during the monsoon period has been reported to be of 47 mm at Zabid town station. Thus with 80% of the yield rate it is possible to collect 376 m$^3$ of water with the maximum rainfall condition from an area of 1 hectare. The total capacity of the storage tank is 125m$^3$, thus it would be storing water of order of 125,000 litres, which should be sufficient for the daily need of 2,500 persons at 50 litres/day rate. The details of the layout described are given in the fig 8.11. With the annual rainfall of the order of 180 mm and 80 % of the yield level, the water that can be collected will be equal to 1.44 million litres, which will be sufficient for the annual need of 80 persons from the area of Tihama plain, even in the year 2030 for which 50 litres per day per
Plan for rainwater harvesting Plot

100 metre

Trench outlets

Pipeline
Grass Beds
Pipeline
Grass Beds
Pipeline
Grass Beds
Pipeline
Grass Beds
Pipeline
Grass Beds
Pipeline
Grass Beds
Pipeline
Grass Beds
Pipeline
Grass Beds
Pipeline
Grass Beds
Pipeline
Grass Beds
Pipeline
Grass Beds
Pipeline
Grass Beds

Siltation Tank

Dimension 5x5x5

Storage Tank

Section

Runoff movement

Fig. 8.11
capita water requirement have been assumed. Depending on the size of the village in terms of its population the area requirement of most of the villages in Zabid district is less than 5 ha. However, in case of villages from ozlas like Al Ma‘asilah is as high. In such cases water from larger area may have to be collected and it is recommended that it may be collected at more than one place. Though the plan given in the diagram is in the form of a theoretical design, the details may be worked out according to the area requirements as per the size of the population as well as the terrain conditions. Except for Zabid district where the rainfall is quite low, in other districts like Al-Udain or Ibb, the area requirements are quite low. It may be seen from the appendix that the area requirement for collecting the water for annual need of the total population of the different ozlas in different districts varies considerably.

Such areas, which are to be reserved for the rainwater harvesting, should be as far as possible close to the village settlement, so that the water thus collected can be utilized without incurring transportation cost. These waters can safely be used for all other domestic needs except for the consumptive water utilization by human beings. For consumption utilization it may need some processing in terms of purification, however the total requirement of consumptive utilization is of the order of 15-20% of the total domestic utilization. Thus, by this method over 80-85% of the dependence on ground water for domestic need will be reduced and it can then be utilized for other needs.

Conclusions

The present work attempts to deal with one of the most important resource. The water is vital resource due to a variety of uses it is being put to. As a result of tremendously increasing demand it is becoming a saleable commodity. As a result, those who have access to the water are going to be dictating the terms for those who do not have easy access to it. Many a times it has been said that in near future disputes over water
between individuals or societies are going to be a cause of great concern. Therefore, managing available water resources and maintaining the quantitative and qualitative levels of available water is likely to prove major tasks to be preformed.

In preceding chapters attempts have been made to analyse the availability of water within Wadi Zabid area. In the process the first part of the present work has dealt with climatic conditions of the wadi area, which governs the process of rainfall occurrences. The analysis of quantity of water availability has been presented in chapter VI and assessment of requirements of water for municipal as well as agricultural needs has been discussed in chapter VII.

In the preceding pages of the present chapter some discussion on management of water resource as well as some techniques of watershed development and management have been presented. Certain measures, which can be taken through watershed programmes, have also been included in the later part of the discussion. Considering the analysis carried out the researcher would like to state certain conclusion:

- The available data on rainfall as well as flow conditions in Wadi Zabid basin clearly indicates that the high variability does not mean the absence of rainfall. As has already pointed out that there is no year during the available records of 30 years when any of the station has not received rainfall in period of one year. There are spatial and temporal variations in the amounts of rainfall. Hence it is a reason for attempting different policies in managing water resources of the region.
- Though the amounts are meagre, it is possible that the available water, if managed properly, can be sufficient to fulfil the demands of local population.
- The heavy dependence on groundwater for generations together is putting pressure on groundwater resources and the demand is increasing day by day. The extraction of the groundwater has
already gone beyond the normal annual discharge level. This is evident from the fact that the deepening of the wells is required and it has reached the deep-seated groundwater. This tendency if allowed further is likely to make the groundwater turn into a non-renewable resource.

- Considering the situation as described above it is clear that a new approach to the problem of water availability has to be thought of and the researcher seriously feels that the rainfall harvesting can be a better solution, rather the only solution under present situation.

For the present study municipal water as well as agricultural requirements formed subject matter. The municipal water requirement has to be taken into consideration on priority level as it directly relates to the consumptive water needs of human beings. Through the analysis of these requirements the researcher has been able to quantify and project the volume of water requirements and has also attempted to find a solution as how these waters can be made available for each of village and town from different ozlas in the wadi area. The total extent of area, which is required to be earmarked, for collecting the rain waters has also been found out.

It has been already pointed out that of 341 ozlas the area requirement is less than 10 ha in case of 30% of ozlas and for 90% of ozlas it is less than 50 ha. Of course this requirement relates to ozlas. The water requirements are to be fulfilled on the basis of villages and not ozlas. If one considers the average size of villages and their water requirements it may be seen that 320 ozlas out of 341 ozlas the area requirement is less than 5 ha. Villages from only 6 ozlas may have area requirement more than 10 ha. By 2030 the level of area requirement will certainly be enhanced as a result of increase in population as well as increase in levels of water consumption. The graphs shown in figure 8.12 represent the 1994 and 2030 S-VI conditions so far as the villagewise area requirement is concerned. It may be noted from the diagram that in 1994
Fig. 8.12

Villagewise area requirement (1994)

Villagewise area requirement (2030-S6)
for almost 94% of ozlas the villagewise area requirement was less than 2 ha. However, by 2030 the conditions will change and the area requirement will increase. Out of 341 ozlas the area requirement will still be less than 5 ha in case of 102 (about 30%) ozlas and it will be well below 10 ha in for as many as 60% of ozlas. Thus the municipal water requirement can be managed through the rainwater harvesting method by collecting the water from the area as less as 10 ha in most of the villages.

The problem of rainwater harvesting for municipal requirements will be more serious in case of urban centres. Barring a few centres in the Zabid basin most of the major cities the area requirements are going to be quite high. The area requirement runs in hundreds of hectares in case of some of the large centres and getting such areas near the cities where the land prices are on higher side will always become difficult. However, considering the present status of ground water resources though not in totality, at least sizable proportion of the demand will have to be fulfilled through surface water collection. The vacant lands around cities, generally under the direct jurisdiction of the local governments can be utilized for such water collections.

As far as the water requirements for agriculture sector is considered it may be noted that the requirements have to be thought of with reference to the crop that is grown in the region and hence it would differ from crop to crop even in the same rainfall zones. The water requirement of the crops and irrigation water needs have been quantified and presented in the last chapter. Providing for the irrigation water needs of specific crops in totality is not always possible and only a few crops can bear the cost of water. Moreover the agrarian lands cannot be considered in isolation and one needs to consider the entire area and the development of the same. In light of this the watershed development programmes become the possible solutions for the overall development. The rain fed agriculture still and would continue to be the major activity and hence attempts must be made
to ensure that the rain fed agricultural activity is well supported by such efforts.

Recommendations

Based on the certain facts which surfaced out quite evidently during the course of the present studies and the conclusions reached the researcher would like to make certain recommendations pertaining to the problems faced as well as some of the solutions thought of during this work. Each of the recommendation made is followed by some justification.

Availability of data

- It is recommended that the rain gauge station Fulieh that was in operation some time back up to 1974 year may be re-established and a few more may be stated in western and central zone.

The rainfall data that becomes the basic input for the study of any water related management problem has to be adequate and the density of the rain gauge stations needs to be increased. This is particularly so in case of the central zone of the basin. There does not exit any station in the north central part of the basin.

Municipal water requirement

- The collection water through the rainwater harvesting methods as suggested from the specific area defined for a few urban centres should be initiated on experimental basis. The problem of domestic water requirements from rural areas can be addressed through the watershed programmes and hence need not separately considered.

The collection of surface water is now becoming a dependable and rather the only source for municipal water requirement. However the feasibility of the same and that of managing such resources at individual settlement level needs to be tested. Therefore it is being suggested that such efforts be initiated on experimental basis in different rainfall zone.
Watershed development programme

- The watershed development and management is a multifaceted programme involving a variety of aspects. The micro watersheds from different zones need to be selected and the programmes initiated. The watershed development programmes in all the zones for should take into account the domestic water needs as one of the essential component of the programme besides the normal aspects of soil erosion, conservation of water resources as well as the natural vegetation. However considering the peculiarities of each zone though the basic principles may be same the purposes can differ considerably. Hence the recommendations related to the watershed programme are given separately for East, Central and Western zones.

- The Eastern Zone. The nature of terrain and the rainfall pattern in the area is such that the programme has to be centred more around the soil erosion and conservation than any other purpose. The steep slopes and heavy showers are the major problems in the region. Due to which the losses by erosion are tremendous. The availability of water is not such a serious problem as in case of the other two zones. Hence checking erosion through rigorous line treatment measures and ensuring maintenance of the flow in wadi channels for longer period should be emphasised in the programme.

- The Central zone. The most difficult area to manage in the basin is the central zone. This is because of the fact that the region suffers from the adversaries related to both the rainfall and relief. Besides giving due emphasis on the domestic water
requirements the programme in the central zone need to address to the problems of inadequacy of water availability for agricultural sector. The region needs to be treated with large number of farm ponds, percolation pits, refill trenches, hill slope runoff divergence channels and similar techniques so that the valley flats particularly in the form of higher terraces and pediment surfaces, which have good potential for agricultural extensions, can be tapped. The lower hill slopes particularly can be turned into good pasture lands if measures like area treatment in the form of continuous contour trenches are taken along with committed efforts of introducing high yielding grass varieties between the contour trenches.

➢ The Western Zone or Tihama Plains. The problems of Tihama plains are altogether different from those of the other two zones discussed above. The plains have good potentials for agriculture and hence this zone is being considered as the granary of Yemen. Hence the rainwater harvesting for rural as well as urban areas for managing the municipal water requirement is recommended.

- The relief and drainage conditions of this part of the basin are such that one does not find a well defined watershed. This is mainly because due to low rainfall and high porosity of the sand of the plain the surface drainage is very poor, if any. It is in this region one may have to think more in terms of rainwater harvesting as the solution for a number of problems than the normal watershed development. However the region suffers from the availability of surface water. The dependable rainfall is too low and hence rain fed agriculture is almost absent. The agrarian activity has to depend on the irrigation either surface water in the form of wadi irrigation ground water. The
wadi courses start getting dried out once they descend down the Plains and hardly have any discharges reaching their final destination at Red Sea. Except for the area in the vicinity of the wadi courses surface irrigation in the form flood irrigation from wadis is not possible. The areas between the wadi courses and the regions along the scarp piedmont zone are the most severely affected zone.

Cultivable Areas.

- *It is recommended that the cultivable area in the wadi basin should be maintained to the maximum possible extent.*

The area under cultivation in Yemen or particularly the wadi Zabid is relatively too low and the annual coverage of the same is supposed to vary following the vagaries of rainfall. The variations in the area under agriculture from year to year appear to follow the vagaries of rainfall and in many years the area gets reduced to almost 30% of the total cultivable areas adversely affecting the food production. With the introduction of the programme of watershed management as well as the rainwater harvesting this should not be difficult. The researcher believes that this can be a good and at the same time an achievable target.

In order to achieve the desired results it would be desirable that the efforts are made by the government to initiate the programme of watershed development and management at micro level and also the rainwater harvesting programme either part of the watershed programme or as separate efforts particularly for the Tihama Plains. For this it would be necessary to make people aware about the need of such programmes and its utility. This work can be assigned to the NGOs.