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CHRISTIAN RELIEF & DEVELOPMENT ASSOCIATION

Training Programme
On
Water Harvesting Techniques

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March 27th to April 1st, 1995

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I. Perspective of Agricultural Water Requirements in Ethiopia

Agriculture is the back-bone of the Ethiopian economy. The sector provides a livelihood for over 80% of the country's population and is responsible for about 90% of its export. The performance of this sector is thus critically important for development in Ethiopia. The agricultural sector is dominated by cropping and livestock with forestry accounting for less than 2% of the value of the sector.

Agricultural production and productivity is governed by environmental factors. Of these climate plays a detrimental role in Ethiopias agriculture. For example, because of climatic limitation, almost all rainfed cropping* is within the highland area above 1500 m.a.s.l. which constitutes only 43% of the country's surface area.

In order to develop the sector, therefore, it would be essential to asses the various requirements of the sector and develop strategies to ensure that the requirements are met.

This paper is an attempt to put into perspective one of the most important requirements of the sector, water, in the country. It should be born in mind that water requirements in agriculture should also consider the community who are engaged in the sector in one way or another. However, it is beyond the scope fo this paper to treat all the sub-sectors and community requirement. The paper, therefore, will in the main focus on crops.

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RAINFALL AMOUNT

The amount of water that is available for agriculture, domestic and municipal purpose, power, etc. is primarily determined by the amount of water that reaches the surface. This water comes directly from precipitation. It is thus vital to review the distribution of mean annual rainfall of the country.

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*Less than 2-3% of the estimated area under crop is irrigated while the remaining is rainfed.

The distribution of mean annual rainfall amount over the country is shown in figure 1. One can easily observe quite considerable variation in the figure. The highest annual rainfall occurs in the South-Western part and inland mountains of the highlands. On the other hand, most of the eastern parts have an arid climate. The observed regional variation is determined by the direction of moisture bearing seasonal air current and elevation.

The distribution of the mean annual rainfall does not show the variability in time. This information is important as it gives an indication on the reliability of rainfall. Extreme variation in time exists, but in general rainfall variability is inversely related to amount of rainfall. Thus rainfall variability is lower where amounts are high and higher where amounts are low.

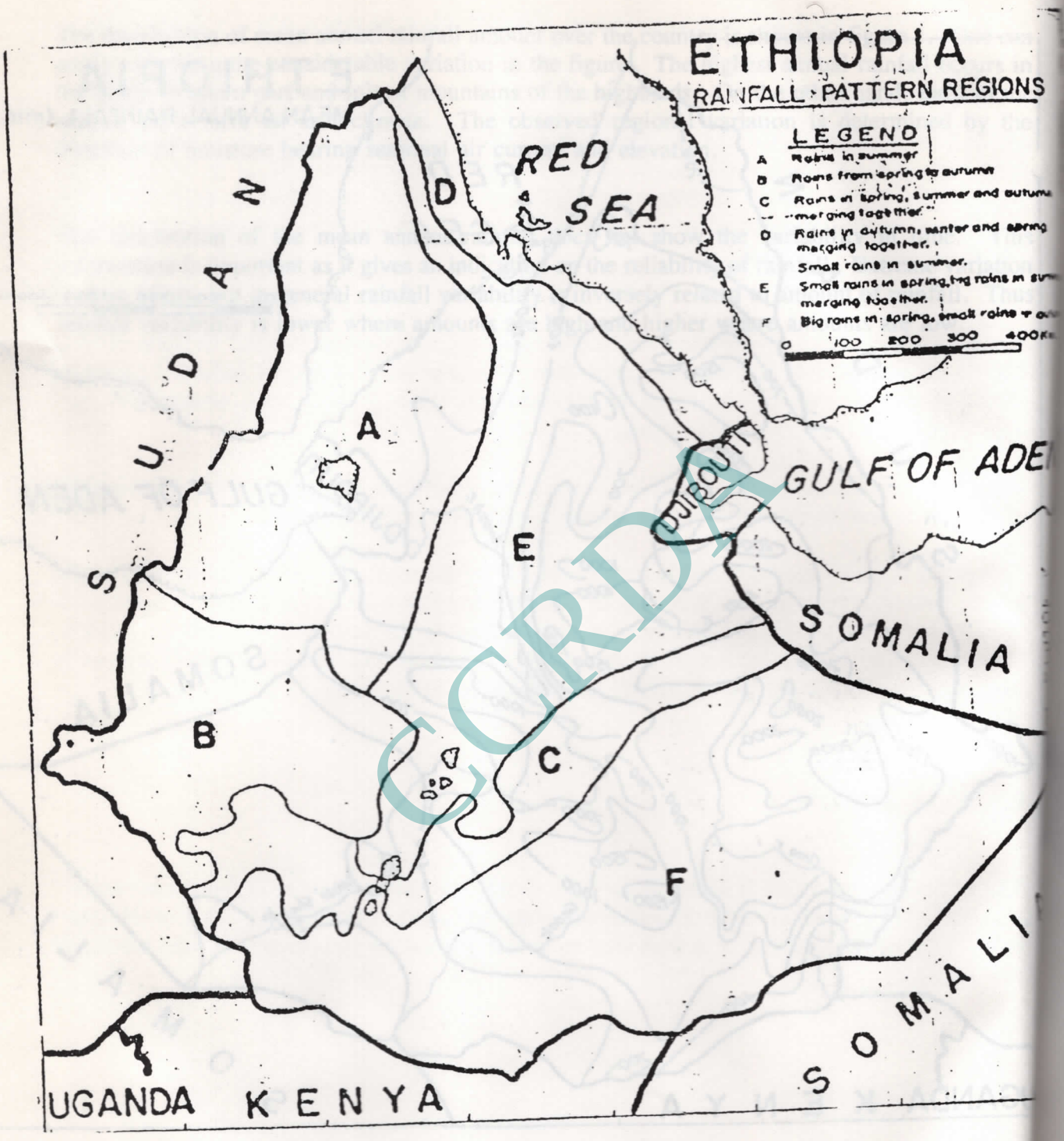
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Fig. 1 Mean annual rainfall



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Fig. 2 Rainfall pattern regions



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RAINFALL PATTERN REGIONS

Inorder to divide the country into homogeneous areas with similar rainfall, rainfall pattern regions are established. This was done by grouping together stations without significant difference in their mean rainfall patterns. These were further grouped into six vast rainfall pattern regions of the highest order and are shown is figure 2. The characteristics of each region are summarized below:

A. Rainfall regions with rain from March - October.
B. Rainfall regions with rain from March - September.
C. Rainfall regions with small rains from March - April and big rains from June - September.
D. Rainfall regions with rain from December - February. Very few rain showers in summer.
E. Rainfall regions with rain from March - August.
F. Rainfall regions with rain from March - May and from September - November.

WATER BUDGET

Total amount of rainfall does not indicate the actual amount of water which is available for agricultural and other purposes. It is the amount that is left after the evapotranspiration requirement is satisfied which is important. Thus defining moisture regions is more revealing as far as assessing water requirement is concerned.

Inorder to define moisture regions, Potential Evapotranspiration (PET) has to be calculated and its distribution determined. This was done for the country using empirical methods.

Once PET is estimated, the difference between rainfall amount and PET is calculated for each month. If the amount of rainfall is higher, the month is recorded as water surplus and if it is lower, it is recorded as water deficit (a maximum soil field capacity of 100 mm is taken into account).

The moisture regions are based on moisture indices determined by working out monthly water surpluses and deficiencies. The moisture index is defines as:

$$IM = (100\ S - 60\ D) / PET$$

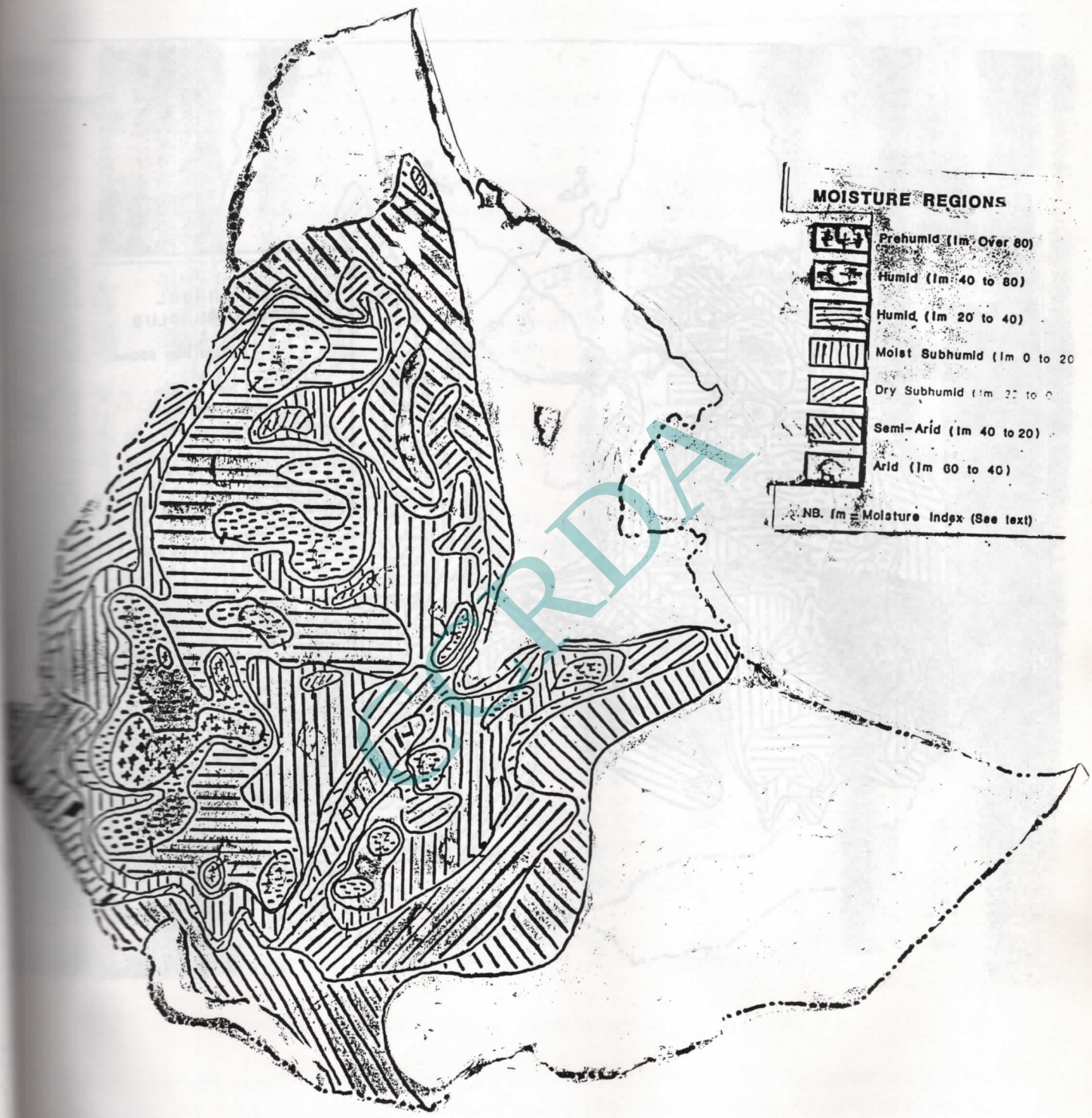
Where S is surplus and D is deficiency.

The index implies that where rainfall is always equal to PET, there is neither water surplus nor deficiency and the climate is neither humid nor arid. As deficiency increases the climate

becomes more arid and as surplus increases it becomes more humid.

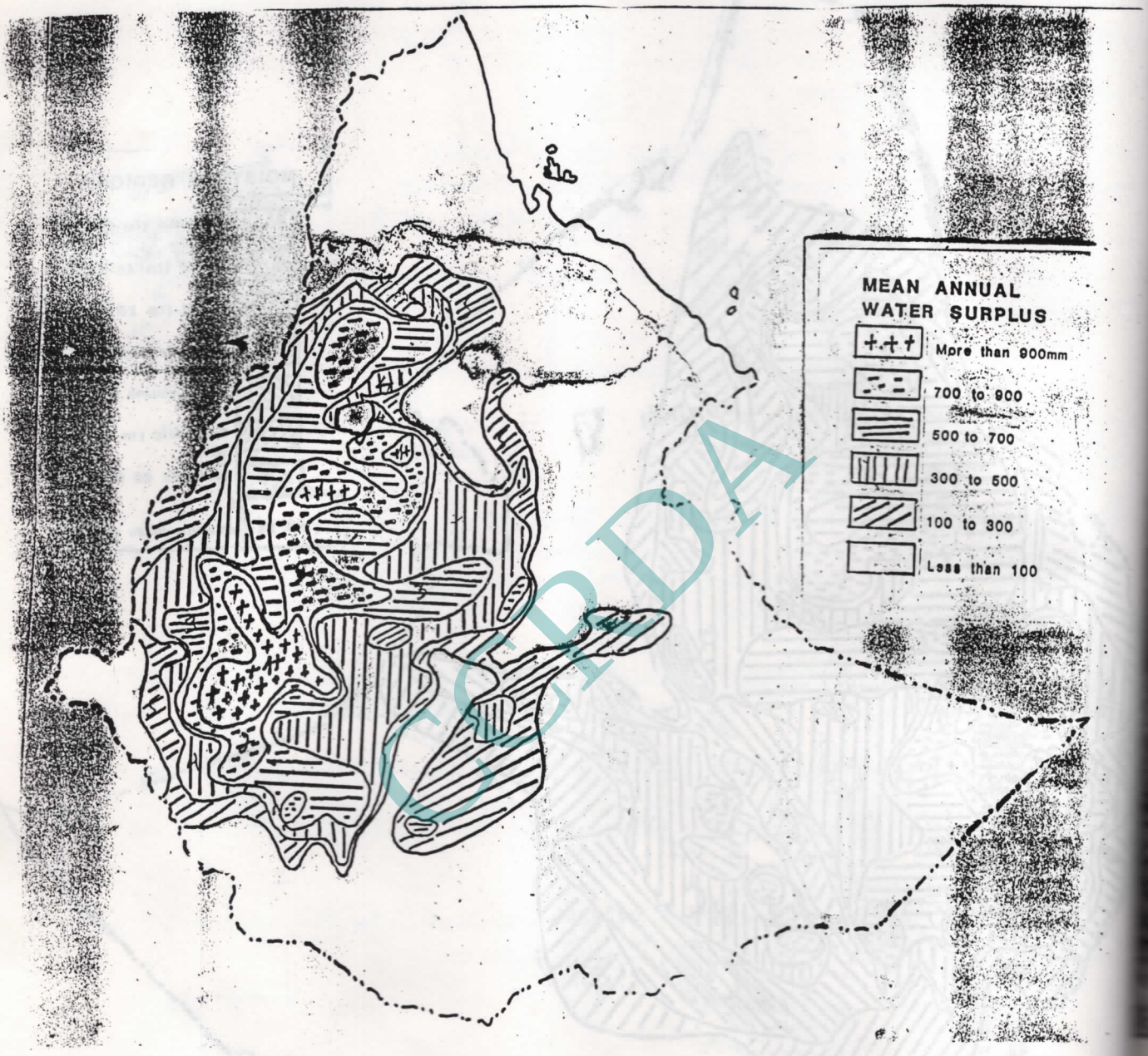
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Fig. 3 Moisture regions



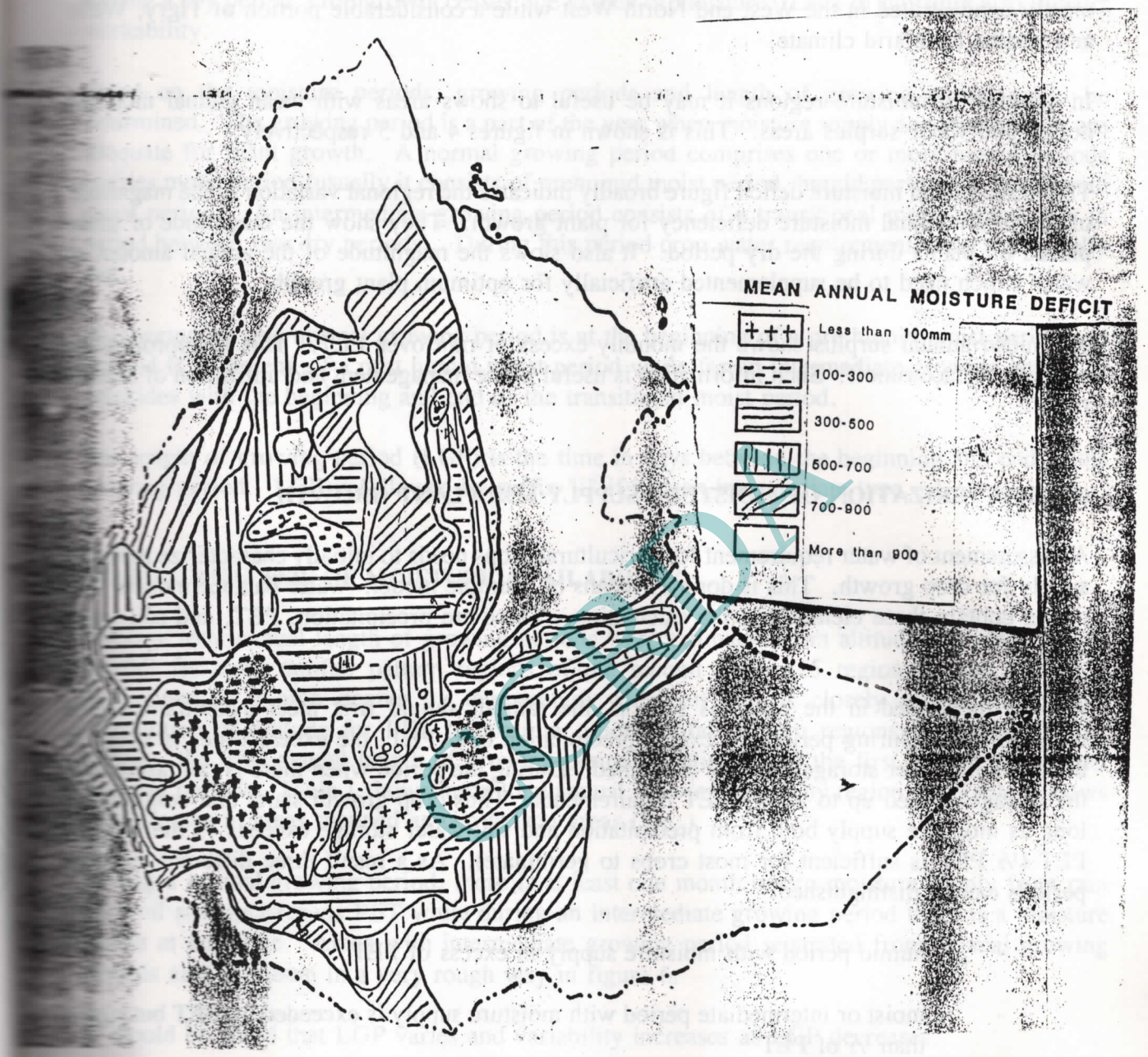
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Fig. 4 Mean annual water surplus



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Fig. 5 Mean annual water deficit



Accordingly 7 moisture regions are defined as shown in figure 3. The figure shows the relative magnitude of moisture availability for plant growth and other purposes. Humid regions are mostly concentrated in the West and North West while a considerable portion of Tigry, Wello and Harrar have arid climate.

In addition to moisture regions it may be useful to shows areas with mean annual moisture deficit and water surplus areas. This is shown in figures 4 and 5 respectively.

The mean annual moisture deficit figure broadly indicates the regional variation in the magnitude of the mean annual moisture deficiency for plant growth. They show the magnitude of stress placed on plants during the dry period. It also slows the magnitude of the annual amount of water which need to be supplemented artificially for optimum plant growth.

The mean annual surplus shows the monthly excess of rain over PET. This is appropriately equal to surface runoff. Such information is useful in the management and utilization of surface runoff.

CHARACTERIZATION OF MOISTURE SUPPLY FOR PLANT GROWTH

An assessment of water requirement for agricultural crops needs to initially characterize moisture supply for crop growth. This is done by means of a simple model: water balance model. The model contain three elements in the calculation. These are precipitation, PET, and soil water storage.

As was mentioned in the previous section, the rainfall should first meet evapotranspiration requirements. During periods of excess precipitation over PET, the excess water is stored in the soil until water storage capacity is reached. During the period when there is rainfall deficit, the storage is used up to satisfy PET requirements. Thus crop growth starts and continues as long as moisture supply both from precipitation and soil water storage exceeds ½ the value of PET (½ PET is sufficient for most crops to germinate). As a result three different moisture periods can be distinguished:-

- humid period with moisture supply in excess of PET
- moist or intermediate period with moisture supply is exceeded by PET but higher than ½ of PET
- dry period during where moisture supply is below ½ of PET.

During the humid period plant growth is not hampered by lack of moisture. However, lack of air could temporarily inhabit growth. Moreover, working in the field could be very difficult and harvesting during this period could affect the quality.

During a moist period, crop growth could be sustained although under stress from insufficient moisture. On the other hand field work and harvesting are more convenient.

During a dry period, crop growth ceases due to lack of moisture. Lack of moisture also impairs workability.

Based on the moisture periods, growing periods and length of growing period could be determined. The growing period is a part of the year when moisture supply and temperature are adequate for plant growth. A normal growing period comprises one or more humid periods besides moist period (usually it consists of prehumid moist period, humid period and post humid moist period). An intermediate growing period consists of a transitional moist period only (a period between two dry periods). During this period crop water requirements may not be fully met.

The beginning of a normal growing period is at the beginning of a pre humid moist period and the end is at the end of a post humid moist period while for an intermediate growing period, it coincides with the beginning and end of the transitional moist period.

The length of growing period (LGP) is the time in days between the beginning and end of the growing period. LGP is followed by suffix "i" if it is an intermediate type.

SPATIAL ANALYSIS OF MOISTURE AVAILABILITY

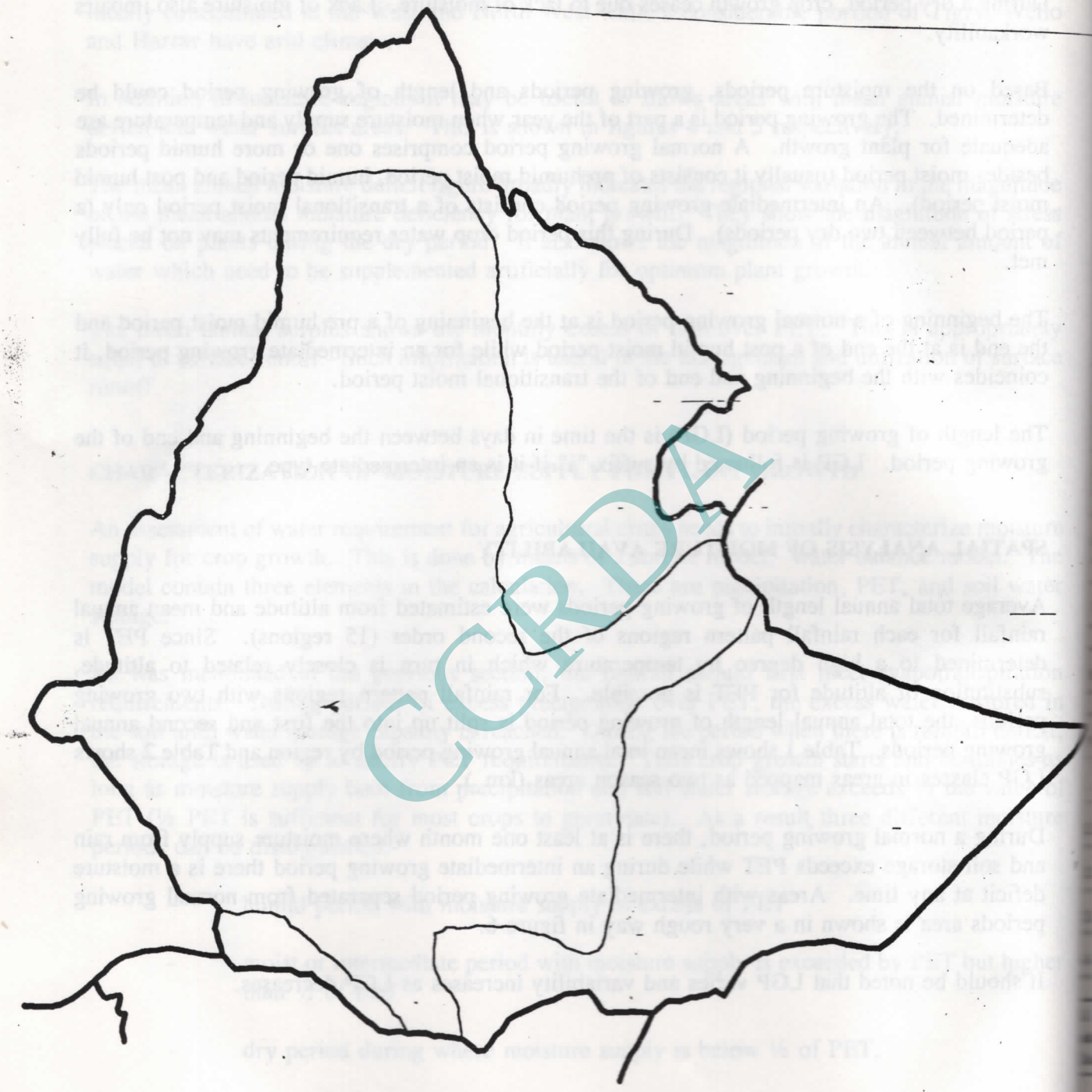
Average total annual length of growing periods were estimated from altitude and mean annual rainfall for each rainfall pattern regions of the second order (15 regions). Since PET is determined to a high degree by temperature which in turn is closely related to altitude, substitution of altitude for PET is possible. For rainfall pattern regions with two growing periods, the total annual length of growing period is split up into the first and second annual growing periods. Table 1 shows mean total annual growing period by region and Table 2 shows LGP classes in areas mapped as two season areas (km_).

During a normal growing period, there is at least one month where moisture supply from rain and soil storage exceeds PET while during an intermediate growing period there is a moisture deficit at any time. Areas with intermediate growing period separated from normal growing periods area is shown in a very rough way in figure 6.

It should be noted that LGP varies and variability increases as LGP decreases.

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Fig. 6 Areas with intermediate and normal growing periods



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Table 1. Mean total annual growing periods by LGP classes and region

ETHIOPIA: MEAN TOTAL ANNUAL LGP (km^2)

	LGP-type	Arsi	Bale	Eritrea	Gamo Gofa	Gojam	Gonder	Harerge	Ilubabor	Kefa	Shewa	Sidamo	Tigray	Welega	Welo	Ethiopia
	n.a.	-	-	24 361	-	-	-	5 306	-	-	-	-	17 529	-	23 771	70 967
	t 1/	-	30 236	8	2 313	-	-	40 121	-	-	-	1 196	-	-	-	73 874
	i	-	-	22 625	-	-	-	15 798	-	-	-	-	6 277	-	9 057	53 757
	t 1/	-	15 981	1 035	1 170	-	-	70 212	-	-	-	2 232	-	-	-	90 630
	n	-	-	176	-	-	-	-	-	-	-	-	-	-	-	176
	i	-	-	18 057	-	-	-	10 652	-	-	1 465	-	5 000	-	2 746	37 920
	t 1/	-	5 242	179	1 397	-	-	24 165	-	-	-	15 357	-	-	39	46 379
	n	-	-	1 319	-	-	-	1 128	-	-	1 121	-	-	-	-	3 568
	i	-	-	8 735	-	-	-	1 575	-	-	805	-	2 303	-	1 521	14 939
	t 1/	-	4 114	224	1 625	-	-	13 765	-	-	-	13 796	302	-	336	34 162
	n	41	-	3 225	-	-	-	4 519	-	-	1 644	-	580	-	342	10 351
	i	-	-	7 703	-	-	-	-	-	-	8	-	1 477	-	369	9 557
	t 1/	-	5 739	249	1 057	-	-	8 451	-	-	-	7 650	344	-	356	23 846
	n	204	-	18 146	-	-	75	4 002	-	-	1 302	-	10 995	-	4 347	39 071
	i	-	-	5 678	-	-	-	62	-	-	-	-	637	-	-	6 377
	t 1/	-	5 705	1 054	1 625	-	-	10 348	-	80	-	9 115	833	-	919	29 679
	n	204	-	6 312	-	6 177	20 361	2 035	-	6	2 806	-	15 971	2 785	9 718	66 357
	i	-	-	-	-	-	-	2 458	-	-	-	-	-	-	-	2 458
	t 1/	-	8 189	133	1 292	-	-	2 245	-	1 349	344	12 867	1 264	-	1 951	29 634
	n	408	-	-	196	11 607	21 239	3 876	-	357	14 809	227	2 377	2 940	10 531	68 561
	i	-	193	-	-	-	-	5 475	-	-	-	-	-	-	-	5 668
	t 1/	-	7 790	117	1 668	-	-	117	-	833	895	12 139	203	-	3 941	27 702
	n	3 230	1 376	-	226	13 786	15 127	6 922	6 835	674	8 691	1 806	-	6 818	1 881	67 376
	i	-	664	-	-	-	-	4 118	-	-	-	-	-	-	-	4 782
	t 1/	-	12 272	139	1 975	-	-	-	-	754	2 892	6 003	119	-	4 841	28 995
	n	5 872	716	-	302	20 699	15 401	10 418	12 496	6 920	19 932	938	-	24 878	-	118 577
	[illegible]	-	[illegible]	127	2 094	-	-	-	-	471	3 983	7 579	-	-	2 762	23 406
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	t 1/	-	3 212	136	3 641	-	-	-	-	120	3 104	9 575	-	-	1 612	21 408
	n	3 254	1 863	-	1 552	4 358	-	2 007	7 929	7 701	3 179	2 962	-	7 303	-	42 106
	t 1/	-	915	222	1 295	-	-	-	-	199	950	1 671	-	-	-	5 252
	n	5 422	5 060	-	4 159	-	-	1 253	4 841	10 537	-	2 263	-	-	-	33 535
	t 1/	-	431	82	495	-	-	-	-	160	574	782	-	-	-	2 524
	n	1 151	2 800	-	8 833	-	-	-	7 191	10 820	-	3 036	-	-	-	33 831
	t 1/	-	-	-	-	-	-	-	-	-	382	32	-	-	-	414
	n	514	2 305	-	2 749	-	-	-	440	3 481	-	4 144	-	-	-	13 633
	t 1/	-	-	-	-	-	-	-	-	-	550	-	-	-	-	550
	n	24 176	16 543	29 178	18 593	62 878	74 508	43 158	49 194	47 270	67 914	17 391	29 923	70 930	26 819	578 477
	i	-	857	62 797	-	-	-	40 138	-	-	2 278	-	15 694	-	13 693	135 457
	t 1/	-	75 982	3 691	19 334	-	-	129 303	-	3 965	13 676	98 800	3 065	-	16 758	364 574

1/ for lengths of first and second annual growing periods

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Table 2 LGP classes mapped as two season areas

ETHIOPIA: LGP-CLASSES IN AREAS MAPPED AS TWO-SEASON-A[illegible]AS (km^2)

Major rainy season 1/

LGP-class	LGP-type	Bale	Eritrea	Gamo Gofa	Harerge	Kefa	Shewa	Sidamo	[illegible]gray	Welo	Ethiopia
0	n.a.	30 236	888	2 313	40 121	-	-	1 196	-	-	74 754
1	i	22 124	966	592	89 370	-	-	23 877	45	268	137 242
2	i	8 368	226	2 369	32 839	-	-	7 219	332	335	51 688
3	n	3 092	34	-	-	-	-	5 567	-	-	8 693
"	i	3 107	256	2 699	4 479	2 305	-	12 780	365	315	26 306
4	n	8 494	166	725	-	-	-	11 485	420	324	21 614
"	i	766	53	3 451	1 322	792	-	2 325	183	243	9 135
5	n	19 660	128	1 833	-	249	729	16 033	625	1 977	41 234
"	i	1 203	-	1 328	861	256	-	1 969	-	-	5 617
6	n	7 114	168	1 780	-	180	1 045	13 759	823	7 102	31 971
"	i	802	-	1 281	433	-	-	1 299	-	-	3 815
7	n	1 251	153	2 153	-	108	8 874	2 491	271	5 885	21 186
"	i	-	-	1 040	-	-	-	-	-	-	1 040
8	n	-	211	83	-	75	3 028	-	-	307	3 704
9	n	-	356	-	-	-	-	-	-	-	356
10	n	-	92	-	-	-	-	-	-	-	92
Total (excluding LGP class 0)	n	39 611	1 308	6 574	-	612	13 676	49 334	139	15 597	128 851
	i	36 370	1 501	12 760	129 303	3 353	-	49 468	925	1 161	234 843

Minor rainy season 2/

LGP-class	LGP-type	Bale	Eritrea	Gamo Gofa	Harerge	Kefa	Shewa	Sidamo	[illegible]gray	Welo	Ethiopia
0	n.a.	46 549	1 950	3 381	120 252	-	-	9 407	-	-	181 539
1	i	14 428	266	6 355	40 186	1 557	720	34 684	624	4 708	104 528
2	n	-	-	-	-	-	-	960	-	-	960
"	i	12 760	208	2 241	4 661	908	2 754	14 223	287	3 683	42 725
3	n	-	-	-	-	-	-	3 040	-	474	3 514
"	i	6 812	259	1 786	3 054	746	7 464	10 502	154	4 055	34 832
4	n	6 518	76	247	-	-	196	3 457	-	998	11 492
"	i	4 050	77	4 424	873	278	926	5 426	-	1 240	17 294
5	n	13 293	863	-	-	-	369	12 238	-	1 024	27 787
"	i	733	-	3 033	399	267	126	2 065	-	578	7 201
6	n	1 074	-	-	-	-	334	3 995	-	-	5 403
"	i	-	-	180	-	209	-	-	-	-	389
7	n	-	-	-	-	-	239	-	-	-	239
8	n	-	-	-	-	-	550	-	-	-	550
Total (excluding LGP class 0)	n	20 885	939	247	-	-	1 688	23 690	-	2 496	49 954
	i	38 783	810	18 019	49 173	3 965	11 990	66 900	065	14 263	206 968

1/ Spring in Bale, Gamo Gofa, Harerge, Kefa, and Sidamo;
Summer in Shewa, Tigray, and Welo;
Winter in Eritrea.

2/ Spring in Shewa, Tigray, and Welo;
Summer in Eritrea;
Autumn in Bale, Gamo Gofa, Harerge, Kefa, and Sidamo.

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II. Strategies and methods for improving soil moisture availability and use

In part I of the paper an attempt was made to put in perspective the agricultural water requirements in Ethiopia. Most of the northern, eastern and south eastern part of the country have high water deficit of over 500 mm a year (see fig 5). Moisture in the soil is one of the main natural elements of plant growth. Thus agricultural development is constrained in these areas because of lack of adequate moisture. As a result almost all of the agricultural activity is concentrated in the highland areas. Even some of these areas are experiencing frequent moisture deficit during the cropping season despite sufficient total amount of rainfall. In addition to the rainfall pattern being erratic long history of cultivation has resulted in degraded soil and there by undermined the water storage capacity of the soils of these areas.

The long history of cultivation coupled with increased population has resulted in fundamental changes in the production system. As land that is easily developed is already exploited, agricultural land is expanding into marginal lands subject to frequent crop failure, primarily because of inadequate moisture, to relieve population pressure and to provide more food.

The intensified landuse under the existing system, however, can not be sustainable because this will result in increased runoff, soil erosion, reduced ground water discharge and flooding of agricultural lands down stream. Higher soil erosion with further reduction of storage capacity and floods in the lowlands must be expected. In future, intensified and inappropriate landuse will lead to desertification with more recurrent crop failure and shortage of drinking water.

Lack of appropriate water conservation technique for rainfed agriculture results in a loss of precious water. The consequence of mismanaged rainwater are recurrent crop failure and problems of environmental degradation leading to declining productivity. On the other hand, through proper management of water, improvement in moisture availability and use could be achieved making it possible to bring to an optimum one of the main elements to plant growth. This also permits the provision of optimum conditions for fertilizer use, introduction of highly responsive seeds and advanced tillage techniques and practices. It is therefore necessary to introduce a scheme of resource management combining effective conservation and utilization of soil and water with crop production system that maintains productivity and assure dependable harvest.

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Strategies

As we saw in the simple water balance model (part I of this paper), moisture stress occurs when moisture supply to a crop fails to meet the demand of the crop during the growing period (evapotranspiration requirement). The key to overcome the moisture stress, i.e. improving the moisture availability and use, is maintaining the balance between the demand and supply. The strategy to maintain the balance therefore is to introduce practices where by either the supply is increased or the demand is reduced.

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Improvement in moisture availability could be achieved in several ways, depending on environmental condition of the area. In areas where the total amount of rainfall is adequate but not well distributed during the cropping season, the excess water could be conserved so that it can be utilized during periods when there is scarcity. This can be done either by conserving water insitu through increasing soil water holding capacity and increased infiltration rate or retaining the water above the surface by means of artificial barrier. When this is not enough runoff water could also be collected from areas far away and channelled to crop fields.

In semi arid conditions, the primary development strategy must focus on conserving as much rain water as possible in the deep soils with a high storage capacity and on using the stored water in the most efficient way for production.

Irrigation is also a means to influence the availability of water to plants by bridging drought periods. In some areas crops can only grow under irrigation.

Similarly evapotranspiration requirements can be reduced in several ways. Use of artificial environment under plastic or other type of cover, spraying crops with transpiration reducing agents, breeding varieties having low water requirements are some of the techniques that minimize water use and thus improve moisture availability.

Methods

Several methods have been proposed in the literature that assist in improving moisture availability and use. Here the most common ones are briefly discussed. It is taken for granted that other papers that follow will elaborate most of the techniques listed here interms of conditions under which the methods are useful, design, construction, maintenance and other details. Therefore here a very general description will be made.

The various moisture conserving methods available are here grouped into two: water management and water spreading methods.

1. Managing water on crop land

Moisture availability and use can be increased through proper management of water. Several techniques are available for managing water for efficient use. Some of these will be briefly mentioned.

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a. Farming methods

i. Conservation tillage

This method includes reduced tillage, minimum tillage, no-till, direct drill, mulch tillage, stubble mulch farming, trash framing, strip tillage.

The principle in this method is to maximize cover by returning crop residues, and not inverting the top soil, and by maintaining high crop density.

This practice is primarily aimed at soil conservation and is applied mainly in mechanized high production farming. Moreover possible disadvantages of this practice in semi arid conditions are:

- Crop residues may be of value as feed for livestock;
- It is not easy to plant through surface mulch for animal drawn plants;
- dense planting may be incompatible with the well tested strategy of using low plant population to suit low moisture availability.

ii. Deep tillage

This will increase the rooting depth thereby increasing amount of moisture available to crop roots.

Ripping or subsoiling can be beneficial either to increase the porosity of the soil, or to break a pan which is reducing permeability. The deep placement of fertilizer can also be used to encourage more rooting at depth.

This technique requires greater draft power which may not be available under our condition.

iii. Conservation farming

Some of the techniques under this method include:

- Farming on a grade, cultivation and planting are done on a gentle gradient which encourages infiltration but permits run-off at low velocity. This may also be combined with simple practices that encourage infiltration such as returning crop residue.

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- Strip cropping: will reduce runoff to acceptable limits on gentle slopes without any banks or drains.

- Fallowing: this is used to build up soil moisture before sowing in a next season which receives only barley adequate rainfall. Unless the fallow is completely kept free of weeds, it is not that useful. Moreover bimodal rainfall patter is more attractive to this technique.
- Mixed cropping and intercropping: a combination of different planting times and different length of growing periods allows mid season changes of plan according to the rain in the early part of the season. This is a widely applied traditional technique.

- Surface mulching: It improves infiltration and will beneficially reduce soil temperature. Improvement of infiltration is achieved in three ways. First mulches absorb much of the raindrop energy and reduces the effect of splash which is the main reason for sealing of the soil surface resulting in a reduction of infiltration rate . Secondly, mulch initiates biological activity of the soil fauna keeping the soil loose with many micropores. Thirdly, the roughness of the mulch surface decreases the velocity of runoff water.
- Timeliness: This is especially important where rainfall is erratic. Yields can be effected by planting or cultivating at the right time.

- Improved water use efficiency: This involves the selection of crop varieties suitable for arid or semi arid conditions. Such characteristics as short growing varieties, drought resistance or draught avoidance (ability of the plant to adjust to growth habit according to moisture availability).

b. Runoff farming

i. Ridging and tied ridging

By planting on the contour, tillage, weeding, and other operations cause the formation of small banks and ridges that impede the down slope flow of water, and improve infiltration. The surface storage can be enhanced by deliberately building up continuous ridges.

To avoid the risk of over topping during heavy storms, tied ridges on grade will be useful.

ii. Broad bed and furrow system

This will encourage moisture storage in the soil profile. The possibility of double cropping is also increased by inter cropping or sequential (relay) cropping. The large water storage capacity of the soil supports growth more easily during the subsequent dry season.

Other advantages include safe drainage and workability.

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iii. **Conservation bench terraces:** the method of "rainfall multiplier" where runoff from an uncultivated part of the land is diverted onto a cultivated part, thus giving the benefit of more water than it recieves as rain, is used in this technique.

When designing such method, it is important to get the best ratio of the area yielding runoff to the area receiving runon.

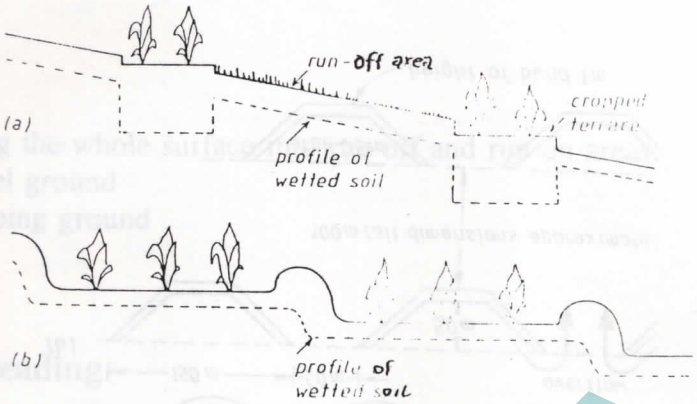
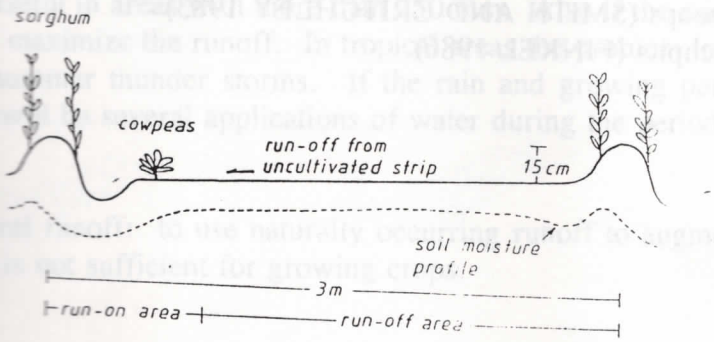


Fig. 7 The effect of conservation bench terraces (CBT)
a) increased available soil moisture under CBTs
b) level ench terraces do not have a rainfall multiplier effect like CBTs

iv. **Contour furrows:** The same principle as CBT applies, i.e., to collect runoff from the catchment to improve soil moisture on the cropped land.



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Fig.8 Improved soil moisture from contour bunds (SMITH and CRITCHLEY 1983)

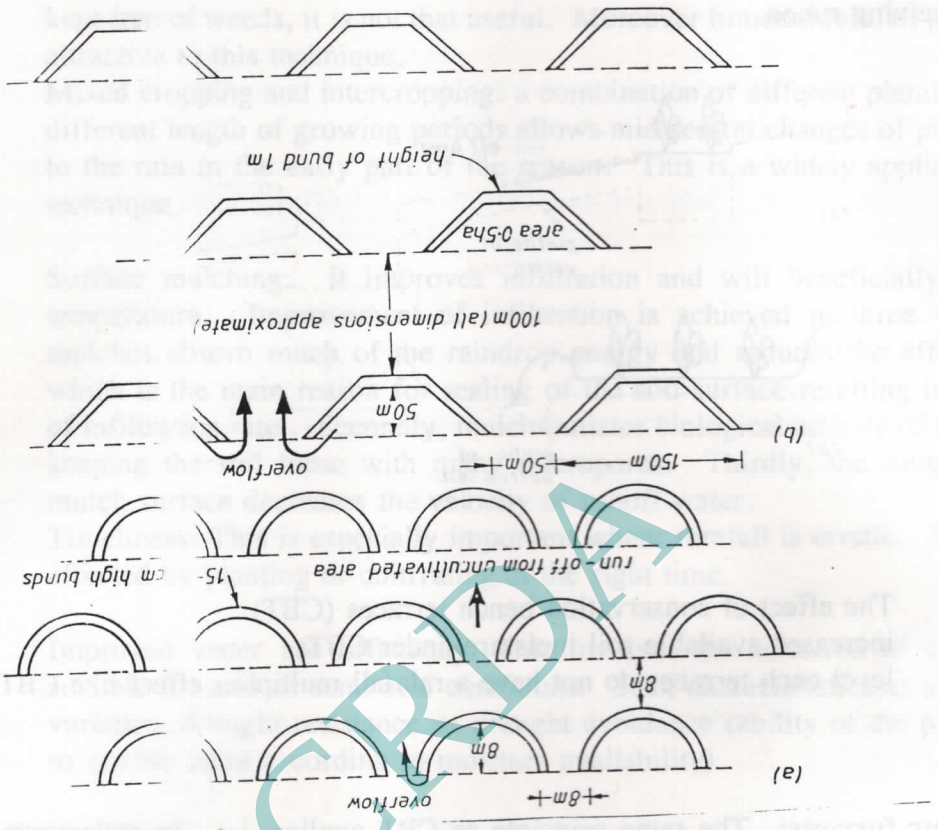


Fig. 9 Simple structures to retain surface run-off
a) semi-circular hoops (SMITH AND CRITCHLEY 1983)
b) trapezoidal catchpits (FINKEL 1986)

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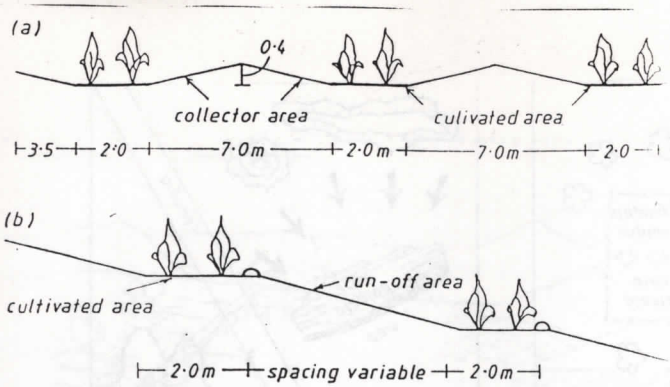


Fig. 10 Shaping the whole surface into run-off and run-on areas:
a) on level ground
b) on sloping ground

2. Water spreading

a) Flood water farming and inundation

This practice encomposes a wide variety of methods that suit different conditions. The methods are influenced in many ways by soil type. For example clay soils have low infiltration rates and high moisture storage capacity and so are suitable for deep flooding for subsequent cropping while sandy soils have quicker infiltration rate but low storage. In this soils diversion is a more suitable scheme. On the other hand deep soils can absorb large amount of water while shallow soils don't and may need overflow outlets to avoid drowning the crop.

Other factors that influence (affect) the method are climate and probability of high intensity rain. If the climate is characterized by low evaporation, runoff farming with mean annual rainfall as far as 100 mm is possible while in tropical summer rain and high evaporation rate, water harvesting is useful in areas with more than 250 mm. Also if the rainfalls in light showers, the objective is to maximize the runoff. In tropical areas the problem into handle the sudden flood from violent summer thunder storms. If the rain and growing period do not coincides, the desired result will be several applications of water during the period of crop growth.

a. Using natural runoff: to use naturally occurring runoff to augment rainfall in areas where the rain alone is not sufficient for growing crops.

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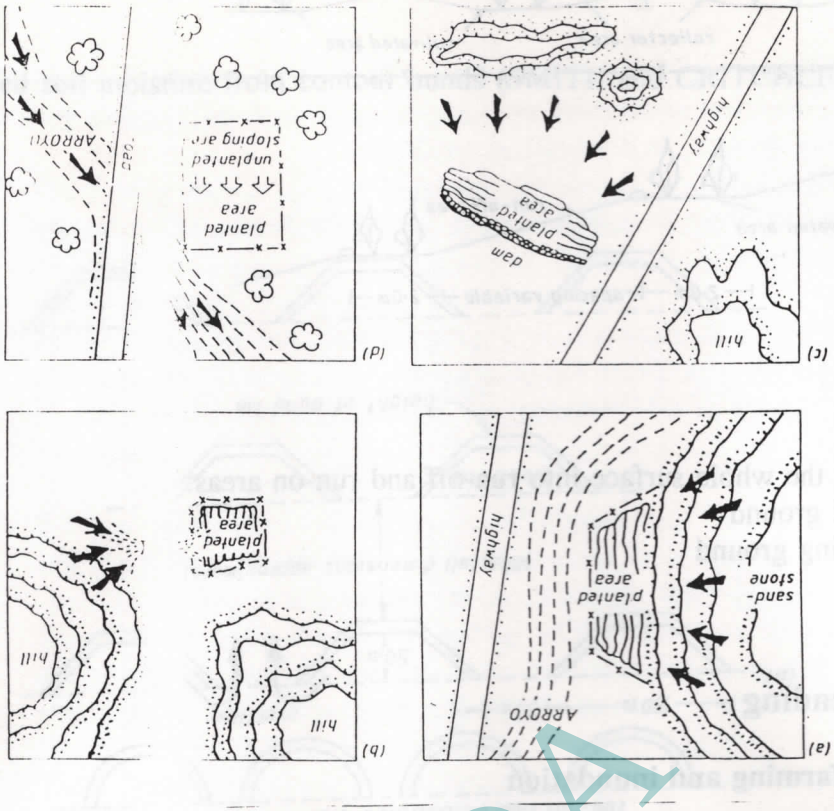


Fig. 11 Floodwater farming in Arizona by Navajo Indians (BILLY 1981)

a) Farming with natural floodwater from a sandstone ridge
b) Floodwater collected by a road drain and channelled through a culvert
c) Planting after floodwater has been retained by a low dam
d) Planting the lower half of a field which receives floodwater from the upper part

ii. Inundation methods impounding of flood water on level areas and retaining them long enough to saturate the soil so that a crop can be grown on the moisture stored in the soil.

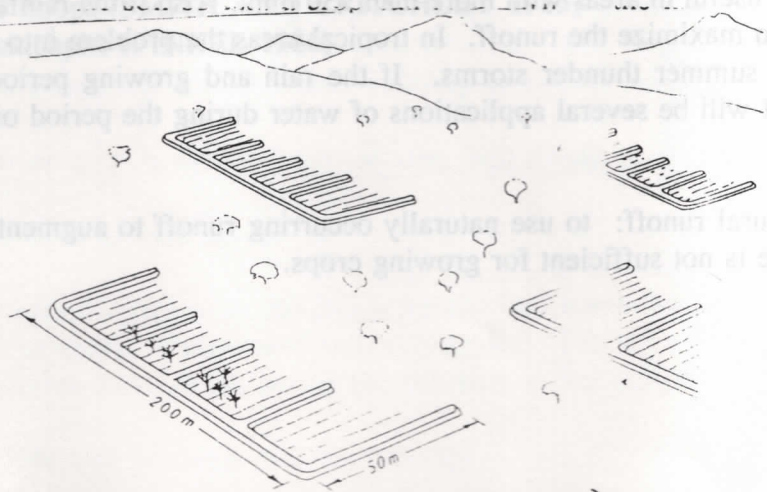


Fig. 12 The "teras" system of the Sudan (CRITCHLEY 1989)

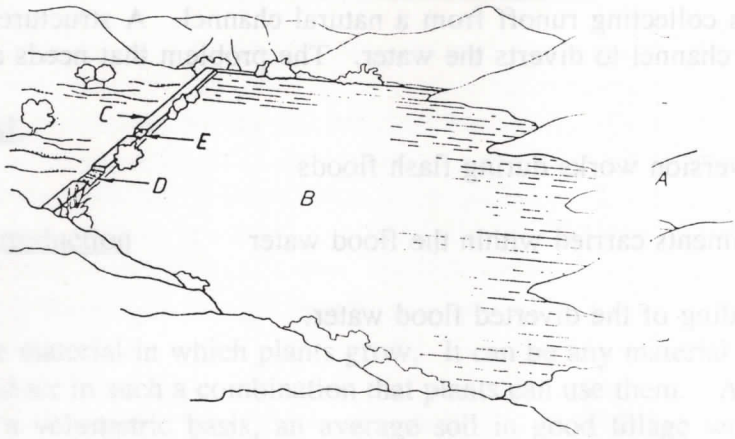


Fig. 13 Inundation farming by "khadin" in Rajasthan, India
A barren hilly catchment area
B large shallow lake, cropped after the flood water has gone
C earth bund impounds run-off, with D an emergency spillway to pass floods, and E a sluice for controlled discharge of surplus water
(KOLARKAE et al 1983)

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Collected and diverted runoff

The system involves collecting runoff from uncultivated land and carried to the farm by ditches or canals.

c) Flood diversion

This method involves collecting runoff from a natural channel. A structure such as a weir is required in the flood channel to diverts the water. The problem that needs attention is:

- damage to the diversion works during flash floods
- deposition of sediments carried within the flood water
- control and spreading of the diverted flood water.

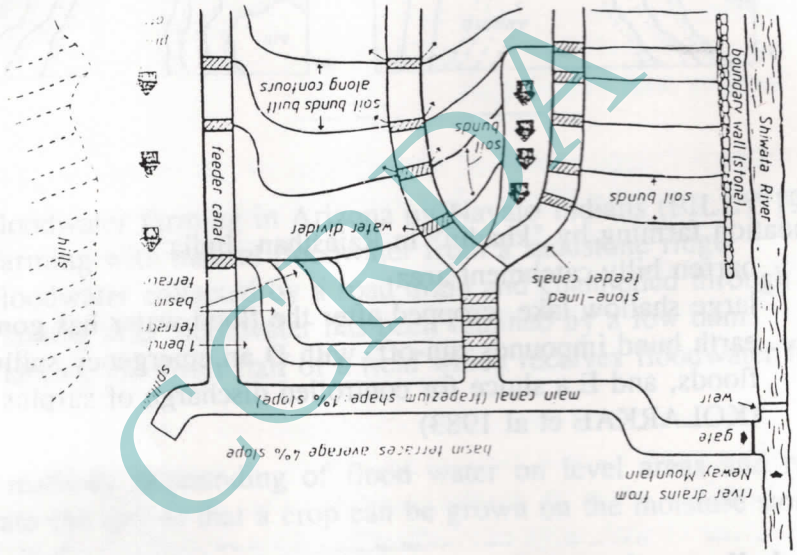


Fig. 14 A small flood diversion scheme in Tigre, Ethiopia (BENNETT 1985)

SOIL FOR AGRICULTURE

1. GENERAL

1.1 Introduction

Soil is the material in which plants grow. It can be any material which contains solids, liquid, and air in such a combination that plants can use them. As a general rule, when taken on a volumetric basis, an average soil in good tillage will consist of 50% soil minerals including humus and air and water inequal proportions of 25% respectively.

A fertile soil contains two distinct soil components: **Mineral** and **Organic matter**. Organic matter generally amounts to only a few percent of the solid materials of the soil. All the rest are minerals formed from rock broken down into small particles by a process known as **weathering**.

The **Liquid** portion of the soil consists of water, dissolved minerals and soluble organic matter. It fills part or most of the spaces between the solid particles. this water is absorbed by plant roots and must be periodically replenished by **rain** or **Irrigation**. Thus, the soil serves as a reservoir for moisture.

The **air** or **vopour** porion of the soil occupies those parts of the spaces between the soil particles that are not filled with water. this is an important portion of the soil system as most plants (with the exception of aquatic plants like rice) require some aeration of their root system.

The appearance and composition of most soils vary with depth below the ground surface. One often can identify distinct layers, or **horizons**. While most of the agricultural activity takes place in the **top soil**, the composition of the **sub-soil** or **lower layers**, largely determines the **drainage characteristics** of a soil. In case of **Water Harvesting Systems,** soils for the **catchment area/donor** and the cultivated area have their own specific requirements. The physical and chemical properties of the soil will largely determine the vigour of the growth of plants affecting also the capacity of a soil to hold moisture.

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1.2 Soil Physical Characteristics

1.2.1 Soil Particles

The majority of agricultural soils are composed of particles of minerals, which include large coarse fragments, gravel, particles of sands of varying sizes, silt and clay. Also inaddition there are usually materials of Organic matter in all stages of decomposition.

Two major systems have been developed for classifying soil particles, both based on their sizes.

The simplest of the two that was devised by **International Society of Soil Science** recognizes **five classes.**

Clay < 0.002 mm
Silt 0.002 -0.02 mm
Fine sand 0.02 - 0.2 mm
Coarse sand 0.2 - 2.0 mm and
Gravel > 2.0 mm

Another system developed by the USDA. Soil Conservation Service, further classifies coarse fragments greater than 2 mm, in diameter, with fragments greater than 40 mm in diameter being classed as stony. However, for our purposes we are mainly concerned with a particle size of 2.0 mm and less as they affect the **water holding capacity of the soil.**

1.2.2. SOIL TEXTURE

Soil contains an infinite combinations of **sand, silt** and **clay** and these have been classified according to specific percentages of each of these soils particles they contain.

Essentially these texture classes are ranked in order of increasing amounts of fine particles they contain (fig 1)

eg. **Sand** is a soil which contains 85% or more of sand.

sandy loam contains either 20% clay or less, less than 50% silt and between 45-52% sand.

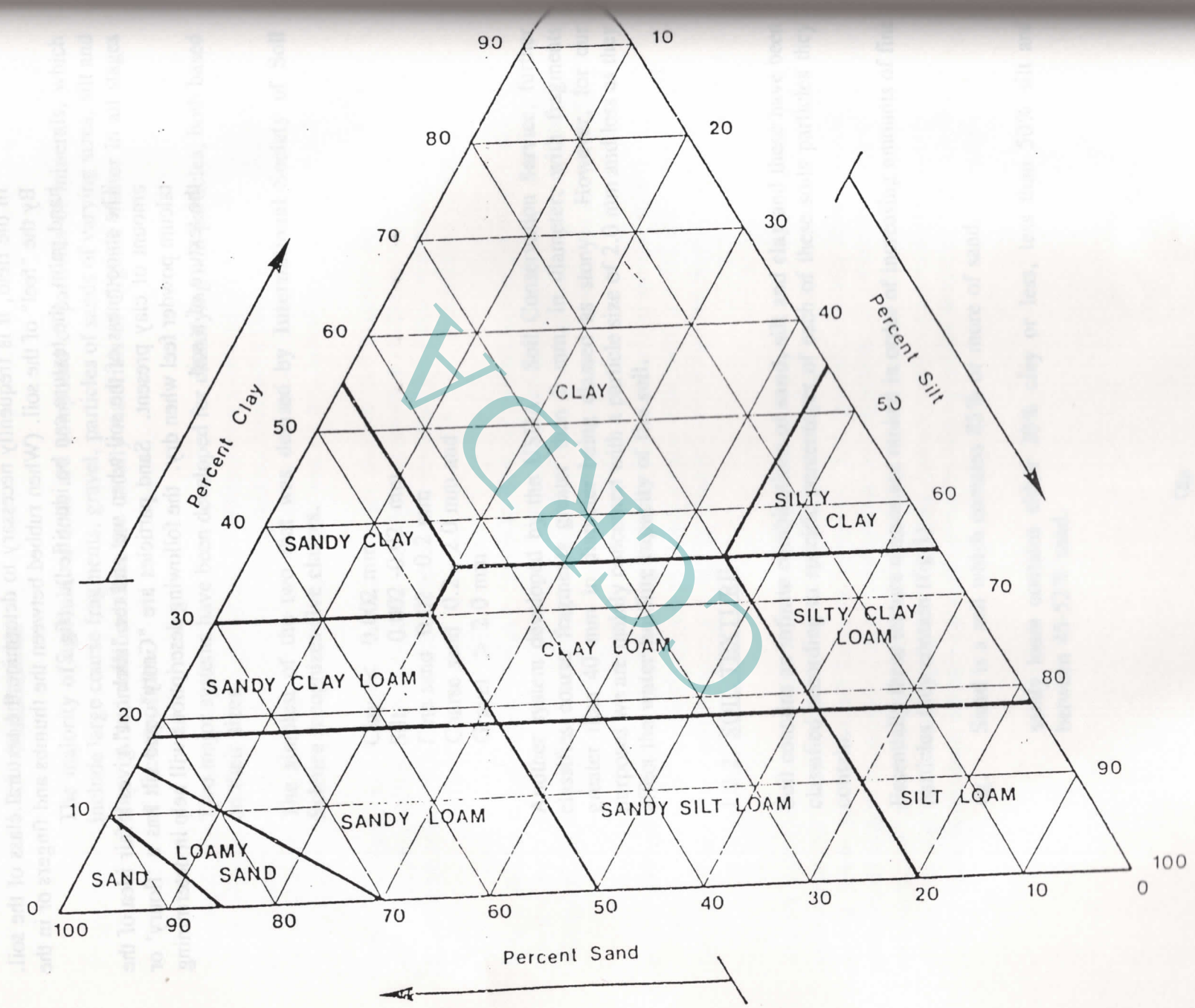
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In the field, it is frequently necessary to determine the textural class of the soil. By the "feel" of the soil. (When rubbed between the thumbs and fingers or in the hand palm, the texture can be identified). (fig 2)

The smoothness of the soil when wet and the "slick out" gives a fair idea of the amount of clay present. Sand particles are "Gritty", and silt has a 'floury' or talcum powder feel when dry. the following descriptions will help in determining the texture of a soil.

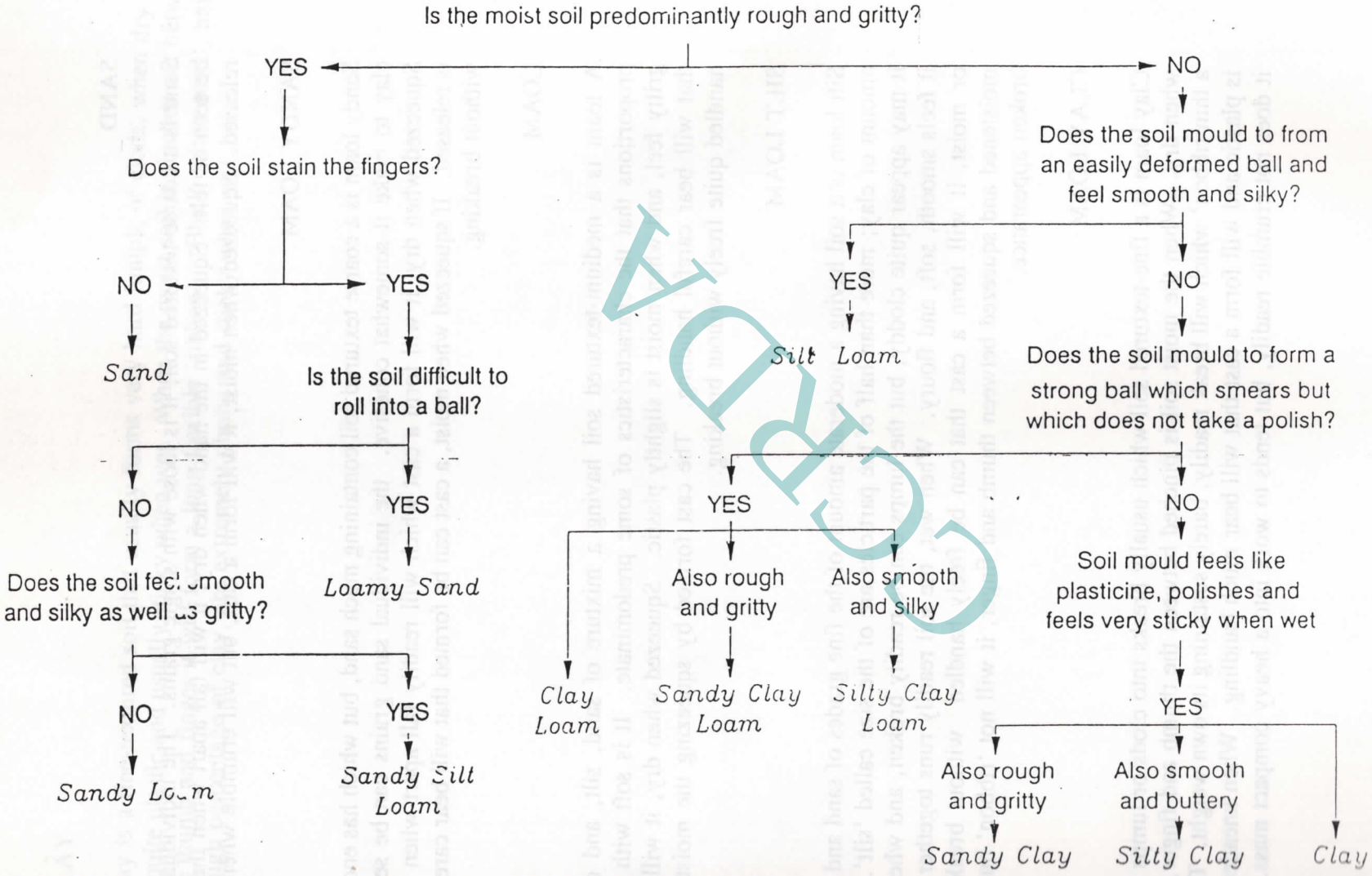
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Fig. 1.


Percent Clay
Percent Silt
Percent Sand
CLAY
SANDY CLAY
SILTY CLAY
SANDY CLAY LOAM
CLAY LOAM
SILTY CLAY LOAM
SANDY LOAM
SANDY SILT LOAM
SILT LOAM
LOAMY SAND
SAND

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Fig. 2.


Is the moist soil predominantly rough and gritty?
YES
NO
Does the soil stain the fingers?
NO
YES
Sand
Is the soil difficult to roll into a ball?
NO
YES
Does the soil feel smooth and silky as well as gritty?
Loamy Sand
NO
YES
Sandy Loam
Sandy Silt Loam
Does the soil mould to from an easily deformed ball and feel smooth and silky?
YES
NO
Silt Loam
Does the soil mould to form a strong ball which smears but which does not take a polish?
YES
NO
Also rough and gritty
Also smooth and silky
Soil mould feels like plasticine, polishes and feels very sticky when wet
Clay Loam
Sandy Clay Loam
Silty Clay Loam
YES
Also rough and gritty
Also smooth and buttery
Sandy Clay
Silty Clay
Clay

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SAND

Sand is a coarse-textured soil; it is loose with single grains. The individual grains can be seen or felt. Squeezed in the hand when dry, it will fall apart when the pressure is released. Squeezed when moist, it will form a cast, but will crumble when touched.

SANDY LOAM

Sandy loam is a coarse textured soil containing much sand, but which has enough silt and clay to make it somewhat cohesive. the individual sand grains can be seen and felt. Squeezed when dry, it will form a cast which will readily fall apart when the pressure is released. If squeezed when moist, a cast can be formed that will bear careful handling without breaking.

LOAM

A loam is a medium-textured soil having a mixture of sand, silt, and clay in such proportions that the characteristics of some predominate. It is soft with a somewhat gritty feel, and when moist is slightly plastic. Squeezed when dry, it will form a cast that will bear careful handling. The cast formed by squeezing the moist soil can be handled quite freely without breaking.

SILT LOAM

Silt loam is a soil having a moderate amount of the fine grades of sand and only a small amount of clay; more than half of the particles are of the size called 'silt'. When dry, it may appear quite cloddy, but the lumps can be readily broken, and when pulverized it feels smooth, soft, and floury. When wet, the soil readily runs together. Either dry or moist, it will form a cast that can be freely handled without breaking. When moistened and squeezed between thumb and finger, it will not 'ribbon' but will have a broken appearance.

CLAY LOAM

Clay loam is a fine-textured soil which usually breaks into clods or lumps that are hard when dry. When the moist soil is pinched between the thumb and finger, it will form a thin ribbon' which will break readily, barely sustaining its own weight. The moist soil is plastic and will form a cast that will bear much handling. When kneaded in the hand it does not crumble readily, but tends to work into a heavy compact mass.

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CLAY

Clay is a fine-textured soil that usually forms very hard lumps, or clods, when dry and is quite plastic and usually sticky when wet. When the moist soil is pinched out between the thumb and finger it will form a long flexible 'ribbon'. 'Black cotton soils', having a high percentage of clay, are extremely plastic and sticky when wet.

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1.2.3 SOIL STRUCTURE

This describes the arangment of individual particles of soil or clusters of them into aggregates. such aggregates may be held together by geological or chemical bonds. **Geological Bonding** may be caused by plant exudates from roots, soil borne fungi, bacteria and other life forms such as earth worms.

Chemical Bonding, particularly in tropical zones such aggregates are often held together by electrical forces. For example by positively charged oxides or iron and aluminum with the negatively charged silicate clay minerals.

Soil structure can be categorized into:

1) grade
2) class
3) type

(1) The grade of soil structure describes the distinctness of the degree of aggregation, thus:-

Structureless - is the condition where there is no observable aggregation of soil particles.

Weak - express the degree of aggregation found in poorly formed in distinct peds, that are barely observable. such soils are not stable.

Moderate - strong etc.

(2) The **class** of soil refers to the range of the size of the aggregates. The classes are as follows:

- very thin or very fine, < 1 mm - 10 mm

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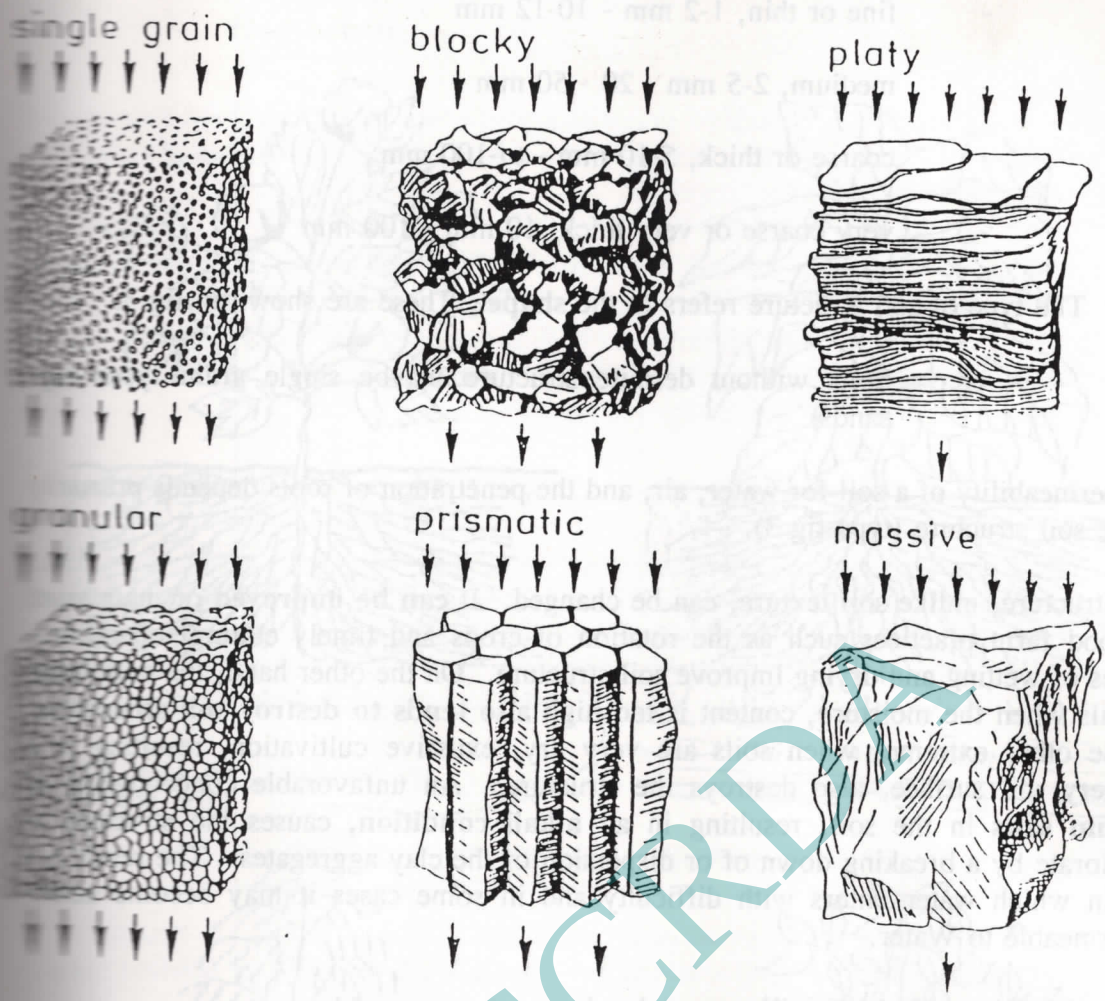


Fig. 3 The effect of soil structure on the downward movement of water.

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- fine or thin, 1-2 mm - 10-12 mm
- medium, 2-5 mm - 20 - 50 mm
- coarse or thick, 5-10 mm - to-100 mm
- very coarse or very thick 10 mm - 100 mm

(3) The type of soil structure refers to the **shape**. These are shown in fig 3.

eg. Soils without definite structure maybe single grain types (eg. sands)

The permeability of a soil for water, air, and the penetration of roots depends primarily on the soil structure (type fig 3).

Soil structure, unlike soil texture, can be changed. It **can be improved** or maintained by good farm practices such as the rotation of crops and timely cultural operations. Cycles of wetting and drying improve soil structure. On the other hand, the cultivation of soils when the moisture, content is too high also **tends to destroy soil structures**. At the other extreme, when soils are very dry, exussive cultivation, resulting in a powdery soil surface, also destroys the structure. An unfavorable concentration of **Sodium salts** in the soil, resulting in an **alkali condition,** causes the structure to deteriorate by a breaking down of or dispersion of the clay aggregates. The result is a soil in which water enters with difficulty and in some cases it may become nearly impermeable to Water.

1.3 Limiting effects of soil on root development

If a soil contains a compacted layer or 'hard-pan' root penetration is seriously affected. Roots cannot penetrate a hard layer except through cracks. In many cultivated soils, a compacted layer at plough depth - a 'plough-pan' - restricts crop roots to the upper 20 cm of the soil. Since roots do not grow in dry soil, a layer of dry soil below the surface can restrict the depth of rooting. Consequently, the depth of irrigation also affects the depth of rooting.

A deficiency of plant nutrients in the subsoil or a saline (alkaline) subsoil also limits the depth of root penetration. Figure 4 illustrates the effect on root development of some of the limiting factors in soil.

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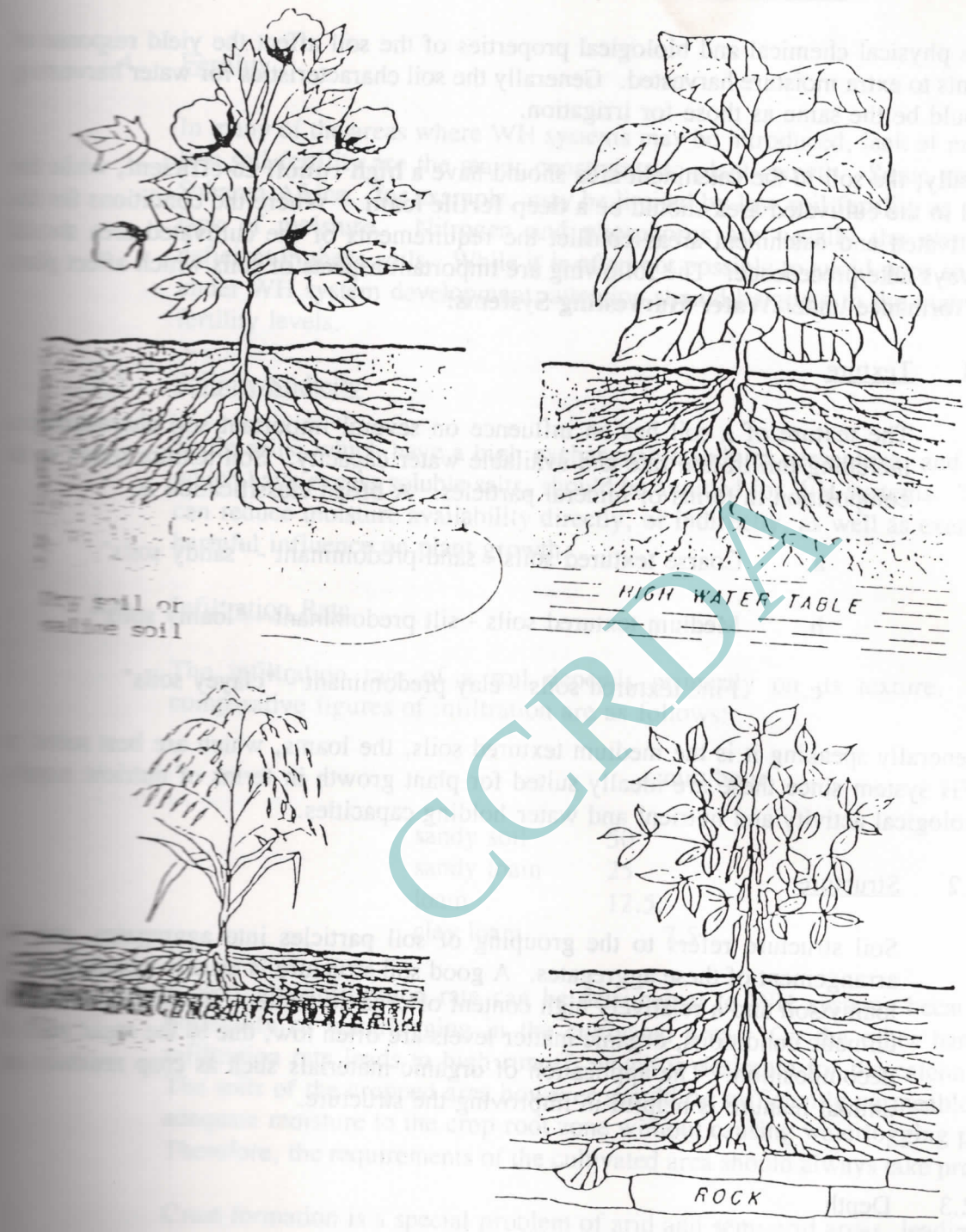


Fig. 4. Soil effects on root development.

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II. SOIL REQUIREMENTS FOR WATER HARVESTING

The physical chemical and biological properties of the soil affect the yield response of plants to extra moisture harvested. Generally the soil characteristics for water harvesting should be the same as those for irrigation.

Ideally, the soil in the catchment area should have a **high runoff co-efficient,** while the soil in the cultivated area should be a **deep fertile loam.** Where the conditions for the cultivated and catchment areas conflict the requirements of the cultivated area should always take precedence. The following are important aspects of soils which affect plant performance under **Water Harvesting Systems:**

2.1 Texture

The texture of a soil has an influence on several important soil characteristics including infiltration rate and available water capacity. Soil texture refers to its composition in terms of mineral particles. A broad classification is:

a. Coarse textured soils - sand predominant - "sandy soils"

b. Medium textured soils - silt predominant - "loamy soils"

c. Fine textured soils - clay predominant - "clayey soils"

Generally speaking it is the medium textured soils, the loams, which are best suited to WH system since these are ideally suited for plant growth in terms of nutrient supply, biological activity and nutrient and water holding capacities.

2.2 Structure

Soil structure refers to the grouping of soil particles into aggregates, and the arrangement of these aggregates. A good soil structure is usually associated with loamy soil and a relatively high content of organic matter. Inevitable, under hot climatic conditions, organic matter levels are often low, due to the rapid rates of decomposition. The application of organic materials such as crop residues and animal manure is helpful in improving the structure.

2.3 Depth

The depth of soil is particularly important where WH systems are proposed. Deep soils have the capacity to store the harvested runoff as well as providing a greater amount of total nutrients for plant growth. Soils of less than one metre

deep are poorly suited to WH. Two metres depth or more is ideal, though rarely found in practice.

2.4 Fertility

In many of the areas where WH systems may be introduced, lack of moisture and low soil fertility are the major constraints to plant growth. Some areas in Sub-Saharan Africa. for example, may be limited by low soil fertility as much as by lack of moisture. Nitrogen and phosphorus are usually the elements most deficient in these soils. While it is often not possible to avoid poor soils in areas under WH system development, attention should be given to the maintenance of fertility levels.

2.5 Salinity/Sodicity

Sodic soils, which have a high exchangeable sodium percentage, and saline soil which have excess soluble salts, should be avoided for WH systems. These soils can reduce moisture availability directly, or indirectly, as well as exerting direct harmful influence on plant growth.

2.6 Infiltration Rate

The infiltration rate of a soil depends primarily on its texture. Typical comparative figures of infiltration are as follows:

	mm/hour
sandy soil	50
sandy loam	25
loam	12.5
clay loam	7.5

A very low infiltration rate can be detrimental to WH systems because of the possibility of waterlogging in the cultivated area. On the other hand, a low infiltration rate leads to high runoff, which is desirable for the catchment area. The soils of the cropped area however should be sufficiently permeable to allow adequate moisture to the crop root zone without causing waterlogging problems. Therefore, the requirements of the cultivated area should always take precedence.

Crust formation is a special problem of arid and semi-arid areas, leading to high runoff and low infiltration rates. Soil compaction as a result of heavy traffic either from machinery or grazing animals could also result in lower infiltration rates.

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2.7 Available Water Capacity (AWC)

The capacity of soils to hold, and to release adequate levels of moisture to plants is vital to WH. AWC is a measure of this parameter, and is expressed as the depth of water in mm readily available to plants after a soil has been thoroughly wetted to "field capacity". AWC values for loams vary from 100-200 mm/metre. Not only is the AWC important, but the depth of the soil is critical also. In WH systems which pond runoff, it is vital that this water can be held by the soil and made available to the plants.

The AWC has implications for technical design - for example simple calculation demonstrates that even in deep soils (2 metres) with high AWC values (200 mm/metre) there is no point ponding water to depths greater than 40 cm. This quantity when infiltrated is adequate to replenish the soil profile from permanent wilting point to field capacity and any surplus will be lost by deep drainage as well as being a potential waterlogging hazard.

2.8 Constructional Characteristics

The ability of a soil to form resilient earth bunds (where these are a component of the WH system) is very important, and often overlooked. Generally the soils which should particularly be avoided are those which crack on drying, namely those which contain a high proportion of montomorillonite clay (especially vorticellas or "black cotton soils"), and those which form erodible bunds, namely very sandy soils, or soils with very poor structure.

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SOILS - Exercise

1. A mineral soil contains 30% clay, 30% silt and 40% sand particles. What is its texture?

2. A mineral soil cantains 10% clay, 20% silt and 70% sand particles. What is its texture?

3. A mineral soil is assissed for texture by feel. It feels gritty, the small ball cracks badly when dropped, and it dirties the fingers. What is its texture?

4. A miniral soil is assessed for texture by feel. It does not feel gritty, it does take a polish, and is extremely difficult to deform. What is its texture?

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SOIL-PLANT-WATER RELATIONSHIPS

This chapter on soil-plant-water relationships treats those physical properties of **soils** and **plants** that affect the **movement, retention** and **use of Water**. i.e, concepts of **Soil Moisture, Retention, available soil water, field capacity, permanent wilting point, rooting depth** are introduced.

I Soil Water/Moisture

Constant supply of water in the soil is necessary for plant survival and growth, knowledge as to how water **moves** in a given soil, **how much** water a soil **can hold** and howmuch of it is **available** to plants, and how the water supply can be replenished will be discussed. The first two are related to **size** and **distribution** of the soil pores and to size of the soil particles and their attraction for moisture. The amount of water a soil holds also depends on the amount of organic matter in the soil. Generally, the finer the soil particles and the larger the amount of organic matter, the more water a soil holds.

1.1 Kinds of Water in the Soil

The soil pores, spaces between the particles, form a network of connected cavities of different shape and size. When water is added to a dry soil by either rain or irrigation it is distributed around the soil particles where it is held by **adhesive** and **cohesive forces**. When all the pores, large and small, are filled, the soil is said to be **saturated** and is at its maximum retentive capacity.

The water in the large pores that moves down word freely under the influence of **gravity** is called **gravitational water** or **free water**. When the supply of water to the surface is cut off, water continues to drain from the large pores for a few days. In well drained soils, the free water near the surface usually has moved out before crops are damaged. The large pores are again filled with air, water in the small pores moves because of capillary forces and is called **capillary water**.

Hygroscopic Water

Water held on the particle surfaces, so tightly as a result of evaporation from the surface and absorption of moisture by growing plants that much of it is non-liquid and moves as a vapour. i.e. not available to plants. (fig 1)

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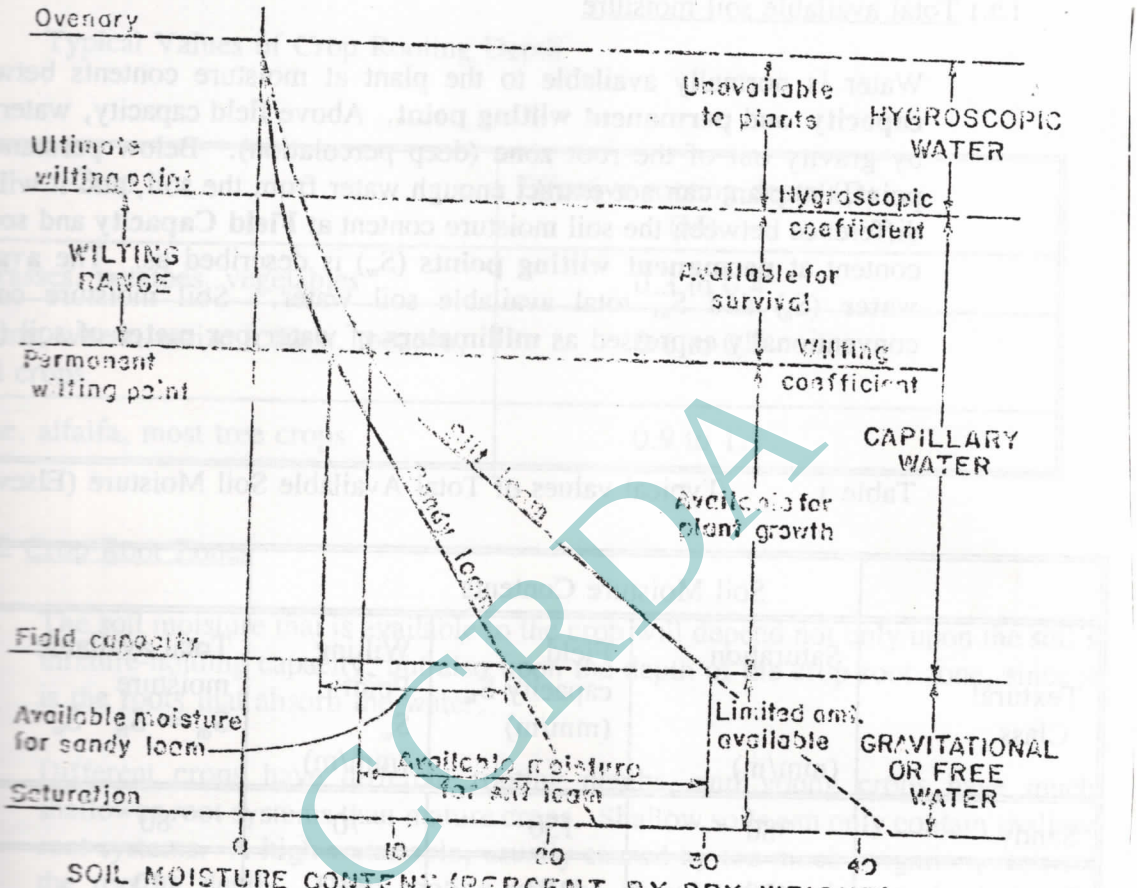


Figure 13.--Kinds of water in the soil and difference in available-moisture content between a sandy loam and a silt loam. The silt loam contains more than twice as much readily available water.

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1.2 Moisture retention in soils

Soils vary in their capacity to hold soil moisture according to their texture and physical structure with the fine soils like clays being able to store much more water than coarser textured soils, such as sands.

1.2.1 Total available soil moisture

Water is normally available to the plant at moisture contents between **Field capacity** and **permanent wilting point**. Above field capacity, water will drain by gravity out of the root zone (deep percolation). Below permanent wilting point, the plant can not extract enough water from the soil, and it will die. The difference between the soil moisture content at **Field Capacity** and soil moisture content at **permanent wilting points** (S_w) is described as. The **available soil water** (S_a) and S_a, total available soil water. Soil moisture contents are conventionally expressed as **millimeters** of water **per meter** of soil (mm/m)

Table 1 Typical values of Total Available Soil Moisture (Elsevier)

	Soil Moisture Contents			
Textural Class	Saturation (mm/m)	Field capacity S_{fe} (mm/m)	Wilting Point S_w (mm/m)	Total available moisture $S_m = S_{fe} - S_w$
Sandy	380	150	70	80
Sandy loam	430	210	90	120
Loam	470	310	140	170
Clay loam	490	360	170	190
Silty clay	510	400	190	210
Clay	530	440	210	230

To calculate how much water can be stored in a particular soil and made available for use by the crop, it is necessary to consider the depth of soil from which the plant roots can draw water. this is called the rooting depth (D), and can be estimated from Table 2 for various crops, or determined on site by diffing a pit beside healthy plants.

total available moisture (mm/m) $S_a = S_{fc} - S_w$

depth of total available water (mm) = Sa X D

The depth of totally available water (mm) can then be compared directly with evaportranspiration rates (mm/d).

Table 2 Typical Values of Crop Rooting Depth

Crop	Effective rooting depth (D) (M)
Pasture grasses, potatoes, vegetables	0.3 to 0.4
Small grains, wheat, maize, cotton, tobacco, most field crops	0.6 to 0.8
Sugar cane, alfalfa, most tree crops	0.9 to 1.1

1.2.2 Crop Root Zones

The soil moisture that is available to the crop will depend not only upon the soil's mixture-holding capacity, but also upon the depth of the crop root zone, since it is the roots that absorb the water.

Different crops have different rooting depths, and young crops have much shallower root systems than mature crops. Shallow soils can only contain shallow root systems. A high watertable, usually caused by too much irrigation, restricts the rooting depth. Deep rooting will be stimulated by deep and not overly frequent irrigation.

In uniform soils that are fully supplied with available moisture, plants use water rapidly from the upper part of the rootzone and slowly from the lower part. A typical moisture extraction pattern is shown in figure 4.

As most of the water consumed by plants is easily taken from half of the rootzone, only half of the available moisture is readily used.

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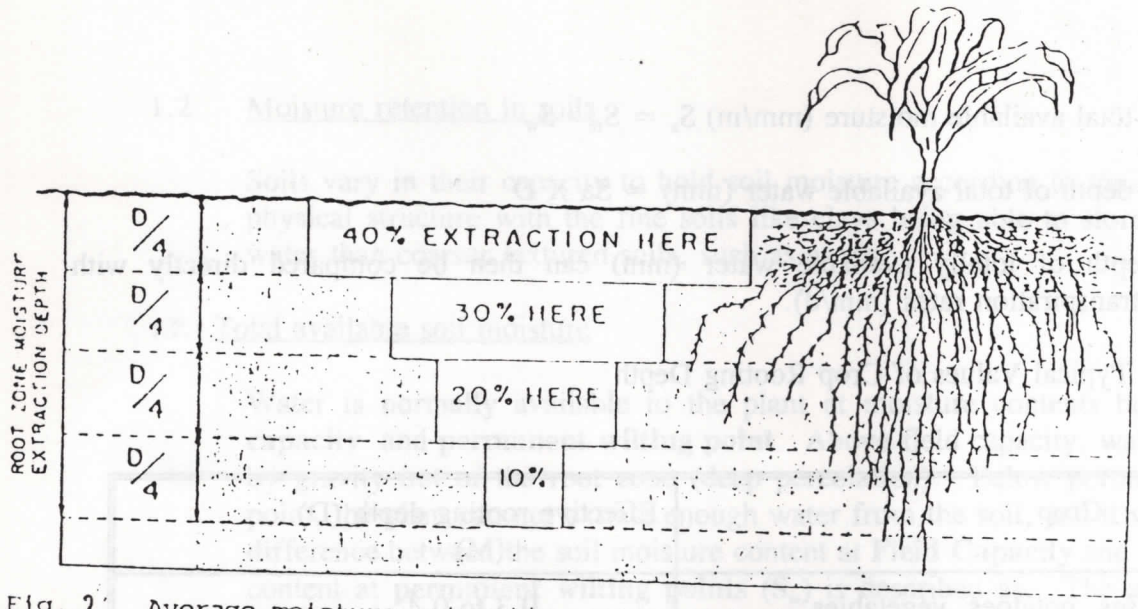


Fig. 2 Average moisture-extraction pattern of plants growing in a soil without restrictive layers and with an adequate supply of available moisture throughout the root zone.

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1.2.3 Freely Available Waer

When the soil is at field capacity, the plant can extract water easily, to maintain the maximum rate of evapotranspiration (ET_m). As the plant removes water from the soil moisture reservoir, the suction it has to exert increases as the moisture content decreases (because the water held at low sections is removed first). After a certain level of depletion, it cannot extract the water fast enough to maintain ET_m, and the evapotranspiration drops. The plant is then said to be under moisture stress.

Freely available soil moisture is defined as the fraction (p) to which the total available soil moisture can be depleted without causing the evapotranspiration to drop below ET_m. The depth of freely available soil moisture in a soil with rooting depth D is given by:

$$P \times S_a \times D$$

The balance of the total available water is called "not freely available water", with a depth of:

$$(1-p) \times Sa \times D$$

The value of p is sometimes taken as 0.5, but more accurate figures have been published by FAO, Irrigation and Drainage papers. No. 33.

Table 3 Crop Groups according to Soil Water Depletion

Group	Crops
1	Onion, pepper, potato
2	banana, cabbage, grape, pea, tomato
3	alfalfa, bean, citrus, groundnut, pineapple, sunflower, watermelon, wheat
4	cotton, maize, olive, safflower, sorghum, soybean, sugarbeet, sugarcane, tobacco

Table 4 Soil Water Depletion Fraction (p) for Crop Groups and Maximum Evapotranspiration (ETm)

Crop Group	Soil Water Depletion Factor (p)								
	ETm mm/day								
	2	3	4	5	6	7	8	9	10
1	0.50	0.425	0.35	0.30	0.25	0.225	0.20	0.20	0.175
2	0.675	0.575	0.475	0.40	0.35	0.325	0.275	0.25	0.225
3	0.80	0.70	0.60	0.50	0.45	0.425	0.375	0.35	0.30
4	0.875	0.80	0.70	0.60	0.55	0.50	0.45	0.425	0.40

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1.3 The infiltration of water

The infiltration rate of a soil is the maximum rate which water enters the soil when applied at its surface. In general, the rate is determined by the physical characters of the soil, namely, its structure and texture. As wetting increases, the infiltration rate decreases and usually assumes a constant rate over a period of time.

The infiltration rate is influenced by the moisture content of the soil, with a more rapid intake where the deeper layers of soil are dry. A number of other soil conditions also affect the movement of water through the soil, notably the presence of a hard pan or layer of impermeable clay as will a high water table which all tend to reduce the infiltration rate.

Compaction caused by the movement of implements and man over the soil will also tend to reduce infiltration by reducing the porosity of the soil.

II. PLANTS AND WATER

2.1 **Water use efficiency/** yield response factor.

This concept needs to be given serious consideration where the water resource is a limiting factor. It is a measure of how efficiently particular crops convert a given amount of water, usually one cubic meter, into 1 kg of harvested yield, be it grain, leaves fruits or roots.

Maize for example is a much more efficient utilizer of water than **wheat**. For it produces on average between 0.8 - 1.6 kg of harvested grain at 13% maisme, whereas the conversion value for wheat grain of a similar moisture content is between 0.8 - 1.0 kg.

Table 5 Shows yield response factors of some crops

Therefore in those circumstances where there is pressure towards using water more efficiently, the cultivation of crops which are better utilizers of water interms of producing economic products should be given priority in any planning operation.

2.2 Crop Water Requirements

Once cropping patterns are planned, crop water requirements are calculated using various methods. (covered by other Lecturer). Whereby critical periods for soil water are taken care of (table -6) **"when"** and **"how much"** water are required by plants and discussed

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Table 5

Crop	Soil requirements	Sensitivity to salinity	Total crop water requirement	Water use efficiency for harvested yield kg/m³ %moisture
Pepper	Light to medium texture pH 5-7	Moderately	600-900	1.5 - 3.0 Fresh fruit(90%)
Potato	Well drained, aerated and porous	"	500-700	4-7 Fresh tuber (70-75%)
Rice	Heavy soils high tolerance to oxygen deficit pH 5.5-6.0	"	350-700	0.7 - 1.1 Paddy(15-20%)
Safflower	Fairly deep well drained,medium Texture pH 6-8	Moderately tolerant	600-1200	0.2 - 0.5 Seed (8-10%)
Sorghum	Light to medium/ heavy relatively tolerant to water logging PH 6-8	"	450-650	0.6 -1.0 Grain(6-10%)
Soybean	Wide range except sandy well drained pH 6-6.5	"	450-700	0.4-0.7 Grain (6-10%)
Sugarcane	Deep well drained water table >1.5-2.0 PH 5-8.5	"	1500-2500	Cane 5-8(80%) Sugar 0.6-1.0(10%
Sunflower	Fairly deep soils pH 6-7.5		600-1000	0.3 - 0.5 Seed (6-10%)
Tomato	Light loam, well drained without water logging PH 5-7	Moderately	400-600	10 -12 Fresh fruit (80-90%)
Water melon	Sandy loam pH 5.8 - 7.2	"	400-600	10-12 Fresh fruit (80-90%)
Wheat	Medium texture relatively to-lerant to high water table pH 6-8	Moderately tolerant	450-650	0.8-1.0 Grain(12-15%) 0.5 - 1.6 grain

Source:- J.Doorenbos and A.H.Kassem " Yield response to water " Irrigation and drainage paper No. 33 FAO, Rome, 1986.

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Table 6

Critical Periods for Soil Water Stress for Different Crops

Alfalfa	just after cutting for hay and at the start of flowering for seed production
Apricots	period of flower and bud development
Barley	early boot stage > soft dough stage > onset of tillering or ripening stage
Beans	flowering and pod setting period > earlier > ripening period. However, ripening period > earlier if not prior water stress.
Broccoli	during head formation and enlargement
Cabbage	during head formation and enlargement
Castor bean	requires relatively high soil water level during full growing period
Cauliflower	requires frequent irrigation from planting to harvesting
Cherries	period of rapid growth of fruit prior to maturing
Citrus	flowering and fruit setting stages; heavy flowering may be induced by withholding irrigation just before flowering stage (lemon); "June drop" of weaker fruits may be controlled by high soil water levels
Cotton	flowering and boll formation > early stages of growth > after boll formation
Groundnuts	flowering and seed development stages > between germination and flowering and end of growing season
Lettuce	requires wet soil particularly before harvest
Maize	pollination period from tasselling to blister kernel stages > prior to tasselling > grain filling periods; pollination period very critical if no prior water stress
Oats	beginning of ear emergence possibly up to heading
Olives	just before flowering and during fruit enlargement
Peaches	period of rapid fruit growth prior to maturity
Peas	at start of flowering and when pods are swelling
Potatoes	high soil water levels; after formation of tubers, blossom to harvest
Radish	during period of root enlargement
Sunflower	possibly during seeding and flowering - seed development stage
Small grains	boot to heading stage
Sorghum	secondary rooting and tillering to boot stage > heading, flowering, grain formation > grain filling period
Soybeans	flowering and fruiting stage and possibly period of maximum vegetative growth
Strawberries	fruit development to ripening
Sugarbeet	3 to 4 weeks after emergence
Sugarcane	period of maximum vegetative growth
Tobacco	knee high to blossoming
Tomatoes	when flowers are formed and fruits are rapidly enlarging
Turnips	when size of edible root increases rapidly up to harvesting
Water melon	blossom to harvesting
Wheat	possibly during booting and heading and two weeks before pollination

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Soil-Plant-Water Relationship Exercies

1. What is the freely available water expressed in millimeters depth in the following case?

   Crop type - Maize

   Soil type - Clay loam

   Crop evapotranspiration rate (Etc) - 7 mm/day

2. What would hte freely available water be for a crop of onions in the case given in Question 1?

3. Given the following information calculate how many days it will be before irrigation is required?

   Crop type - Onion

   Soil type - Clay loam

   Potential evaporationspiration rate (ETo) - 5 mm/day

   Soil moisture deficit status - 10 mm

4. Given the following information how many days will it be therefoer the crop suffers permanent damage and dies?

   Crop type - Poteto

   Soil type - Clay loam

   Potential evapotranspiration rate (ETo) - 4 mm/day

   Initial soil moisture deficit - 5 mm

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CROP WATER REQUIREMENT

Introduction

The irrigation requirement determined for a specific crop is not universally applicable to a variety of environmental conditions. Even within a given arid or semi-arid zone, the variations in climatic conditions are so great that differences in evapotranspiration are appreciable. Plants need soil, sunlight, air and water to enable them to lvie and grow. Water is an essential component of all plants tissue and fulfills three primary functions.

- It keeps plants erect by filling the cells which make up plant tissue
- It acts as a cooling agent in evaporating from the leaves
- Preventing overheating under hot conditions and it conditions and it carries nutrients in solution from the soil into the plants through their roots.

Under the same climatic conditions different crops require different amounts of water and the quantities of water used by a particular crop vary with it's stage of growth. Initially during seeding, sprouting and early growth a crop uses water at relatively slow rate. As growth develops this rate will increase reaching maximum in most crops at the approaches flowering and then declining towards maturity.

The effect of climate on crop water requirement

For crop water requirements and related studies the weather phenomena to be observed should preferably include temperature, humidity, wind, rainfall, sunshine duration and evaporation. To estimate or calculate crop water requirements. Reference crop evapotranspiration (ETo) should be determined.

There are four methods to estimate reference crop evapotranspiration (ETo). The Blaney-criddle, Radiation, Penman and Pan evaporation. The choice of the method must be based on the type of climatic data available and on the accuracy required in determining water needs.

Method	Temp.	Hum.	Wind	Sunshine	Radiation	Evap.	Envir.
1. Blaney-criddle	*	0	0	0	-	-	0
2. Radiation	*	0	0	*	(*)	-	0
3. Penman	*	*	*	*	(*)	-	0
4. Pan evaporation	-	0	0	-	-	*	*

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* measured data
0 estimated data
(*) if available, but not essential

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The modified penman method would offer the best results with minimum possible error of plus or minus 10 percent in summer and up to 20 percent under low evaporative conditions.

The pan method can be graded next with possible error or 15 percent depending on the location of the pan. The radiation method, in extreme conditions, involves a possible error of up to 20 percent in summer.

Reference crop Evapotranspiration

Evaporation is the process by which water, in form of water vapour, enters the atmosphere from open water surfaces such as Lakes, rivers or moist soil.

Transpiration is the evaporation which takes place at the surfaces of plant leaves. Physically both evaporation and transpiration processes are identical, because both involve a change of phase of water from liquid form to vapor form and transport of water in to th atmosphere.

Evapotranspiration is the total movement of water vapor into the air from land which supports plant life, including transpiration from plants, and evaporation from water or soil surfaces.

Reference crop evapotranspiration (ETo) is defined as the rate of evaporation from an extensive surface of 8 to 15 cm tall green grass cover of uniform height, actively growing, completely shading?? the ground and not short of water.

The Blaney-criddle method

$ETo = C[P(0.46T+8)]$ mm/day

where, ETo = reference crop evapotranspiration in mm/day
T = mean daily temperature in °c over the month considered.
P = mean daily percentage of total annual day time hour obtained from table for a given month and latitude
C = adjustment factor which depends on minimum relative humidity, sunshine hours and day time wind estimates

This method uses data for a single weather factor, mean daily temperature (24 hrs), and should only be used when temperature data are the only weather data available and where it is possible to classify the climate according to humidity (low to high), sunshine hours (low to high), and wind speed (low to high).

Sample calculations

The simple calculation procedure to obtain the mean daily value of P (0.46T+8) mm is illustrated using the measured mean daily temperature and the day length factor for one month. In this case values of P are obtained from the following table (table 1),

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Table 1 Mean Daily Percentage (p) of Annual Daytime Hours for Different Latitudes

Latitude North / South[1]	Jan / July	Feb / Aug	Mar / Sept	Apr / Oct	May / Nov	June / Dec	July / Jan	Aug / Feb	Sept / Mar	Oct / Apr	Nov / May	Dec / June
60°	.15	.20	.26	.32	.38	.41	.40	.34	.28	.22	.17	.13
58	.16	.21	.26	.32	.37	.40	.39	.34	.28	.23	.18	.15
56	.17	.21	.26	.32	.36	.39	.38	.33	.28	.23	.18	.16
54	.18	.22	.26	.31	.36	.38	.37	.33	.28	.23	.19	.17
52	.19	.22	.27	.31	.35	.37	.36	.33	.28	.24	.20	.17
50	.19	.23	.27	.31	.34	.36	.35	.32	.28	.24	.20	.18
48	.20	.23	.27	.31	.34	.36	.35	.32	.28	.24	.21	.19
46	.20	.23	.27	.30	.34	.35	.34	.32	.28	.24	.21	.20
44	.21	.24	.27	.30	.33	.35	.34	.31	.28	.25	.22	.20
42	.21	.24	.27	.30	.33	.34	.33	.31	.28	.25	.22	.21
40	.22	.24	.27	.30	.32	.34	.33	.31	.28	.25	.22	.21
35	.23	.25	.27	.29	.31	.32	.32	.30	.28	.25	.23	.22
30	.24	.25	.27	.29	.31	.32	.31	.30	.28	.26	.24	.23
25	.24	.26	.27	.29	.30	.31	.31	.29	.28	.26	.25	.24
20	.25	.26	.27	.28	.29	.30	.30	.29	.28	.26	.25	.25
15	.26	.26	.27	.28	.29	.29	.29	.28	.28	.27	.26	.25
10	.26	.27	.27	.28	.28	.29	.29	.28	.28	.27	.26	.26
5	.27	.27	.27	.28	.28	.28	.28	.28	.28	.27	.27	.27
0	.27	.27	.27	.27	.27	.27	.27	.27	.27	.27	.27	.27

1/ Southern latitudes: apply 6 month difference as shown.

Example: Olgolcho, Chilalo, Arsi is 8°1 North, thus the values for p in July, August an September are respectively 0.29, 0.28 and 0.28. For Bahir Dar, Gojam situated at 11°6 North the same va would apply as 10° is the nearest figure in the table. In the cas Arba Minch 6°1 north, the values for 5° would be used.

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MEAN DURATION OF MAXIMUM SUNSHINE HOURS (N) FOR DIFFERENT MONTHS AND LATITUDES.

Table 2 Mean Daily Duration of Maximum Possible Sunshine Hours (N) for Different Months and Latitudes

Northern Lats / Southern Lats	Jan / July	Feb / Aug	Mar / Sept	Apr / Oct	May / Nov	June / Dec	July / Jan	Aug / Peb	Sept / Mar	Oct / Apr	Nov / May	Dec / June
50	8.5	10.1	11.8	13.8	15.4	16.3	15.9	14.5	12.7	10.8	9.1	8.1
48	8.8	10.2	11.8	13.6	15.2	16.0	15.6	14.3	12.6	10.9	9.3	8.3
46	9.1	10.4	11.9	13.5	14.9	15.7	15.4	14.2	12.6	10.9	9.5	8.7
44	9.3	10.5	11.9	13.4	14.7	15.4	15.2	14.0	12.6	11.0	9.7	8.9
42	9.4	10.6	11.9	13.4	14.6	15.2	14.9	13.9	12.6	11.1	9.8	9.1
40	9.6	10.7	11.9	13.3	14.4	15.0	14.7	13.7	12.5	11.2	10.0	9.3
35	10.1	11.0	11.9	13.1	14.0	14.5	14.3	13.5	12.4	11.3	10.3	9.8
30	10.4	11.1	12.0	12.9	13.6	14.0	13.9	13.2	12.4	11.5	10.6	10.2
25	10.7	11.3	12.0	12.7	13.3	13.7	13.5	13.0	12.3	11.6	10.9	10.6
20	11.0	11.5	12.0	12.6	13.1	13.3	13.2	12.8	12.3	11.7	11.2	10.9
15	11.3	11.6	12.0	12.5	12.8	13.0	12.9	12.6	12.2	11.8	11.4	11.2
10	11.6	11.8	12.0	12.3	12.6	12.7	12.6	12.4	12.1	11.8	11.6	11.5
5	11.8	11.9	12.0	12.2	12.3	12.4	12.3	12.3	12.1	12.0	11.9	11.8
0	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1

Note: Example shown is for Olgolcho, Chilalo, Arsi situated at $8^{o}1$ North. Use the value for 10^{o} North, thus for July it is 12.6, August 12.4 and September 12.1

In calculating sunshine n/N we require an estimate or recorded value for sunshine hours. Example the average value for Olgolcho in July is 5.1, then n/N is 5.1/12.6 = 0.40 which is low. In this case we refer to block IX in figure 1.

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thus you should refer to a map of your area to obtain the latitude of the site in question. All of Ethiopia is within Northern hemisphere thus the upper list of months applies. For example at 10° North of latitude and the value for January is 0.26 and for May 0.28 respectively.

Thus if we are interested in obtaining P values for say Olgolcho, chilalo, Arsi for the month of July, August and September, then using the mean month temperature data available we can calculate P for each of these months.

Thus

	July	**August**	**September**
T mean	19.5	19.2	18.2
P from table	0.29	0.28	0.28
P(0.46T+8)	0.29(0.46x19.5+8)		
	0.29 (16.97)		
	4.9 mm/day	4.7mm	4.7mm

Latitude for Olgocho is 8°N Nearest value is 10° north

In order to convert this value of P to ETo we need to refer figure 1, which predicts ETo from this series of graphs which take into account the effect of monthly humidity, wind and sunshine data which can be obtained from records or published weather descriptions. for example if no absolute values are available i.e. sunshine, wind run or humidity data, local knowledge can usually describe weather the relative humidity is high, wind light or moderated and whether sunshine hours are low, medium or high

In the wet season, humidities are generally high, wind light or moderate, and sunshine hours low. In the dry season humidities are medium (except Dire-Dawa, Borena, and the ogaden - which are low) winds usually light to moderate and sunshine hours medium to high.

Using the example of olgolcho, chilalo, Arsi, for July, relative humidity (RH) is high 50%, wind speed is low (U day time) i.e. between 0-2 m/sec. a wind speed of 2m/second is equivalent to a wind run or 172.8 km/day. This is the usual way wind is measured and quoted. Sunshine hours at Ologolcho are low, just over 5 hrs. we can obtain an estimate on n/N sunshine using table 2, which gives the mean daily duration of maximum possible sunshine (N) for different months and latitude. For ologolcho the latitude is 8° North, however the nearest figure we can refer to is 10°N. The value for northern latitudes in July is 12.6 hrs, thus the ratio or actual sunshine hours to maximum possible is n/N i.e. 5.1/12.6 = 0.40. This is in the low classification. The next step is to select the correct block/box, marked 1-X1 in figure 1. In our example the correct block/box is No.1X namely RH is high sunshine n/N is low, less than 0.45. Within this box we select also line 1 where U day time is low-between 0-2 m/Second. Using our previously calculated value 4.9 mm/day rounded to 5 mm take a vertical line from the

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horizontal axis or block IX which are for values of P and at its point of interception or sloping line 1, take a horizontal line towards the vertical axis which gives ETo mm/day. At Olgolcho for July, the ETo derived in this way is 2.8 mm/day. This example has been drawn to show the Methodology. For the months of August and September the technique is the same, except the sunshine hours are higher n/N is 5.8/12.4 = 0.46 and September 5.3/12.1 = 0.44.

Thus for August we should select block VI high RH, Medium sunshine and low wind, U daytime is between 0.2 m/second.

Note: Example shown is for olgolcho, chilalo, Arsi situated at 8° North, use the value for 10o North for July is 12.6 August 12.4 and 10^0 September 12.1. In calculating sunshine n/N we require an estimate or recorded value for sunshine hours. Example, the average value for Olgolcho in July is 5.1 then n/N 5.1/12.6 = 0.40 which is low.

In this case we refer to block IX in figure 1. Using the August value for P 4.7 we repeat the process and obtain an estimate of ETo of 3.3 mm/day, see example in figure,1 block VI.

For September, where P is also 4.7 we refer to block IX as also humidity is the same, sunshine hours are low n/N = 0.44.

Using line 1 in block IX we obtain an ETo of 2.7 mm/day . We have obtained the following estimate of ETo for the months of July, August and September, namely 2.8, 3.3 and 2.7 mm/day.

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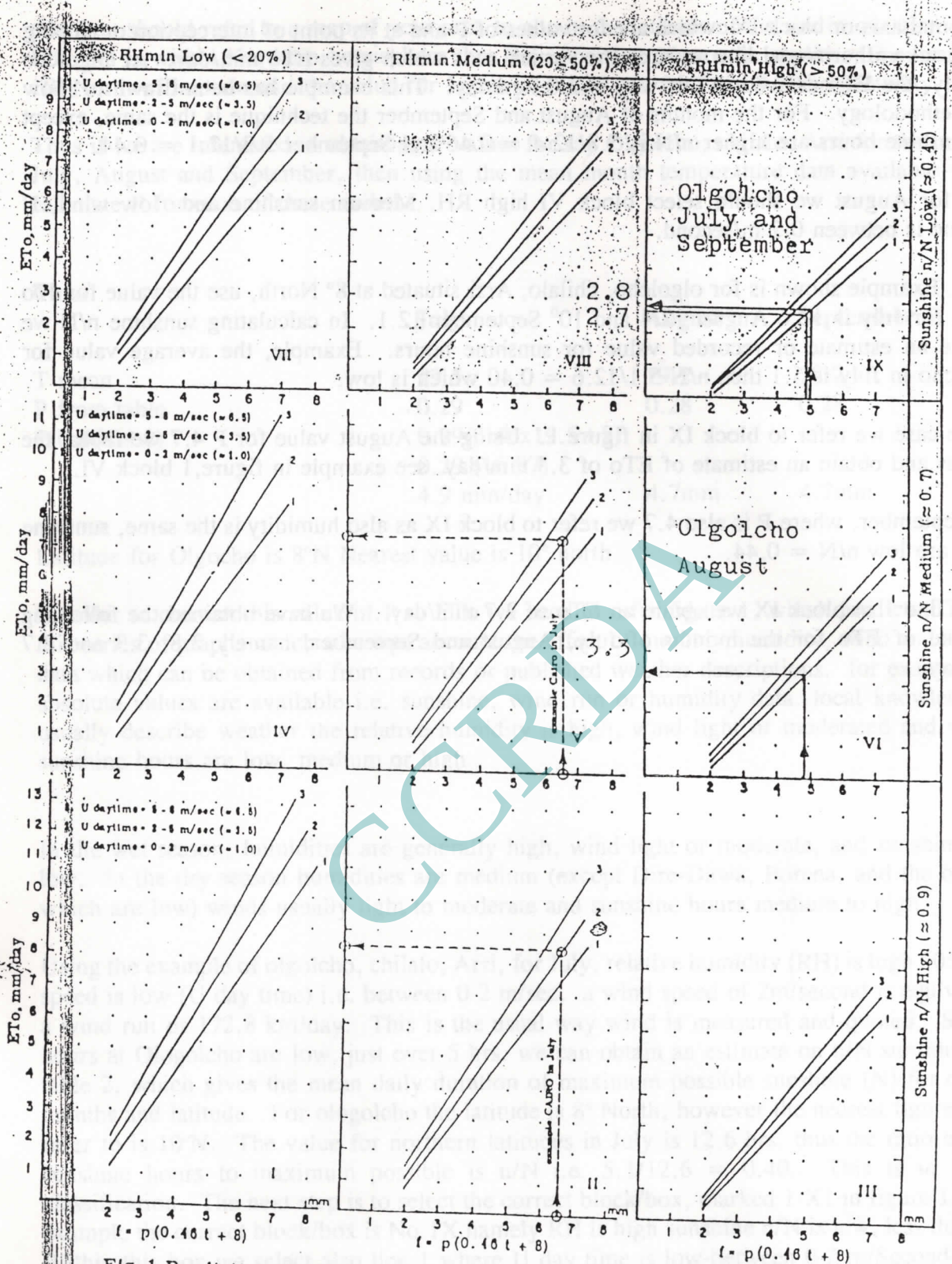


Fig. 1 Prediction of ETo from Blaney-Criddle f factor for different conditions of minimum relative humidity, sunshine duration and day time wind.

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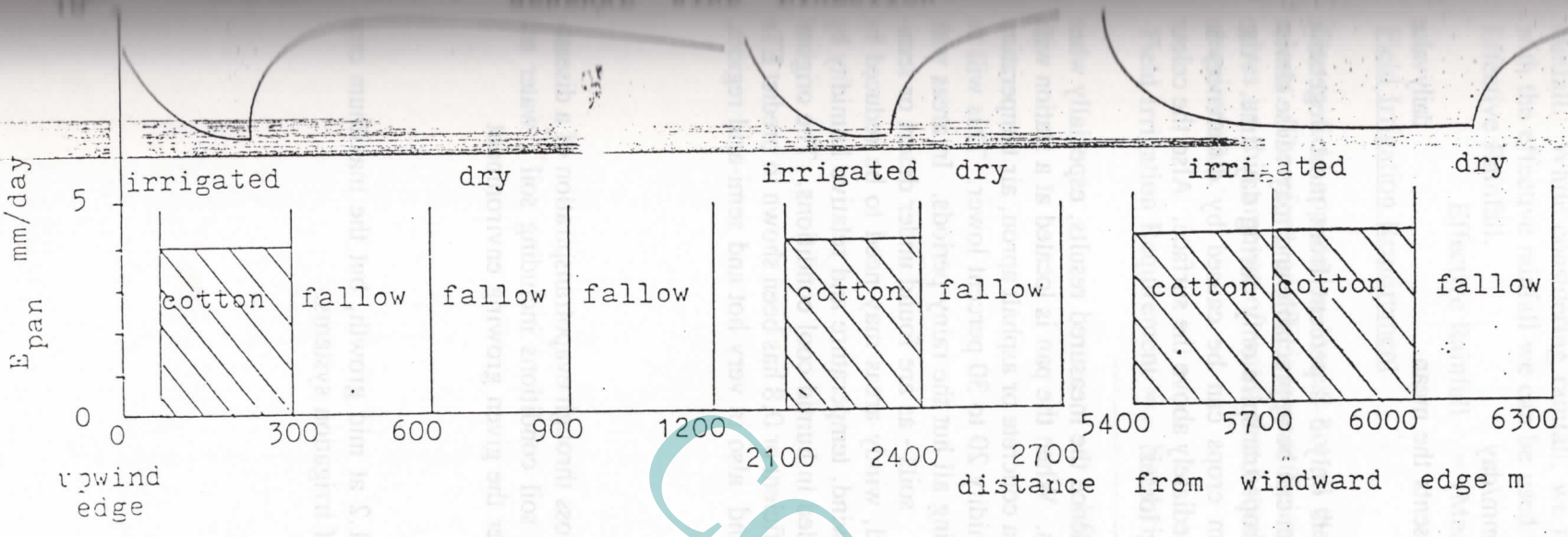
Calculating ETo from Pan Evaporation.

Pan evaporation (E pan) can be converted to ETo by multiplying it by a pan coefficient, KP. The value of this coefficient differs for different types of pan and for the same type of pan it varies with the relative humidity of the air and the speed of the wind at the time of measurement, and with the sitting of the pan in relation to crops and vegetation. The table below may be used as a guide to selecting the appropriate value for KP with American class A type evaporation pans.

Pan coefficients (KP) for American class A type evaporation pans.

Relative humidity	Cropped area			Dry-fallow area		
	Less than 40%	40-70%	Over 70%	Less than 40%	40-70%	Over 70%
Wind:-						
Light	0.65	0.75	0.85	0.60	0.70	0.80
Moderate	0.60	0.70	0.55	0.65	0.65	0.70
Strong	0.55	0.60	0.70	0.50	0.55	0.65
Very strong	0.50	0.55	0.60	0.40	0.50	0.55

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Variation with the size of the Development, Advection.

In arid and semi-arid climates, irrigated fields surrounded by extensive dry fallow areas are subject to advection. Airmasses moving into the irrigated fields gives up heat as it passes over. The result is a clothesline effect at the upwind edge and an oasis effect inside the irrigated field. With warm, dry winds, appreciably higher ET_{CROP} can be expected at the upwind edge of the field. With increased distance the air becomes cooler and more humid. The clothesline effect becomes negligible with increasing distance from the border which may extend in hot dry climates for 100m to 400m for windspeeds greater than 5m/sec.

It follows that due to the clothesline effect, results derived from irrigation trials carried out on a patchwork of small fields and located in dry surroundings may show up to double the ET_{CROP} as to that of future large schemes. Conversely, due to the oasis effect ET_{CROP} will be inflated in fields surrounded by dry fallow lands.

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Evaporation pans provide a measurement of integrated effect of radiation, wind, temperature and humidity on evaporation from specific water surface.

$ETo = K^p \times E^{pan}$

where ETo = Reference crop evapotranspiration mm/day
Kp = pan coefficient
E^{pan} = Pan evaporation in mm/day and represents the mean daily value of the period considered

Reflection of solar radiation from a water surface is only 5-8 percent from most vegetative surface 20-25 percent. Storage of heat within the pan can be appreciable and may cause almost equal evaporation during night and day, but most crops transpire only during day time. Also the difference in water losses from pans and from crops can be caused by differences in turbulence, temperature and humidity of the air immediately above the surface. Also the colour of the pans and the use of screens will affect water losses.

The sitting of the pan and the pan environment influence the measured results, especially when the pan is placed in fallow rather than cropped fields. When the pan is located at a station with very poor grass cover, dry bare soil or, undesirably, a concrete or asphalt apron, air temperature at pan level may be 2 to 5°c higher and relative humidity 20 to 30 percent lower. This will be most pronounced in arid and semi-arid climates during all hut the rainy periods. In areas with no Agricultural development and extensive areas of soils - as are found under desert or semi-desert conditions - the value of Kpan given for arid, windy areas may need to be reduced by upto 20 percent; for areas with moderate levels of wind, temperature and relative humidity by 5 to 10 percent; no or little reduction in K_{pan} is needed in humid cool conditions. The original penman Evaporation (Eo) equation using a crop coefficient or 0.8 has been shown to predict ETo closely, not only in cool, humid regions as in england also in very hot and semi-arid regions.

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Crop water requirement (ETo)

Def:- The depth of water needed to meet the water loss through evapotranspiration of a disease-free, growing in large fields under non restricting soil conditions including soil , water and fertility and achieving full production potential under the given growing environment

ETcr or ET crop

K.c may vary from 0.3 (short growing phase) to 1.2 at mid growth, but the maximum crop water requirements are significant for the Design of irrigation systems.

Net Irrigation Requirement

For planning irrigation, all aspects or crop water requirements have to be considered, including growing period, cultivation programme for each crop, and any possible contribution from rainfall. While considering rainfall, we must not use to measured rainfall data, but calculate with the effective rainfall we can be used by the plants. Net Irrigation Requirement = ETcr - Effective Rainfall.

Effective Rainfall = (Measured rainfall X 70%) - 10 mm

Field Irrigation Requirement

Due to field application losses, not all the water delivered to the field will be available to the plants. Therefore, an efficiency coefficient should be used. In divided by efficiency coefficient gives us this amount of water that actually has to be delivered to the field (Field Irrigation requirement).

$$\text{Field Irrigation Requirement} = \frac{\text{Net Irrigation requirement}}{\text{Efficiency coefficient}}$$

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Sample calculation of crop water requirement

Project Meki Ziway Crop Pepper Soil type Loam
Code _____ Variety Marko-fana _____
Region South Shewa Date _____ No. _____

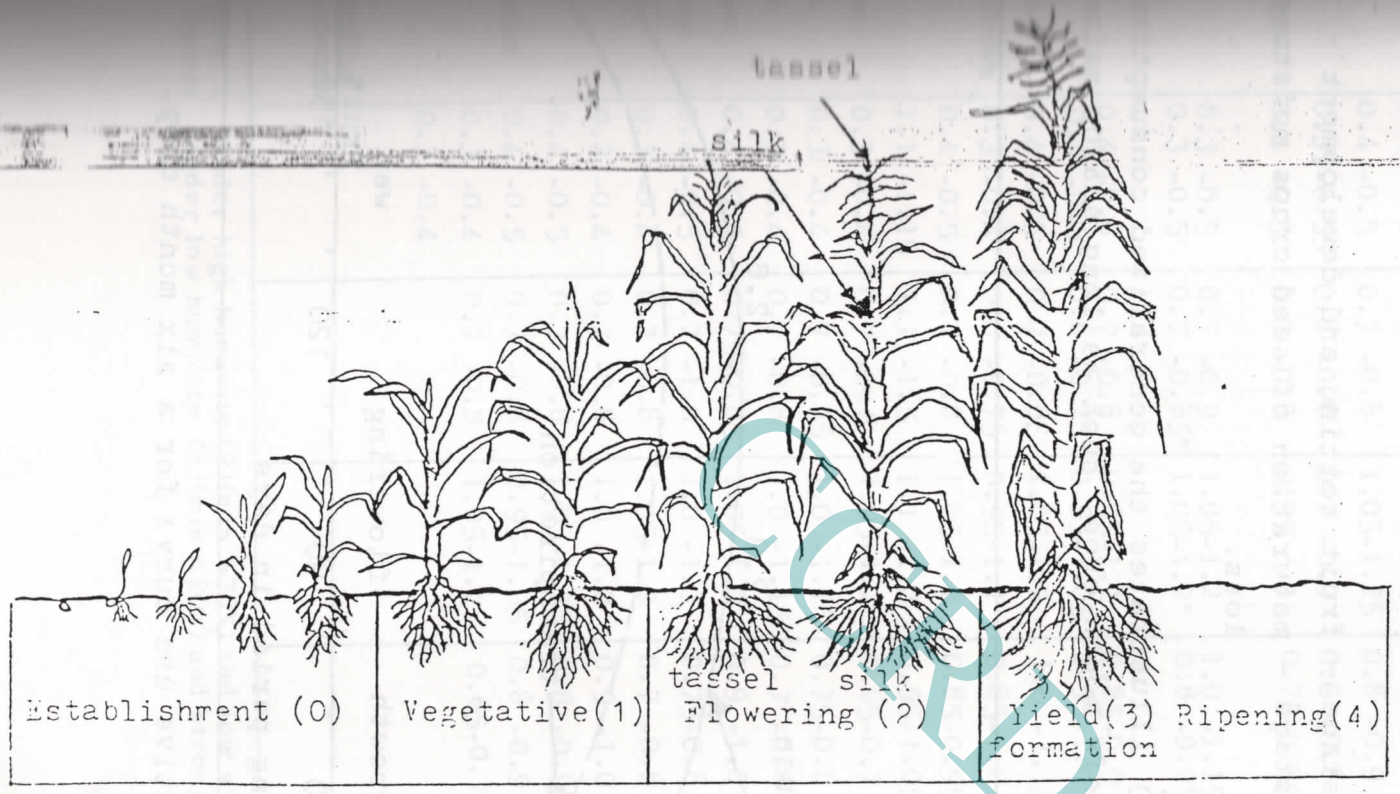
_____	J	F	M	A	M	J	A	S	O	N	D	
K.C		0.4	0.8	1.1	0.9							
ETo (mm)	133	129	153	145	141	143	126	125	112	134	133	125
ETcr (mm)		52	122	160	127							
Rainfall measured (mm)	18	31	29	46	66	78	126	110	96	37	-	-
Effective R.F.(mm)	3	12	10	22	36	45	78	67	57	16	-	-
Net Irrigation (mm)		40	112	138	91							
Field efficiency 50%												
Field Irrigation r. (mm)		80	224	276	182							
	Total water requirement = 80+224+276+182 = 762 mm 1mm of Irrigation water height equals to 10 m^3/ha = 762x10 m^3 = 7620m^3/ha.											

Exercise

Calculate the total volume of water per ha using the above data for the following crops.

Crop	K.C.	Planting months
1. Tomato	0.4,0.8,1.2,0.9,0.6	February
2. Papya	0.8	January
3. Banana	0.9	January

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Establishment (0)	Vegetative(1)	Flowering (2)	Yield formation (3)	Ripening(4)
15-25 days	25-50 days	15-30 days	35-50 days	10-25 days

NOTE! lower figures apply to 3 month cultivars, i.e. Katumani; higher values relavent for 6 month local cultivars.

THE GROWING PERIODS OF MAIZE.

CCRDA

The Consumption of Water by Plants

Stage of crop growth

The seasonal use of water by plants is determined by their stage of growth. The growth of a crop can be divided into four main stages:-

(i) Vegetative - From emergence to full vegetative development
(ii) Flowering -
(iii) Fruiting wet stage - fruit setting and development
(iv) Fruiting dry stage - maturation of seed crops moisture loss.

Figure 10 illustrates the generalized consumptive use of water for a six month crop, such as long season maize cultivars.

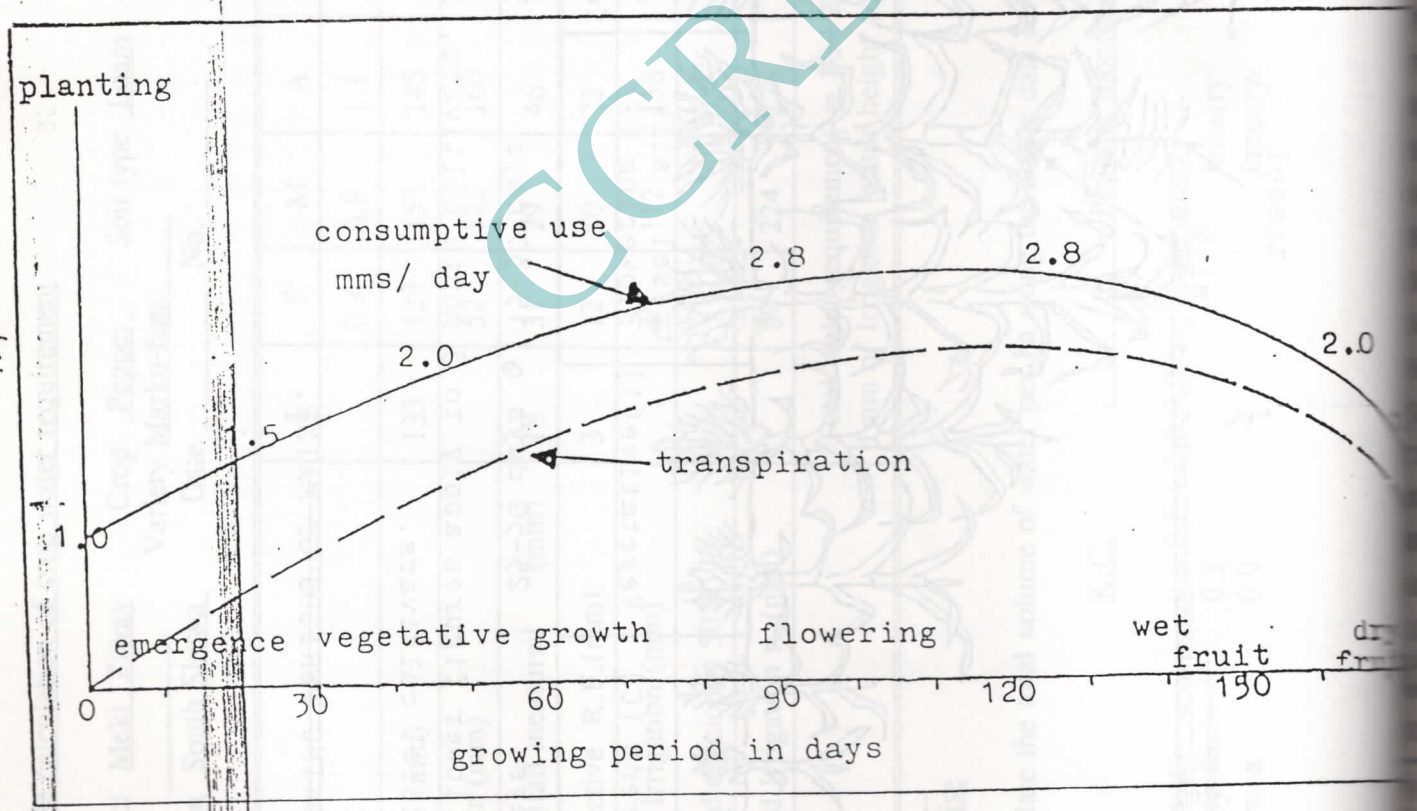


Figure 10 Consumptive use curve for a six month crop.

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Crop Coefficients (kc)

CROP	Crop Development stages					Total growing period
	Initial	Crop development	Mid-season	Late season	At harvest	
tropical	0.4 -0.5	0.7 -0.85	1.0 -1.1	0.9 -1.0	0.75-0.85	0.7 -0.8
ubtropical	0.5 -0.65	0.8 -0.9	1.0 -1.2	1.0 -1.15	1.0 -1.15	0.85-0.95
green	0.3 -0.4	0.65-0.75	0.95-1.05	0.9 -0.95	0.85-0.95	0.85-0.9
dry	0.3 -0.4	0.7 -0.8	1.05-1.2	0.65-0.75	0.25-0.3	0.7 -0.8
abbage	0.4 -0.5	0.7 -0.8	0.95-1.1	0.9 -1.0	0.8 -0.95	0.7 -0.8
arrot	0.4 -0.5	0.7 -0.8	1.05-1.25	0.8 -0.9	0.65-0.7	0.8 -0.9
auliflower	0.35-0.55	0.6 -0.8	0.7 -0.9	0.6 -0.8	0.55-0.7	0.55-0.75
roundnut	0.4 -0.5	0.7 -0.8	0.95 1.1	0.75-0.85	0.55-0.6	0.75-0.8
sweet	0.3 -0.5	0.7 -0.9	1.05-1.2	1.0 -1.15	0.95-1.1	0.8 -0.95
green	0.3 -0.5*	0.7 -0.85*	1.05-1.2*	0.8 -0.95	0.55-0.6*	0.75-0.9*
dry	0.4 -0.6	0.7 -0.8	0.95-1.1	0.85-0.9	0.75-0.85	0.8 -0.9
green	0.4 -0.6	0.6 -0.75	0.95-1.05	0.95-1.05	0.95-1.05	0.65-0.8
fresh	0.4 -0.5	0.7 -0.85	1.05-1.2	1.0 -1.15	0.95-1.1	0.8 -0.95
, fresh	0.3 -0.4	0.6 -0.75	0.95-1.1	0.85-1.0	0.8 -0.9	0.7 -0.8
	0.4 -0.5	0.7 -0.8	1.05-1.2	0.85-0.95	0.7 -0.75	0.75-0.9
	1.1 -1.15	1.1 -1.5	1.1 -1.3	0.95-1.05	0.95-1.05	1.05-1.2
lflower	0.3 -0.4	0.7 -0.8	1.05-1.2	0.65-0.7	0.2 -0.25	0.65-0.7
	0.3 -0.4	0.7 -0.75	1.0 -1.15	0.75-0.8	0.5 -0.55	0.75-0.85
	0.3 -0.4	0.7 -0.8	1.0 -1.15	0.7 -0.8	0.4 -0.5	0.75-0.9
garbeet	0.4 -0.5	0.75-0.85	1.05-1.2	0.9 -1.0	0.6 -0.7	0.8 -0.9
garcane	0.4 -0.5	0.7 -1.0	1.0 -1.3	0.75-0.8	0.5 -0.6	0.85-1.05
nflower	0.3 -0.4	0.7 -0.8	1.05-1.2	0.7 -0.8	0.35-0.45	0.75-0.85
	0.3 -0.4	0.7 -0.8	1.0 -1.2	0.9 -1.0	0.75-0.85	0.85-0.95
	0.4 -0.5	0.7 -0.8	1.05-1.25	0.8 -0.95	0.6 -0.65	0.75-0.9
termelon	0.4 -0.5	0.7 -0.8	0.95-1.05	0.8 -0.9	0.65-0.75	0.75-0.85
	0.3 -0.4	0.7 -0.8	1.05-1.2	0.65-0.75	0.2 -0.25	0.8 -0.9
	0.3 -0.4				1.05-1.2	0.85-1.05
weeding						0.65-0.75
ed control						0.85-0.9
						0.4 -0.6

figure : Under high humidity (RHmin >70%) and low wind (U <5 m/sec).
figure: Under low humidity (RHmin <20%) and strong wind (>5 m/sec).

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Appendix 2

Soil and water requirements of the major crops

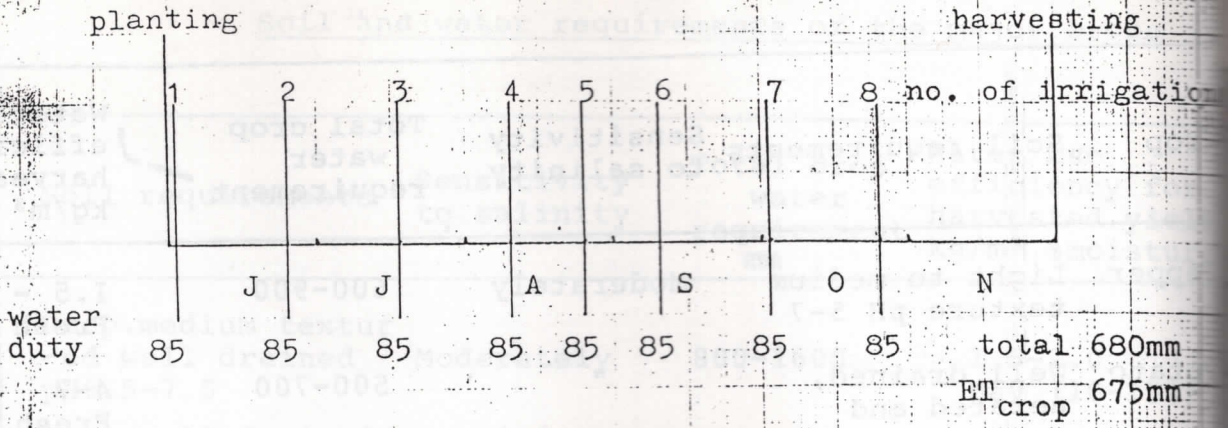
Crop	Soil requirements	Sensitivity to salinity	Total crop water requirement mm	Water use efficiency for harvested yield kg/m³ %moisture
Alfalfa	Deep.medium textur-ed well drained pH6.5-7.5	Moderately	800-1600	1.5-2.0 hay (10-15%)
Banana	Deep well drained loam PH 5-7	Sensitive	1200-2200	2.5-6.0 fruit (70%)
Bean	Deep friable,well drained & aerated PH 5.5-6.0	"	300-500	green(1.5-2.0 Dry 0.3-0.6(1
Cabbage	Well drained PH 6.0-6.5	Moderately	380-500	12-20 head 90-95%
Citrus	Deep well aerated light medium tex-ture PH 5-8	Sensitive	900-1200	2-5 fruit (55%)
Cotton	Deep,medium to heavy texture PH 7-8	Tolerant	700-1300	0.4-0.6 Seed cotton
Grape	Well drained,light soils preferred	Moderately	500-1200	2-4 fresh fruit 80%
Ground nut	Well drained fri-able,medium texture loss top soil PH, 5.5 -7	"	500-700	0.6 -0.8 unshelled nu 15%
Maize	Well drained and aerated, deep water table, no water logging PH 5-7	"	500-800	0.8 - 1.6 grain (13%)
Onion	Medium textured PH 6-7	Sensitive	350-550	8-10 bulb (55-90%
Pea	Well drained PH 5.5-6.5	"	350-500	Fresh 0.5-0.7 (70-80%) Dry 0.5-0.2 (12%)

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Crop	Soil requirements	Sensitivity to salinity	Total crop water requirement	Water use efficiency for harvested yield kg/m³ %moisture
Pepper	Light to medium texture pH 5-7	Moderately	600-900	1.5 - 3.0 Fresh fruit(90%)
Potato	Well drained, aerated and porous	"	500-700	4-7 Fresh tuber (70-75%)
Rice	Heavy soils high tolerance to oxygen deficit pH 5.5-6.0	"	350-700	0.7 - 1.1 Paddy(15-20%)
Safflower	Fairly deep well drained, medium Texture pH 6-8	Moderately tolerant	600-1200	0.2 - 0.5 Seed (8-10%)
Sorghum	Light to medium/ heavy relatively tolerant to water logging pH 6-8	"	450-650	0.6 -1.0 Grain(6-10%)
Soybean	Wide range except sandy well drained pH 6-6.5	"	450-700	0.4-0.7 Grain (6-10%)
Sugarcane	Deep well drained water table >1.5-2.0 pH 5-8.5	"	1500-2500	Cane 5-8(80%) Sugar 0.6-1.0(10%
Sunflower	Fairly deep soils pH 6-7.5		600-1000	0.3 - 0.5 Seed (6-10%)
Tomato	Light loam, well drained without water logging pH 5-7	Moderately	400-600	10 -12 Fresh fruit (80-90%)
Water melon	Sandy loam pH 5.8 - 7.2	"	400-600	10-12 Fresh fruit (80-90%)
Wheat	Medium texture relatively tolerant to high water table pH 6-8	Moderately tolerant	450-650	0.8-1.0 Grain(12-15%)

Source:- J.Doorenbos and A.H.Kassem " Yield response to water " Irrigation and drainage paper No. 33 FAO, Rome, 1986.

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Example of irrigation scheduling for a six month maize crop growing at Sheled, Chilalo, Arsi planted in June
Note effective rainfall not included in this illustration

Note. effective rainfall not included in this illustration.

It can be seen from this first example for maize grown for dry grain that the increasing crop water requirement which reaches its peak during tasseling of the maize is met by decreasing the time between irrigation from 21 days (irrigation 1-3) to 14 days (irrigation 4 & 5) during peak crop water demand, resuming the 21 day cycle for irrigation 6-8. The first irrigation immediately follows planting and the last is applied around 135 days later allowing the crop to mature on the residual soil moisture. A fixed water duty of 85mm is applied to the root zone at each irrigation.

The second example is an actual one used for large scale irrigated cotton production in the Middle Awash Valley where the seasonal ET_{CROP} calculated from agro-ecological data at Melka Warer and confirmed (1980) from crop water requirement experiments at I.A.R. Melka Warer, is 930 mms.

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ESTIMATED IRRIGATION SCHEDULES FOR THE MAJOR FIELD CROPS DURING PEAK WATER USE PERIODS

	Shallow and/or sandy soil			loamy soil			clayey soil		
	Interval (days)		Net irr. depth (mm)	Interval (days)		Net irr. depth (mm)	Interval (days)		Net irr. depth (mm)
climate	1	2		1	2		1	2	
	9	6	40	13	9	60	16	11	70
	5	3	25	7	5	40	10	7	55
ley/Oats	8	6	40	11	8	55	14	10	70
	6	4	30	8	6	40	10	7	50
	9	6	40	13	9	60	16	11	70
	6	4	25	7	5	35	11	8	50
	8	6	30	11	8	40	15	10	55
	9	6	40	13	9	60	16	11	70
	8	6	40	11	8	55	14	10	70
ber	10	7	40	15	10	60	17	12	70
ers*	3	2	15	4	3	20	7	5	30
	6	4	30	8	6	40	10	7	50
	8	6	40	11	8	55	14	10	70
trees	9	6	40	13	9	60	16	11	70
, small	8	6	40	11	8	55	14	10	70
	11	8	40	15	11	55	19	13	70
	9	6	40	13	9	60	16	11	70
nuts	6	4	25	7	5	35	11	8	50
	6	4	30	8	6	40	10	7	50
	3	2	15	4	3	20	7	5	30
	8	6	40	11	8	55	14	10	70
	9	6	40	13	9	60	16	11	70
	8	6	40	11	8	55	14	10	70
	11	8	40	15	11	55	19	13	70
	3	2	15	4	3	20	7	5	30
	6	4	30	8	6	40	10	7	50
	6	4	25	7	5	35	11	8	50
	6	4	30	8	6	40	10	7	50
	4	3	15	5	4	20	7	5	30
	8	6	40	11	8	55	14	10	70
	8	6	40	11	8	55	14	10	70
	8	6	40	11	8	55	14	10	70
	3	2	15	4	3	20	7	5	30
	10	7	40	15	10	60	17	12	70
	8	6	40	11	8	55	14	10	70
	7	5	40	10	7	55	13	9	70
	8	6	40	11	8	55	14	10	70
	9	6	40	13	9	60	16	11	70
	6	4	30	8	6	40	10	7	50
	6	4	30	8	6	40	10	7	50
	8	6	40	11	8	55	14	10	70

cauliflower, etc.

figures are nett irrigation requirements, i.e. at the zone; gross ammount takes into account the field irrigation efficiency, 0.6. Thus gross irrigation requirement is $\frac{\text{nett}}{6} \times 10$

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Table 32 Critical Periods for Soil Water Stress for Different Crops

Alfalfa	just after cutting for hay and at the start of flowering for seed production
Apricots	period of flower and bud development
Barley	early boot stage > soft dough stage > onset of tillering or ripening stage
Beans	flowering and pod setting period > earlier > ripening period. However, ripening period > earlier if not prior water stress.
Broccoli	during head formation and enlargement
Cabbage	during head formation and enlargement
Castor bean	requires relatively high soil water level during full growing period
Cauliflower	requires frequent irrigation from planting to harvesting
Cherries	period of rapid growth of fruit prior to maturing
Citrus	flowering and fruit setting stages; heavy flowering may be induced by withholding irrigation just before flowering stage (lemon); "June drop" of weaker fruits may be controlled by high soil water levels
Cotton	flowering and boll formation > early stages of growth > after boll formation
Groundnuts	flowering and seed development stages > between germination and flowering and end of growing season
Lettuce	requires wet soil particularly before harvest
Maize	pollination period from tasselling to blister kernel stages > prior to tasselling > grain filling periods; pollination period very critical if no prior water stress
Oats	beginning of ear emergence possibly up to heading
Olives	just before flowering and during fruit enlargement
Peaches	period of rapid fruit growth prior to maturity
Peas	at start of flowering and when pods are swelling
Potatoes	high soil water levels; after formation of tubers, blossom to harvest
Radish	during period of root enlargement
Sunflower	possibly during seeding and flowering - seed development stage
Small grains	boot to heading stage
Sorghum	secondary rooting and tillering to boot stage > heading, flowering and grain formation > grain filling period
Soybeans	flowering and fruiting stage and possibly period of maximum vegetative growth
Strawberries	fruit development to ripening
Sugarbeet	3 to 4 weeks after emergence
Sugarcane	period of maximum vegetative growth
Tobacco	knee high to blossoming
Tomatoes	when flowers are formed and fruits are rapidly enlarging
Turnips	when size of edible root increases rapidly up to harvesting
Water melon	blossom to harvesting
Wheat	possibly during booting and heading and two weeks before pollination

CCRDA

IDD

Cropping Pattern : _____ Project (_____ ha)

ETH

Area (hc / %)

Jan.										
Febr.										
March										
April										
May										
June										
July										
August										
Sept.										
Octob.										
Novem.										
Decem.										

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CROP SELECTION AND MANAGEMENT

1. GENERAL

1.1 Crop Selection

The choice of crops for a proposed project (WH or irrigated) depends on factors falling into three broad areas. ie. **physical, social** and **economic.**

1.1.1 physical considerations

Physical factors to be considered in the choice of crops suitable for the area are:-

- Altitude
- Temperature, mean, max, min (frost hazard)
- Rain fall
- Soils, texture, depth, drainage, fertility, salinity, sodicity.
- Water quality (Salinity, sodium hazard, boron, chloride bicarbonate) and quantity
- Significant threats to crops.

  (animals, pests, diseases)

Table 1 lists the environmental preferences of a number of crops.

1.1.2 Social Considerations

The technical sophistication of the intended beneficiaries of the project is of great importance in the selection of crops; account should be taken of their agricultureal background. If crops requireing a high level of skill in their cultivation are recommended for a target group of resettled pastoralists, the result is likely to be **a failure.**

If all or part of the project's produce is intended for cosumption by the producers, then their food preferences must be taken into account.

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Table 1 Environmental preferences of crops

Crop	Altitude (m)	Mean temp for growing period (deg. C)	Growing period (days)	Rainfall during growing period (mm)	Soil texture, drainage	Input level
Barley	2500-3000	12.5-17.5	120-180	400-800	L-Sc	L/M
	1500-2000	7.5-12.5	90-120	200-400	SL/SiL-C	
		17.5-22.5		800-1200		
Malting barley	2000-3000	12.5-17.5	150-180	500-800	L-Sc	L/M
	1500-2000	7.5-12.5	120-150	400-500	SL/SiC-C(b)	
	3000-3500	17.5-22.5		800-1200		
Wheat	2000-2600	15.0-20.0	120-160	500-800	L-C(r)	L/M
	1500-2000	12.5-15.0	90-120	400-500	SL/C(b)	
	2600-3000	20.0-22.5		800-1200		
Oats	2200-3000	12.5-17.5	90-120	600-1000	SL-SiCL	L/M
	1800-2200	7.5-12.5	75-90	500-600	LS/SC-C(r)	
	3000-3800	17.5-20.0		1000-1300		
Teff	1700-2400	15.0-20.0	90-120	400-600	SiLC(b)	L/M
	1000-1700	12.5-15.0	45-90	200-400	L-SCL	
	2400-2800	20.0-25.0		600-800		
Maize (lowland)	400-1400	22.5-30.0	120-150	600-900	L-SC	L/M
	0-400	20.0-22.5	90-120	400-600	LS-SL/SiC-C(r)	
	1400-1800	30.0-32.5		900-1200		
Maize (highland)	1300-2200	17.5-22.5	150-210	700-1200	L-SC	L/M
	1000-1300	15.5-17.5	120-150	600-700	LS-SL/SiC-C(r)	
	2200-2400	22.5-25.0		1200-1500		
Sorghum (lowland)	1000-1600	20.0-25.0	150-210	600-800	L-C(r)	L/M
	0-1000	17.5-20.0	90-150	300-600	LS-SL/C(b)	
	1600-1900	25.0-32.5		800-1100		
Sorghum (highland)	1500-2200	17.5-22.5	180-210	800-1000	L-SC	L/M
	1200-1500	15.0-17.5	150-180	1000-1200	LS-SL/SiC-C(b)	
	1000-1500	22.5-25.0				
Finger millet	1000-1200	20.0-25.0	90-150	500-900	SL-SC	L/M
	500-1000	17.5-20.0	75-90	300-500	LS/SiC-C(r)	
	1200-2200	25.0-27.5		900-1300		
Paddy	0-1500	22.5-32.5	180-365	Abundant	SCL-C(r)	L/M
	1500-2000	17.5-22.5	150-180		SL-S/C(b)	
Horse bean	2000-3000	12.5-17.5	120-150	650-900	SiL-C(r)	L/M
	1600-2000	10.0-12.5	90-120	500-650	L-SCL/C(b)	
	3000-3200	17.5-20.0		900-1200		
Field pea	2200-3000	12.5-17.5	90-120	500-900	SL-CL	L/M
	1800-2200	10.0-12.5	75-90	350-500	LS/SiCL-C(r)	
	3000-3200	17.5-22.5		900-1000		

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Altitude (m)	Mean temp for growing period (deg. C)	Growing period (days)	Rainfall during Growing period (mm)	Soil texture, drainage	Input level
2200-3000	12.5-17.5	120-150	650-900	LS-C(r)	L/M
1800-2200	10.0-12.5	75-120	500-650		
3000-3200	17.5-20.0		900-1200		
1800-2400	15.0-20.0	120-150	650-700	L-SiC	L/M
1200-1800	12.5-15.0	90-120	550-650	LS-SL/C(r)	
2400-2800	20.0-22.5		700-1000		
1000-1500	20.0-25.0	120-150	700-1000	L-CL	L/M
600-1000	17.5-20.0	90-120	1000-1500	SL/SiCl-C(r)	
1500-1800	25.0-27.5		600-700		
1400-1800	20.0-22.5	90-120	500-1000	SL-C(r)	L/M
1000-1400	17.5-20.0	75-90	400-500	LS/C(b)	
1800-2100	22.5-25.0		1000-1500		
0-1500	22.5-30.0	90-120	500-1000	L-SiC	L/M
1500-1700	20.0-22.5	75-90	400-500	LS-SL/C(r)-C(b)	
			1000-1500		
2200-3000	12.5-17.5	150-180	500-800	SiL-SiC	L/M
1600-3000	10.0-12.5	120-150	400-500	LS-SCL/C(r)	
3000-3200	17.5-20.0		800-1000		
1700-2000	17.5-20.0	120-150	600-800	L-SC	L/M
1100-1700	15.0-17.5	90-120	400-600	LS-SL/SiC(b)	
2000-2400	20.0-25.0		800-1000		
2000-2600	15.0-17.5	150-180	600-900	SL-SiCL	L/M
1500-2000	12.5-15.0	90-150	400-600	LS/SC-SiC	
2600-3000	17.5-20.0		900-1200		
1500-2000	17.5-22.5	120-150	800-1100	L-SiC	L/M
1400-1500	15.0-17.5	90-120	600-800	SL/C(r)-C(b)	
2000-2400	22.5-25.0		1100-1500		
1100-2200	17.5-25.0	90-150	500-1000	LS-SCL	L/M
0-1100	12.5-17.5	75-90	400-500	SiL-SiC	
2200-2400	25.0-30.0		1000-1200		
0-1500	25.5-32.5	90-150	500-700	SL-CL	L/M
1500-1500	20.0-25.5	75-90	400-500	LS/SiCL-C	
			700-1000		
0-1000	25.0-32.5	120-150	500-700	SL-SCL	L/M
1000-1500	20.0-25.0	90-120	400-500	LS/SiL-C(r)	
			700-1200		

CCRDA

Crop	Altitude (m)	Mean temp for growing period (deg. C)	Growing period (days)	Rainfall during growing period (mm)	Soil texture, drainage	Input level
Soyabean	900-1800	20.0-27.5	120-150	600-1000	L-SC	L/M
	400-900	17.5-20.0	90-120	500-600	SL-SiC-C(r)	
	1800-2200	27.5-32.5		1000-1200		
Potato	2200-2800	12.5-17.5	120-180	600-1000	L-SiCL	L/M
	1800-2200	10.0-12.5	90-120	400-600	LS-SL/SC-C(r)	
	2800-3200	17.5-20.0		1000-1200		
Sugarbeet	2200-2800	12.5-17.5	180-240	800-1100	L-SiC	L/M
	1800-2200	10.0-12.5	150-180	700-800	SL/C(r)	
				1100-1500		
Enset	2000-2500	15.0-20.0	270-365	1100-1500	L-C(r)	L/M
	1500-2000	10.0-15.0	210-270	800-1100	SL	
	2500-3200	20.0-22.5		1500-2000		
Taro	0-1800	20.0-30.0	210-270	>1750	SiL-C(b)	L/M
	1800-2100	17.5-20.0	180-210	1500-1750	L-SCL	
Sweet potato	0-1800	20.0-32.5	120-160	500-1000	SL-SiCL	L/M
	1800-2100	17.5-20.0	90-120	400-500	LS/SC-C(r)	
				1000-1200		
Cassava	0-1000	25.0-30.0	240-330	800-1500	LS-SiCL	L/M
	1000-1500	20.0-25.0	150-240	500-800	SC-C(r)	
				1500-2500		
Cotton	500-1300	22.5-27.5	130-180	600-900	L-SC	L/M
	0-500	20.0-22.5	120-130	450-600	SL/SiC-C(b)	
	1300-1800	27.5-32.5		900-1500		
					SL-C(r)	H
Sisal	0-1500	22.5-30.0	180-365	1000-1250	LS	
	1500-2200	17.5-22.5	120-180	600-1000		
				1250-1600		
Kenaf	800-1500	20.0-25.0	120-150	500-750	SL-CL	H
	500-800	15.0-20.0	90-120	350-500	LS/SiCL-C(r)	
	1500-2400	25.0-27.5				
Citrus	1000-1600	20.0-25.0	300-330	900-1200	L-SC	L/M
	500-1000	17.5-20.0	210-300	700-900	LS-SL/SiC	
	1600-1800	25.0-27.5		1200-1500		
Grape	1500-2000	17.5-22.5	150-180	700-900	LS-SCL	H
	1000-1500	15.0-17.5	120-150	500-700	SiL-SiC	
	2000-2100	22.5-25.0	180-210	900-1000		
Banana	0-1600	20.0-30.0	300-365	1500-2000	L-C(r)	L/M
	1600-1900	17.5-20.0	240-300	1000-1500	SL	
				2000-3000		

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	Altitude (m)	Mean temp for growing period (deg. C)	Growing period (days)	Rainfall during growing period (mm)	Soil texture, drainage	Input level
[illegible]	1500-1800	20.0-22.5	240-300	1300-1600	L-C(r)	L/M
	1100-1500	17.5-20.0	180-240	900-1300	SL	
	1800-2200	22.5-25.0		1600-2000		
[illegible]	1200-2000	17.5-22.5	300-365	>1500	L-C(r)	H
	1000-1200	15.0-17.5	240-300	1200-1500	SL	
	2000-2400	22.5-25.0				
[illegible]	1000-1500	20.0-25.0	150-180	400-800	L-SiL	L/M
	700-1000	17.5-20.0	120-150	300-400	LS-SL/CL-C(r)	
	1500-1900	25.0-27.5		800-1000		
[illegible]	2200-2800	12.5-17.5	300-365	900-1200	L-SC	L/M
	1900-2200	10.0-12.5	270-300	800-900	LS-SL/SiC	
	2800-3000	17.5-20.0		1200-2000		
[illegible]	1000-2000	17.5-25.0	150-240	600-900	LS-CL	L/M
	600-1000	15.0-17.5	120-150	500-600	SiCL-SC	
	2000-2400	25.0-27.5		900-1200		
[illegible]	600-1500	22.5-27.5	300-365	2000-2500	SiL-C(r)	L/M
	0-600	17.5-22.5	270-300	1300-2000	SL-SCL/C(b)	
	1500-2000	27.5-32.5		2500-4000		

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1.1.3 Economic Considerations

If some or all the produce from the project is intended for sale, its marketability must be established. This depends on several factors which will determine **what** can be produced and **how much.**

For food crops, consideration must be given to the food preference of the target market. The target market must be large enough and prosperous enough to absorb the proposed amount of produce. If the target market is a long way from the project area, the value of the produce must be such that the cost of tranport to the market is justified.

For specifically cash crops it must be demonstrated that there is a market that will assure the producer of an adequate income.

1.2 Cropping Pattern and Cropping Intensity

Once crops have been selected, one or more cropping patterns must be proposed. If conditions (usually **Soil** or **topography** are markedly different in different parts of the project, the proposal of more than one cropping pattern may be justified.

A cropping pattern shows **what** crops are grown, **how much** of each crop is grown, **when** it is **planted** and **when** it is **harvested.** An example is given in fig. 1. The four principal factors governing the choice of **cropping pattern** are :-

- Climate
- Crop rotation
- Labour availability
- Water availability

1.2.1 Climatic Considerations

The first step is to determine which crops ore **climatically** suitable to be grown in the area being considered.

With regard to the effect of **climate,** full advantage should be taken of the rainy **reason(s)** to maximize the use of **rain water** for cropping. If cropping is already practised in the area, the existing planting times will probabley be followed fairly closely. The prevailing **temperature,** particularly incidences of frost hazard (low temperature) must be given due considerations.

The next step is estimate the length of the growing period for the various crops under consideration, taking into account the time required to prepare the land, plant the crop and harvest. Table 2 indicates growing seasons of various crops.

2.2. Other Considerations

Having arrived at a list of suitable crops, which reflects their climatic requirements, (table 3) farmer experience and preference etc, it is important to plan how the various crops should be grown during the entire calander year taking into consideration particularly:

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- Crop rotation for reason of disease avoidence avoidance of ---- up of pests, maintenance of soil fertility etc.

- Making the most efficent use of land & water in terms of crop production.

- Labour availabilty and size of holding different crops need different numbers of mandays, oxendays for their cultivation and for their cultivation and harvesting. An example of those requirements is given for Sorghum in tables 4 and 5.

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Table 22 Length of Growing Season and Crop Development Stages of Selected Field Crops; Some Indications

Artichokes	Perennial, replanted every 4-7 years; example Coastal California with planting in April 40/40/250/30 and (360)1/; subsequent crops with crop growth cutback to ground level in late spring each year at end of harvest or 20/40/220/30 and (310).
Barley	Also wheat and oats; varies widely with variety; wheat Central India November planting 15/25/50/30 and (120); early spring sowing, semi-arid, 35°-45° latitudes and November planting Rep. of Korea 20/25/60/30 and (135); wheat sown in July in East African highlands at 2 500 m altitude and Rep. of Korea 15/30/65/40 and (150).
Beans (green)	February and March planting California desert and Mediterranean 20/30/30/10 and (90); August-September planting California desert, Egypt, Coastal Lebanon 15/25/25/10 and (75).
Beans (dry) Pulses	Continental climates late spring planting 20/30/40/20 and (110); June planting Central California and West Pakistan 15/25/35/20 and (95); longer season varieties 15/25/50/20 and (110).
Beets (table)	Spring planting Mediterranean 15/25/20/10 and (70); early spring planting Mediterranean climates and pre-cool season in desert climates 25/30/25/10 and (90).
Carrots	Warm season of semi-arid to arid climates 20/30/30/20 and (100); for cool season up to 20/30/80/20 and (150); early spring planting Mediterranean 25/35/40/20 and (120); up to 30/40/60/20 and (150) for late winter planting.
Castorbeans	Semi-arid and arid climates, spring planting 25/40/65/50 and (180).
Celery	Pre-cool season planting semi-arid 25/40/95/20 and (180); cool season 30/55/105/20 and (210); humid Mediterranean mid-season 25/40/45/15 and (125).
Corn (maize) (sweet)	Philippines, early March planting (late dry season) 20/20/30/10 and (80); late spring planting Mediterranean 20/25/25/10 and (80); late cool season planting desert climates 20/30/30/10 and (90); early cool season planting desert climates 20/30/50/10 and (110).
Corn (maize) (grains)	Spring planting East African highlands 30/50/60/40 and (180); late cool season planting, warm desert climates 25/40/45/30 and (140); June planting sub-humid Nigeria, early October India 20/35/40/30 and (125); early April planting Southern Spain 30/40/50/30 and (150).

1/ 40/40/250/30 and (360) stand respectively for initial, crop development, mid-season and late season crop development stages in days and (360) for total growing period from planting to harvest in days.

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Cotton	March planting Egypt, April-May planting Pakistan, September planting South Arabia 30/50/60/55 and (195); spring planting, machine harvested Texas 30/50/55/45 and (180).
Crucifers	Wide range in length of season due to varietal differences; spring planting Mediterranean and continental climates 20/30/20/10 and (80); late winter planting Mediterranean 25/35/25/10 and (95); autumn planting Coastal Mediterranean 30/35/90/40 and (195).
Cucumber	June planting Egypt, August-October California desert 20/30/40/15 and (105); spring planting semi-arid and cool season arid climates, low desert 25/35/50/20 and (130).
Egg plant	Warm winter desert climates 30/40/40/20 and (130); late spring-early summer planting Mediterranean 30/45/40/25 and (140).
Flax	Spring planting cold winter climates 25/35/50/40 and (150); pre-cool season planting Arizona low desert 30/40/100/50 and (220).
Grain, small	Spring planting Mediterranean 20/30/60/40 and (150); October-November planting warm winter climates; Pakistan and low deserts 25/35/65/40 and (165).
Lentil	Spring planting in cold winter climates 20/30/60/40 and (150); pre-cool season planting warm winter climates 25/35/70/40 and (170).
Lettuce	Spring planting Mediterranean climates 20/30/15/10 and (75) and late winter planting 30/40/25/10 and (105); early cool season low desert climates from 25/35/30/10 and (100); late cool season planting, low deserts 35/50/45/10 and (140).
Melons	Late spring planting Mediterranean climates 25/35/40/20 and (120); mid-winter planting in low desert climates 30/45/65/20 and (150).
Millet	June planting Pakistan 15/25/40/25 and (105); central plains U.S.A. spring planting 20/30/55/35 and (140).
Oats	See Barley.
Onion (dry)	Spring planting Mediterranean climates 15/25/70/40 and (150); pre-warm winter planting semi-arid and arid desert climates 20/35/110/45 and (210).
(green)	Respectively 25/30/10/5 and (70) and 20/45/20/10 and (95).
Peanuts (groundnuts)	Dry season planting West Africa 25/35/45/25 and (130); late spring planting Coastal plains of Lebanon and Israel 35/45/35/25 and (140).
Peas	Cool maritime climates early summer planting 15/25/35/15 and (90); Mediterranean early spring and warm winter desert climates planting 20/25/35/15 and (95); late winter Mediterranean planting 25/30/30/15 and (100).

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Peppers	Fresh - Mediterranean early spring and continental early summer planting 30/35/40/20 and (125); cool coastal continental climates mid-spring planting 25/35/40/20 and (120); pre-warm winter planting desert climates 30/40/110/30 and (210).
Potato (Irish)	Full planting warm winter desert climates 25/30/30/20 and (105); late winter planting arid and semi-arid climates and late spring-early summer planting continental climate 25/30/45/30 and (130); early-mid spring planting central Europe 30/35/50/30 and (145); slow emergence may increase length of initial period by 15 days during cold spring.
Radishes	Mediterranean early spring and continental summer planting 5/10/15/5 and (35); coastal Mediterranean late winter and warm winter desert climates planting 10/10/15/5 and (40).
Safflower	Central California early-mid spring planting 20/35/45/25 and (125) and late winter planting 25/35/55/30 and (145); warm winter desert climates 35/55/60/40 and (190).
Sorghum	Warm season desert climates 20/30/40/30 and (120); mid-June planting Pakistan, May in mid-West U.S.A. and Mediterranean 20/35/40/30 and (125); early spring planting warm arid climates 20/35/45/30 and (130).
Soybeans	May planting Central U.S.A. 20/35/60/25 and (140); May-June planting California desert 20/30/60/25 and (135); Philippines late December planting, early dry season - dry: 15/15/40/15 and (85); vegetables 15/15/30/- and (60); early-mid June planting in Japan 20/25/75/30 and (150).
Spinach	Spring planting Mediterranean 20/20/15/5 and (60); September-October and late winter planting Mediterranean 20/20/25/5 and (70); warm winter desert climates 20/30/40/10 and (100).
Squash (winter) pumpkin	Late winter planting Mediterranean and warm winter desert climates 20/30/30/15 and (95); August planting California desert 20/35/30/25 and (110); early June planting maritime Europe 25/35/35/25 and (120).
Squash (zucchini) crookneck	Spring planting Mediterranean 25/35/25/15 and (100+); early summer Mediterranean and maritime Europe 20/30/25/15 and (90+); winter planting warm desert 25/35/25/15 and (100).
Sugarbeet	Coastal Lebanon, mid-November planting 45/75/80/30 and (230); early summer planting 25/35/50/50 and (160); early spring planting Uruguay 30/45/60/45 and (180); late winter planting warm winter desert 35/60/70/40 and (205).
Sunflower	Spring planting Mediterranean 25/35/45/25 and (130); early summer planting California desert 20/35/45/25 and (125).
Tomato	Warm winter desert climates 30/40/40/25 and (135); and late autumn 35/45/70/30 and (180); spring planting Mediterranean climates 30/40/45/30 and (145).
Wheat	See Barley.

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Table 2

CLIMATIC, SOIL AND WATER REQUIREMENTS FOR CROPS

Crop	Total growing period (days)	Temperature requirements for growth, °C optimum[1] (range)	Daylength requirements for flowering	Specific climatic constraints/ requirements	Soil requirements
Alfalfa	100-365	24-26 (10-30)	Day neutral	Sensitive to frost; cutting interval related to temp.; requires low RH in warm climates	Deep, medium-textured, well-drained, pH = 6.5-7.5
Banana	300-365	25-30 (15-35)	Day neutral	Sensitive to frost; temp. <8°C for longer periods causes serious damage; requires high RH, wind < 4 m/sec	Deep, well-drained loam without stagnant water; pH = 5-7
Bean	fresh: 60-90 dry : 90-120	15-20 (10-27)	Short day/ day neutral	Sensitive to frost; excessive rain, hot weather	Deep, friable soil, well-drained and aerated; opt. pH = 5.5-6.0
Cabbage	100-150+	15-20 (10-24)	Long day	Short periods of frost (-6 to -10°C) are not harmful; opt. RH = 60-90%	Well-drained; opt. pH = 6.0-6.5
Citrus	240-365	23-30 (13-35)	Day neutral	Sensitive to frost (dormant trees less), strong wind, high humidity; cool winter or short dry period preferred	Deep, well-aerated, light to medium-textured soils, free from stagnant water; pH = 5-8
Cotton	150-180	20-30 (16-35)	Short day/ day neutral	Sensitive to frost; strong or cold winds; temp. req. for boll development: 27-32°C (18-38); dry ripening period required	Deep, medium to heavy-textured soils; pH = 5.5-8.0 with opt. pH = 7.0-8.0
Grape	180-270	20-25 (15-30)		Resistant to frost during dormancy (down to -18°C) but sensitive during growth; long, warm to hot, dry summer and cool winter preferred/ required	Well-drained, light soils are preferred
Groundnut	90-140	22-28 (18-33)	Day neutral	Sensitive to frost; for germination temp. >20°C	Well-drained, friable, medium-textured soil with loose top soil; pH = 5.5-7.0
Maize	100-140+	24-30 (15-35)	Day neutral/ short day	Sensitive to frost; for germination temp. >10°C; cool temp. causes problem for ripening	Well-drained and aerated soils with deep water table and without waterlogging; opt. pH = 5.0-7.0
Olive	210-300	20-25 (15-35)		Sensitive to frost (dormant trees less); low winter temp. required (< 10°C) for flower bud initiation	Deep, well-drained soils free from waterlogging
Onion	100-140 (+30-35 in nursery)	15-20 (10-25)	Long day/ day neutral	Tolerant to frost; low temp. (< 14-16°C) required for flower initiation; no extreme temp. or excessive rain	Medium-textured soil; pH = 6.0-7.0
Pea	fresh: 65-100 dry : 85-120	15-18 (10-23)	Day neutral	Slight frost tolerance when young	Well-drained and aerated soils; pH = 5.5-6.5
Pepper	120-150	18-23 (15-27)	Short day/ day neutral	Sensitive to frost	Light to medium-textured soils; pH = 5.5-7.0
Pineapple	365	22-26 (18-30)	Short day	Sensitive to frost; requires high RH; quality affected by temperature	Sandy loam with low lime content; pH = 4.5-6.5
Potato	100-150	15-20 (10-25)	Long day/ day neutral	Sensitive to frost; night temp. < 15°C required for good tuber initiation	Well-drained, aerated and porous soils; pH = 5-6
Rice	90-150	22-30 (18-35)	Short day/ day neutral	Sensitive to frost; cool temp. causes head sterility; small difference in day and night temp. is preferred	Heavy soils preferred for percolation losses, high tolerance to O_2 deficit; pH = 5.5-6.0
Safflower	spring: 120-160 autumn: 200-230	early growth: 15-20 later growth: 20-30 (10-35)		Tolerant to frost; cool temp. req. for good establishment and early growth	Fairly deep, well-drained soils, preferably medium-textured; pH = 6-8
Sorghum	100-140+	24-30 (15-35)	Short day/ day neutral	Sensitive to frost; for germination temp. > 10°C; cool temp. causes head sterility	Light to medium/heavy soils relatively tolerant to periodic waterlogging, pH = 6-8
Soybean	100-130	20-25 (18-30)	Short day/ day neutral	Sensitive to frost; for some var. temp. >24°C required for flowering	Wide range of soil except sandy, well-drained; pH = 6-6.5
Sugarbeet	160-200	18-22 (10-30)	Long day	Tolerant to light frost; toward harvest mean daily temp. <10°C for high sugar yield	Medium to slightly heavy-textured soils, friable and well-drained; pH = 6-7
Sugarcane	270-365	22-30 (15-35)	Short day/ day neutral	Sensitive to frost; during ripening cool (10-20°C), dry, sunny weather is required	Deep, well aerated with ground water deeper than 1.5-2 m but rel. tolerant to periodic high water tables and O_2 deficit; pH = 5-8.5; opt pH = 6.5
Sunflower	90-130	18-25 (15-30)	Short day/ day neutral	Sensitive to frost	Fairly deep soils; pH = 6-7.5
Tobacco	90-120 (+40-60 in nursery	20-30 (15-35)	Short day/ day neutral	Sensitive to frost	Quality of leaf depends on soil texture; pH = 5-6.5
Tomato	90-140 (+25-35 in nursery)	18-25 (15-28)	Day neutral	Sensitive to frost, high RH, strong wind; opt. night temp. 10-20°C	Light loam, well-drained without waterlogging; pH = 5-7
Watermelon	80-110	22-30 (18-35)	Day neutral	Sensitive to frost	Sandy loam is preferred; pH = 5.8-7.2
Wheat	spring: 100-130 winter: 180-250	15-20 (10-25)	Day neutral/ long day	Spring wheat: sensitive to frost; Winter wheat: resistant to frost during dormancy (>-18°C), sensitive during post-dormancy period; requires a cold period for flowering during early growth. For both, dry period required for ripening	Medium-texture is preferred; relatively tolerant to high water table; pH = 6-8

[1] mean daily temperatures

[2] k_y of the total growing period:

low	:	k_y <0.85
medium-low	:	k_y 0.85 - 1.0
medium-high	:	k_y 1.0 - 1.15
high	:	k_y >1.15

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Sensitivity to salinity	Fertilizer requirements N : P : K kg/ha/growing period	Water requirements mm/growing period	Sensitivity to water supply (ky)	Water utilization efficiency for harvested yield, Ey, kg/m³ (% moisture)	Crop
moderately sensitive	0-40 : 55-65 : 75-100	800-1600	low to medium-high (0.7-1.1)	1.5 - 2.0 hay (10-15%)	Alfalfa
sensitive	200-400: 45-60 : 240-480	1200-2200	high (1.2-1.35)	plant crop: 2.5-4 ratoon : 3.5-6 fruit (70%)	Banana
sensitive	20-40 : 40-60 : 50-120	300-500	medium-high (1.15)	lush : 1.5-2.0 (80-90%) dry : 0.3-0.6 (10%)	Bean
moderately sensitive	100-150: 50-65 : 100-130	380-500	medium-low (0.95)	12-20 head (90-95%)	Cabbage
sensitive	100-200: 35-45 : 50-160	900-1200	low to medium-high (0.8-1.1)	2-5 fruit (85%, lime: 70%)	Citrus
tolerant	100-180: 20-60 : 50-80	700-1300	medium-low (0.85)	0.4-0.6 seed cotton (10%)	Cotton
moderately sensitive	100-160: 40-60 : 160-230	500-1200	medium-low (0.85)	2-4 fresh fruit (80%)	Grape
moderately sensitive	10-20 : 15-40 : 25-40	500-700	low (0.7)	0.6-0.8 unshelled dry nut (15%)	Groundnut
moderately sensitive	100-200: 50-80 : 60-100	500-800	high (1.25)	0.8-1.6 grain (10-13%)	Maize
moderately tolerant	200-250: 55-70 : 160-210	600-800	low	1.5-2.0 fresh fruit (30%)	Olive
sensitive	60-100: 25-45 : 45-80	350-550	medium-high (1.1)	8-10 bulb (85-90%)	Onion
sensitive	20-40 : 40-60 : 80-160	350-500	medium-high (1.15)	fresh: 0.5-0.7 shelled (70-80%) dry: 0.15-0.2 (12%)	Pea
moderately sensitive	100-170: 25-50 : 50-100	600-900 (1250)	medium-high (1.1)	1.5-3.0 fresh fruit (90%)	Pepper
	230-300: 45-65 : 110-220	700-1000	low	plant crop: 5-10 ratoon : 8-12 fruit (85%)	Pineapple
moderately sensitive	80-120: 50-80 : 125-160	500-700	medium-high (1.1)	4-7 fresh tuber (70-75%)	Potato
moderately sensitive	100-150: 20-40 : 80-120	350-700	high	0.7-1.1 paddy (15-20%)	Rice
moderately tolerant	60-110: 15-30 : 25-40	600-1200	low (0.8)	0.2-0.5 seed (8-10%)	Safflower
moderately tolerant	100-180: 20-45 : 35-80	450-650	medium-low (0.9)	0.6-1.0 grain (12-15%)	Sorghum
moderately tolerant	10-20 : 15-30 : 25-60	450-700	medium-low (0.85)	0.4-0.7 grain (6-10%)	Soybean
tolerant	150 : 50-70 : 100-160	550-750	low to medium-low (0.7-1.1)	beet : 6-9 (80-85%) sugar: 0.9-1.4 (0%)	Sugarbeet
moderately sensitive	100-200: 20-90 : 125-160	1500-2500	high (1.2)	cane : 5-8 (80%) sugar: 0.6-1.0 (0%)	Sugarcane
moderately tolerant	50-100: 20-45 : 60-125	600-1000	medium-low (0.95)	0.3-0.5 seed (6-10%)	Sunflower
sensitive	40-80 : 30-90 : 50-110	400-600	medium-low (0.9)	0.4-0.6 cured leaves (5-10%)	Tobacco
moderately sensitive	100-150: 65-110 : 160-240	400-600	medium-high (1.05)	10-12 fresh fruit (80-90%)	Tomato
moderately sensitive	80-100: 25-60 : 35-80	400-600	medium-high (1.1)	5-8 fruit (90%)	Water melon
moderately tolerant	100-150: 35-45 : 25-50	450-650	medium-high (spring: 1.15 winter: 1.0)	0.8-1.0 grain (12-15%)	Wheat

1 kg P = 2.4 kg P_2O_5

1 kg K = 1.2 kg K_2O

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Table 4

Approximate labour requirements (mondays/month) for Sorghum

Operation Month	-2	-1	0	1	2	3	4	5	6	Total
Nursery	-	-	-	-	-	-	-	-	-	0
Pre-planting operation	8	6	-	-	-	-	-	-	-	14
Planting	-	-	5	-	-	-	-	-	-	5
Irrigation	-	-	2	3	3	-	-	-	-	8
Weeding	-	-	-	4	4	-	-	-	-	8
Crop Protection	-	-	-	-	2	-	-	-	-	2
Fertilizer application	-	-	-	2	-	-	-	-	-	2
Harvesting	-	-	-	-	-	-	-	15	-	15
Post-Harvest Operation	-	-	-	-	-	-	-	10	-	10
Total	8	6	9	9	7	0	15	10	0	64

Table 5 Crop Sorghum

Draft Animal requirements (ox - days/month)

Operation	Month	-2	-1	0	1	2	3	4	5	6	Total
Pre-planting operation				8	6						14
Crop operations					6						6
Post - Harvest Operations						4					4
Total				8	6	6	0	0	0	0	24

Water availability - A cropping pattern must ensure that the volume of water available in sufficient to meet the crops water requirements in cropping seasons.

The use of cropping pattern diagram

It is convenient to use a diagram to represent the proposed cropping programme. In planning a cropping programme, it is generally sound policy to include a fairly brood mix of crops, including tree crops, which have a much lower labour requirement once they are established.

Finally, the draft cropping Programme should be discussed in detail with all serous involved in the implementation and where appropriate adjustments and or changes should be made.

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Cropping Patterns

A cropping pattern diagram is used to show:

- the area under each crop type at any time
- the percentage of the total area that is cropped
- the cropping intensity

Figure 1 below shows a typical cropping pattern diagram.

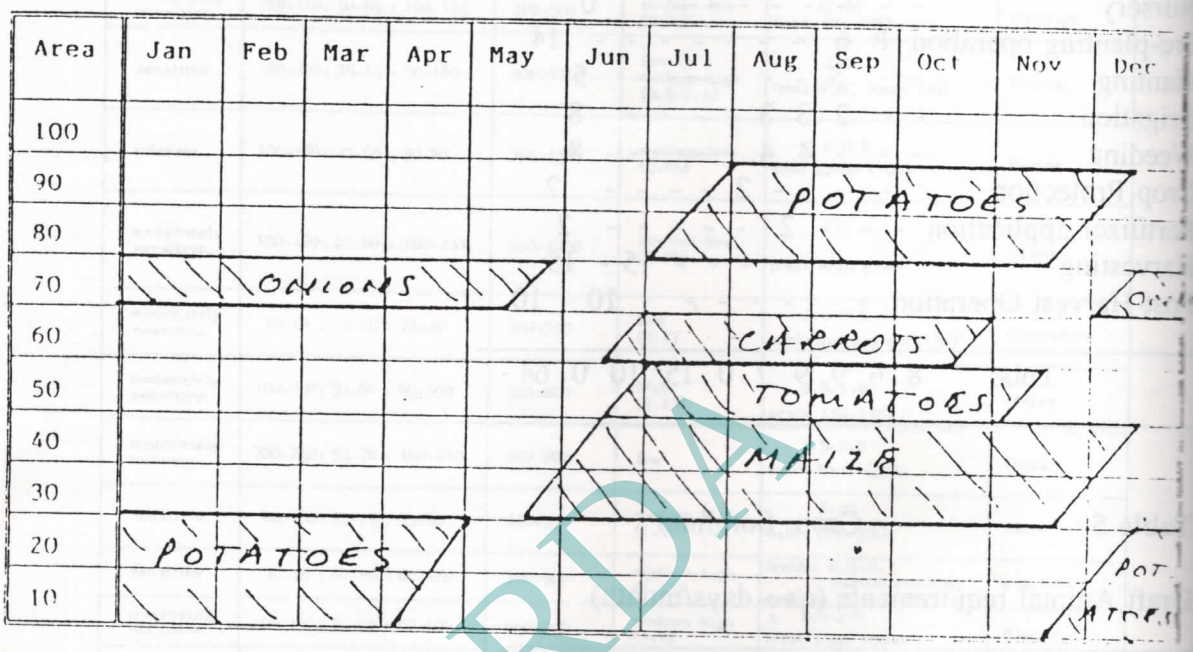


Figure 1 Cropping pattern for crops planted on different plots

In order to plot the cropping pattern diagram the following information is required:

- the crop types
- for each crop type:
  - the start date of planting
  - the end date of planting
  - the total area planted
  - the crop growth duration

The data collected for plotting the above diagram is:

Crop	Area (ha)	Planting dates Start	End	Total crop growth period (days)
Potato	20	15 Nov	15 Dec	140
Maize	20	15 May	15 Jun	180
Tomato	10	15 June	30 June	140
Carrot	10	15 June	30 June	120
Onions	10	30 Nov	15 Dec	160
Potato	20	30 June	31 July	140

To plot the data for each crop mark the start date of planting and the end date of planting. The start and end date marks should be separated by a vertical

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distance equal to the crop area planted. Draw a line connecting the start and end dates. Count from the start date the number of days in the growing period and mark the crop end date. Do the same from the end date of planting and draw a line between these two points (this line will be parallel to the one drawn between the start and end planting dates). Plot each crop in turn as shown in the diagram.

Plotting cropping patterns gets more complicated when farmers plant more than one crop per year. If for the data above the farmers planting the first potato crop follow it with a maize crop and the farmers planting the carrot crop follow it with an onion crop then the cropping pattern diagram will look as in Figure 2.

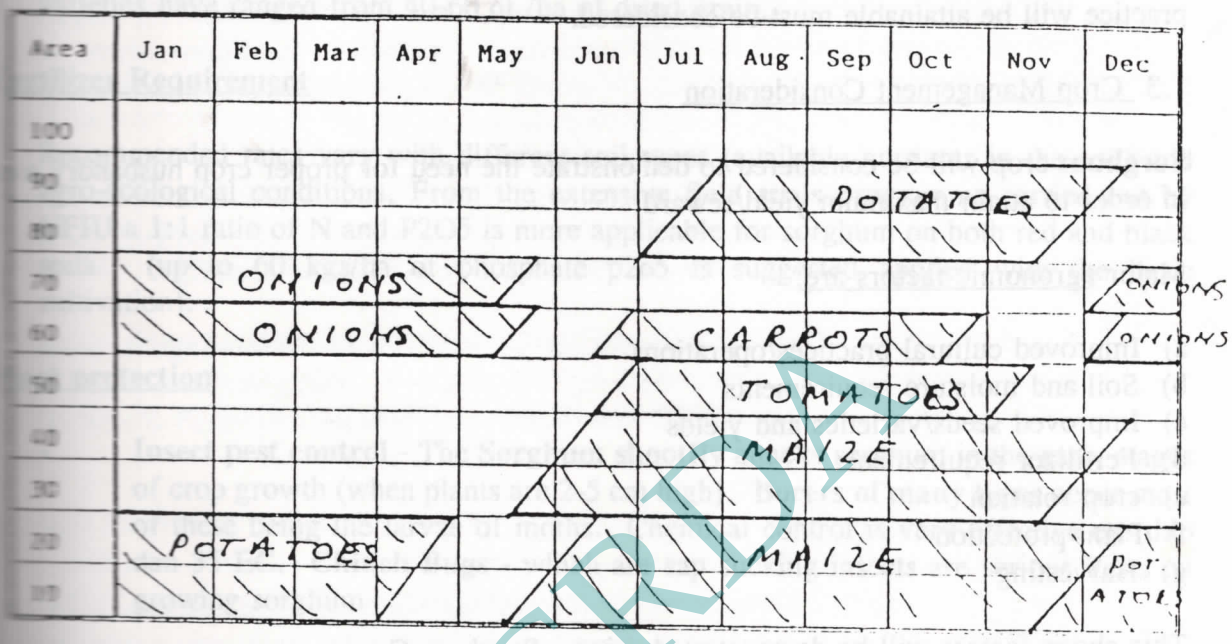


Figure 2 Cropping pattern with double cropping

In the first case the cropping intensity is 90% as 90 ha out of 100 ha have been cultivated in the year. In the second case the cropping intensity is 120 % as a total area of 120 ha has been cultivated in the year.

We can use now the cropping pattern that we have plotted to calculate the irrigation water requirements during the year.

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Cropping Intensity

The final factor to consider is the level of the proposed cropping intensity. The overall objective should be to maximize the utilization of the land and water, given that the Water resource is not a limiting factor and that are the beneficiaries are capable of implementing the proposed programme in terms of supplying the labour and other inputs required.

Where practical it is desirable for the cropping intensity to approach 200%, meaning that all the land intended for cultivation is to be double copped over one calander year. However, in most instances farmers may not be able or willing to realize this target. A more realistic cropping intensity taking into account the likely performances of soil good and bad farmers and which in practice will be attainable must be considered.

1.3 Crop Management Consideration

Sorghum crop will be considered to demonstrate the need for proper crop husbandry measure in order to attain maximum yield/reward.

Major agronomic factors are:

a) Improved cultural practices/operations
b) Soil and moisture requirements
c) Improved seeds/varieties and yields
d) Fertilizer requirements
e) crop rotation
f) Plant protection
g) Harvesting

This above factors will be demonstrated using - Sorghum Crop.

a) Improved cultural practices

- Proper soil preparation
- timely sowing
- seeding rates/sowing density - generally 5kg/ha (depends on variety) eg. 75x15 cm = 88,800 plants/ha
- Weed Control - Perennial weeds controlled by tillage in preparation for planting. Annual weeds are suppressed by hoping or application of Herbicides.
- Cultivation - two cultivations between rows should be provided during the vegetation period followed by fulfilling water requirements.

b) Soil and moisture requirements

The crop grows well on most soils, but thrives best on light medium textured soils which should also be well drained and aerated. It is tolerant to water logging for short periods and is moderately to lerant to soil salinity.

The crop water requirement varies between 450 - 650 mm depending on the climate. Because of its extensive root system the crop is more drought resistant than most other crops. Water stress at the time of crop establishment, flowering and early yield formation should be avoided.

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c) Varieties and yields

Many local and foreign sorghum varieties are tested in Ethiopia.

- Currently the following varieties are recommended:
  1900 - 2200m - ETS 2752 Alemaya 70
  1500 -1900m - Didessa 1050, IS 9323, Awash 1050, Serodo etc.

The average yield for peasant holdings is around 10 qt/ha of dried grain. Under non limiting water supply, growing improved varieties under good crop husbandry a yield of 28 qt./ha should be obtainable. Yields from research stations for the recommended varieties have ranged from 40-60 qt./ha of dried grain.

d) Fertilizer Requirement

Recommended rates vary with different soil types (available nutrients in the soil) and agro-ecological conditions. From the extensive field trials programme carried out by NFIU a 1:1 ratio of N and P2O5 is more applicable for sorghum on both red and black soils. (up to 60 kgs/ha of phosphate p2o5 is suggested applied with the basic cultivation).

e) Plant protection

- **Insect pest control** - The **Sorghum shootfly** attacks sorghum in the early stages of crop growth (when plants are 2-5 cm high). **Borers of many** types occur most of these being the larvae of moths. Chemical control is very effective eg. thio dan 35 EC. **Chinch Bugs** - which are sap sucking insects are serious Pests on growing sorghum

- **Diseases** - There are numerous molds (fungi) that may attack planted seeds when soil temperatures are below 20°c. Chemical treatment of seed before planting is recommended. **Fungal leaf diseases** include: leaf spots, downy mildew, rust, anthracnose and **blights** etc. using of disease resistant strains and crop rotation measure are useful in keeping these diseases at low level.

- **Bird damage** - Sorghum groin is a preferred food of many binds including the **puelea** bird, **sparrows yellow, weavers bishop,** birds, etc. The **quelea bird** is the most damaging of all bind pests. Present research is directed towards reducing total population of quelea birds to a level and to prevent them from building up again.

f) Harvesting

Sorghum grains are fully developed when they reach the dough stage. The bird problem is most serious during this and mature stages of the grain and campaign to repel birds should be concentrated in these stages. Early harvest of heads as soon as the groin reaches black layer is advisable when bird damage threatens to be serious. Moisture content should be reduced to about 10% (from 20-25 when field harvested) to avoid molding. Threshing may occur as soon as the grain is dry.

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II. AGRONOMIC CONSIDERATIONS UNDER WATER HARVESTING SYSTEMS

In General planning and design of **Water Harvesting Systems** , if they are to succeed they must always reconcile these three aspects:

- the **socio economic** factors of the community concerned i.e. degree of acceptance by the community.
- **Agronomic options** (to be discussed) and
- The **Engineering alternatives** i.e., versatility, simplicity and durability.

The **Agronomic factors** will be discussed here. Water Harvesting helps crops by providing extra moisture at different stages of growth in conditions where moisture is the primary limiting factor, although timing cannot be controlled. Periods when the extra moisture can make a significant difference are:

- around sowing time when germination and establishment can be improved.
- during a mid - season dry spell when a crop can be supported until the next rains
- while the crop is at the vital stages of flowering and grainfill

However, there is little point investing in Rain Water Harvesting Structures unless attention is also given to other aspects of Husbandry. Plants which are **well nourished** , **cleanly weeded** and **protected** from **pests** and **diseases** will respond best to the extra water.

2.1 Crop Choice

Water Harvesting will commonly be used for improving the **performance** and the **reliability** of food crops already grown in the area. An ideal crop combines **drought adaptations** with a degree of **temporary water logging.**

Brief notes on the crops most likely to be grown under such system follow:

Sorghum (sorghum bicolor) - is the most common grain crop under water harvesting system. It is a crop of the dry areas, and in addition to its **drought adaption** it also tolerates **temporary waterlogging** - which is common occurrence in some water harvesting system.

Pearl Millet (Pennisetum typhoids) requires **less rain** than sorghum, to lesstes drought better, and is able to produce reasonable in **poor soils.** However, its yield potential is lower, it is in to leant of water logging and it does not rotten. Apart from being drought tolerant, it matures rapidly. **Maize** - (Zea mays) - is potentially the **highest yielding** of the cereals, but it requires **more water** than sorghum or millet, and it is very **intolerant** of **water logging** and **drought stress.** It is occasionally grown under water harvesting but in parts of **East** and **Southern** Africa it is the preferred food grain, and farmers are often reluctant to plant millet or sorghum instead.

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Other crops

- **Legumes** are less frequently grown under water harvesting but should be encouraged because of their ability to fix nitrogen and improve the performance of other crops. eg. cow pres

- **Cash crops** - Although food crops, largely for subsistence, will be the usual choice for water harvesting systems, there is an argument to support the production of cash crops ie. important sources of income to poor farmers eg. like **Acacia senegal** (gum arabic)

2.2 Fertility (Soil factor)

In dry areas soil fertility is usually the second most limiting production factor after moisture stress. The improvement in the supply of water available to plants under water harvesting can lead to depletion of soil nutrients. Therefore it is very important to maintain levels of organic matter by adding animal manure or compost to the soil. Inorganic fertilizers are seldom economic for subsistence crops grown under water harvesting. There is little point increasing water availability to plants which are seriously limited by fertility.

Crop rotation helps maintain the fertility status. Legumes should be alternated with cereals as often as possible. Intercropping of cereals with legumes - sorghum with cowpeas for example - can also lead to higher overall yields as well as soil fertility maintenance.

Some water harvesting systems actually harvest organic matter from the catchment and therefore build up fertility. This can most clearly be seen with stone bunding techniques which filter out soil and other organic particles, thereby building up fertile deposits.

2.3. Other Husbandry Factors

- Weeds are a problem where water harvesting is used, due to the favourable growing conditions where water is concentrated. Weeds are especially a problem at the start of the season and therefore early weeding is extremely important. Early planting makes the best use of limited rainfall. In some areas it may be best to plant seeds before the rains arrive. This technique is known as "dry planting".

- "Opportunistic" or take-a-chance planting of a quick legume crop like cowpeas can make use of late season or out of season rainstorms.

- Low plant populations in themselves can improve yields in low rainfall zones, and therefore spacing of crops is another important consideration.

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Cropping Pattern Diagram Exercise

Using the data given below:

(i) plot the cropping pattern

(ii) calculate the cropping intensity

Crop	Area (ha)	Planting dates Start	End	Total crop growth period (days)
Potato	25	15 Nov	15 Dec	140
Maize	40	15 May	15 Jun	180
Tomato followed	10	15 June	30 June	140
by onion	10	30 Nov	15 Dec	160
Carrot	10	15 June	30 June	120
Onion	10	30 Nov	15 Dec	160
Potato	40	30 June	31 July	140

Area (ha)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
100												
90												
80												
70												
60												
50												
40												
30												
20												
10												

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Water Harvesting WH; history, definition and classification

In a country like Ethiopia where drought is threatening the lives of the people and livestock, population pressure is increasing at an alarming rate and land degradation is one among the causes of low agricultural productivity and is currently economically unable to optimally utilize its large rivers for different development; it is in line with the national, regional and local interest to make use of any form of rain water and its developments as they occur.

The intensity and distribution of rainfall in this country varies with altitude. The highlands, that is, areas above 1500 m above sea level get higher rainfall which may be adequate for plant growth, while areas below this altitude usually get inadequate and eratic rainfall. These areas are catagorized as arid or semi arid according to climatical zonation.

In the arid and semi-arid regions the limited availability of water is in most cases the constraint to rainfed agriculture and domestic or livestock water supply. In the arid regions the amount of rainfall is usually not sufficient to sustain crops, where as in the semi-arid regions the distribution of rainfall is uneven in space and time which makes rainfed agriculture unreliable. As a result of this every drop of rainwater or its developments need to be utilized wisely and efficiently. Therefore, the best way of sustaining crop is by collecting and concentrating runoff from optimum catchment on to a suitable cultivated area or storage place; This technique's defined as Water Harvesting.

Water harvesting in general sense is the collection of rainwater/flood water for productive purposes. That is, instead of run-off causing erosion it is harvested and utilized. Forms of water harvesting has been traditionally effectively practiced in many countries of Asia, Africa, North and Latin America and Australia. Some of oldest agriculture in the Middle East were based on techniques such as diversion of flood water from normally dry water courses (wadi) on to agricultural fields. In the Negev Desert of Israel water harvesting systems date back over 4000 years. These system involved clearing of hillsides from vegetation cover to enhance run off and directing to cultivable fields by means of earth bunds or stone mounds. Runoff that occurred at any time and amount was wisely used in one time or another in this area since the beginning of agriculture.

In the Arabian peninsula the history of "Wadi" diversion is very ancient. In Yemen this technique was practised 3000 years before Christ. The traditional methods based on centuries old experience farming population were elementary and involved construction of diversions and earthen banks across the wadis to divert part of or the entire flood of the ephemeral flow or spate to the adjacent alluvial plain.

In the mountainous and dry province of Baluchistan (Pakistan) bunds are traditionally constructed across the slopes of the land to intercept the run-off and infiltrate. Earthen bunds also capture flood water in the natural water courses.

China with its large population is actively promoting this technique. Here, by diverting flood water, sediment is extensively spread over Chaina's loess areas. Sediment is believed to be rich in soil fertility. This technique is called warping.

In Tunisia several traditional systems are still used such as the Meskat system, a microcatchment water harvesting system which at present is known to cover about 200,000 ha in the Souse region and the Jessour system - a terraced 'Wadi' system in various central and southern Tunisia.

Runoff farming has been practised in the arid regions of Arizona and north-west New-Mexico for atleast 1000 years.

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In sub-saharan Africa, despite the fact that no studies have been carried out on water harvesting techniques, farmers of these countries are known to have been traditionally treating several thousands of ha of land with their techniques. The inhabitants of the arid parts of countries like Algeria, Morocco, Tunisia, Egypt, the Sudan, Somalia, Burkina Faso, Kenya, Ethiopia etc have been practicing water harvesting techniques at least for decades. In the Ethiopian low lands the settled farming societies and rarely agropastoralists crudely use water harvesting for crop production and domestic purpose. The valley floors in Tigray, the land situated at the mouth of the ephemeral streams in the eastern catchment - part of the Awash River Basin have been under subsistence agriculture by using this technique for atleast quarter of a centaury. Most impressing traditional water harvesting farmers in this country being the Konso tribe in the South Omo region. The pattern of terracing on the hillsides and diversion of flood water from creeks and dry river courses to adjacent plots of land seem to have longer years of practice in the system.

Recent Development

Since the last two decades the awareness for the potential of water harvesting technique for the purpose of producing mainly crops has significantly risen as a result of the wid spread of drought and total failurity of crops in many countries of Africa. Trials were conducted in transfering the technology from other countries like Israel as to adopt the well documented work on water harvesting in the Negev Desert. However, much of the experience gained from this technique in well developed countries has limited relevance to resource-poor countries of Africa say Ethiopia. Today in Israel, USA and Australia research emphasis is mainly on catchment treatments to induce maximum run-off without any loss.

In sub saharan Africa many projects have been implemented with the objective of combating drought in the past two decades. However, few of the projects succeeded as a result of combining efficiency with low cost. Others failed because of in appropriate approach and/or inrelevance of the technique adapted with regard to socio-economic conditions

Numerous soil and water conservation projects have been carried out in Ethiopia during the last decades. Recent studies indicate that the result of these conservation programs have little or no positive output with regard to their intended objectives. The main problems being lack of maintenance of structures/ as a result of top-down policy enforced and people did not feel sense of ownership and rather were forced to implement with out interest.

Classification of Water Harvesting System

All water harvesting systems comprise a catchment; land, rooftop, paved area etc and suitable storage component. Therefore, they can be classified on the basis of water source (i.e catchment), the type of storage used or purpose. In this regard, there are three categories of catchments or water sources: root top harvesting, runoff harvesting and flood water harvesting. Again by other authors the first two systems can fall under one category called rain water harvesting ending up to two broad categories, namely rain water harvesting which is a technique used to collect runoff from rooftop or ground surfaces and flood water harvesting a system which collects channel flows for example flash foods.

Water harvesting for specific purposes for example water supply for human caonsumption, livestock or for plant production may be classified based on type of use. The later can be elaborated as indicated below.

Water harvesting systems for crop (trees, fodder etc) production fall under two basic categories.

Micro-catchment water harvesting is usually referred to as 'within field' catchment system and is characterized by overland flow harvested from short catchment length of usually between 1 and 30 m and stored in soil profile.

The ratio of catchment to cultivated area of this category is usually 1:1 to 3:1. Normally overflow component is not provided. Plant growth is even as a result of nearly uniform distribution and uptake of run-off. In view of this patches or strips of bare ground within the fields being cropped may serve as catchment; Typical examples are:

- Negarim microcatchments and contour bunds for trees,
- contour ridges for crops and
- semi circular bunds for range and fodder. This terminologies will be clarified by use of diagrams later on.

External catchment system is where by sheet flow may be harvested from long catchments and characterized by catchment length of usually 30-200 m, run off stored in soil profile and ratio of catchment to cultivated area is usually 2:1 to 10:1. Moreover provision for overflow of excess run-off is allowed and uneven growth of plants can be observed unless land is smoothened or levelled.

Typical examples for this category are:

- contour stone bunds and trapezoidal bunds for crops usually in the valley floors:

Similarly water storage techniques can be classified according to type of storage, namely:

(a) Tanks above ground - usually meant for rooftop rain water collecting. A traditional example of collecting water from roofs covered by corrugated iron sheet, thatch or tiles and require storage facilities above ground like oil drums or tanks built from cement concrete.

(b) Excavated tanks dugouts or cisterns - serve the purpose storing surface runoff for longer time which can be used for domestic or livestock water supply.

(c) Small dams - used to retain flood water behind them and stay longer for different purposes including small scale irrigation

(d) Soil at field capacity - The profile of soil under this condition can store soil moisture leaving ample empty pore spaces in the soil for aeration of the crop's root zone. Therefore the maximum amount of moisture which can be held in soil under this condition is referred to as field capacity of the soil profile.

(e) Soil at saturation - pore space filled with water. At this stage crops apart from rice will suffer water logging problem. aeration is difficult. This can contribute in recharging the ground water resource.

Generally storages can be divided into two types, that is long term storage, which is deep seeding and mostly used for domestic and livestock and short-term storage which is just in the soil profile and used for immediate crop water consumption..

Classification of water harvesting can be illustrated by use of two tables and one figure to indicate similarities and/or differences as categorized by different authors.

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Table 1. according to Paccy and Cullis
Figure 2. according to Crithley
Figure 1. according to Matlock and Dutt

Definition of arid and semi arid regions

Theoretically, water harvesting programme is feasible at any place where water runs off a catchment and could be collected. The system is practicable in a range of climates mostly in the arid and semi arid regions where rainfed agriculture is limited by lack of rainfall or by erratic rainfall.

The arid and semiarid zones are areas where potential evaporation is much higher than precipitation. In arid zones precipitation is not sufficient for crop, trees or fodder production while in the semi arid zones range of plants /crops/ that can be cultivated is limited. Even though water harvesting system is practicable in these climatic zones, they are not always reliable as they depend on erratic rainfall. More over during drought years (no-rain) the systems are not practicable. [Table 2 and 3 climatic zonation]

The mean annual rainfall (mm) is usually taken as the minimum requirements to viability of the system in various places of the arid and semiarid zones: But the most important element is the frequence of rainfall that is believed to sustain crops grown using water harvesting system. In other words if the total amount of rianfall in the year can evenly be distributed over the crop growing period say 6-10 events in the rainy season, one may say reliable rain water can be harvest in that year. However, factors characterizing water harvesting technique are not limited to rainfall, but slope, soil type and costs.

Slope. The ground slope is the main limiting factor for water harvesting. This technique is not recommended on steep slope areas greater than 5%, the main reason being large volume of earthwork and uneven distribution of run-off (that is unequal depth of water stands behind the intercepting structure and hence unequal water infiltrates to soil profile).

Soils. The soil should be deep, fertile, free from salinity or sodicity problems, good water holding capacity and be with good infiltration rate that is preferably medium to fine soil texture.

Cost. The cost of the system selected can be affected by the quantity and type of structure/earth or stone work/ involved. Labour and its financial implication may be a limiting factor to implement the system especially on a self help basis.

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Table 1. A Classification of Rainwater and Floodwater Harvesting Systems According to Catchment and Storage (Source: Pacey and Cullis, 1986)

Some uses of rainwater are denoted as follows:

DD - *drinking water and domestic use*
S - *water for livestock*
G - *garden irrigation (and micro-irrigation)*
F - *field irrigation*

	SMALL CATCHMENTS with sheet runoff		*LARGE CATCHMENTS with turbulent runoff and/or gullying and channel flow*	
	ROOFS of all kinds	*GROUND SURFACES less than 50–150m length: WITHIN-FIELD CATCHMENTS*	*SLOPES longer than 50–150m EXTERNAL CATCHMENTS*	*FLOW in WADIS, GULLIES, RIVERS, and all natural channels FLOODWATER*
WATER STORAGE TECHNIQUES				
TANKS ABOVE GROUND	**DD**	**(DD)**	n.a.	n.a.
EXCAVATED TANKS	**DDSG**	**DDSG**	n.a.	n.a.
SMALL DAMS ("tanks" in INDIA)	n.a.	**DDSG**	**SFDD**	**SFDD**
SOIL AT FIELD CAPACITY	n.a.	contour strips, furrows, bunds and terraces (Morocco, India, North America); microcatchments (Tunisia, Negev);	runoff farms in valley bottoms (Negev, Morocco); bordered gardens (North America); hill terraces with external catchments (Morocco); upland runoff plots (Papago areas, Arizona);	diversion systems (Negev), diversions for water spreading (North America), terraced wadis (Tunisia); check dams for silt trapping (China, North America); warping (China), alluvial fan farms (Hopi areas, Arizona).
SOIL AT SATURATION	n.a.	n.a.	runoff farming by inundation: 'teras' (Sudan) 'ahars' (India) 'khadins' (India)	diversion systems (Yemen, India), river floodplain farming (Africa).

Source of examples quoted: India and China - UNEP 1983. Sudan - Wickens and White 1978. Tunisia - El Amami 1977; Morocco - Kutsch 1982. Arizona - Bradfield 1971; North America - UNEP 1983.

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Table 2

Table 2.. (Sub)climatic Zonation of the Arid and Semi-Arid Regions According to UNESCO (1977)

Zonation	Hyper-arid	Arid	Semi-arid	Semi-humid
Annual precipitation	near zero	80-150 (winter rain) 200-350 (summer rain)	200-500 (winter rain) 300-800 (summer rain)	more than 500- 800
Interannual Variability	up to 100%	50-100%	25-50%	less than 25%
Ratio P/ETP	less than 0.03	0.03-0.2	0.2-0.5	0.5-0.7
Vegetation	nearly absent	scattered	discontinuous steppe	steppe/ savanna
Potential land use	no rainfed agriculture, no grazing	nomadic livestock, AGRICULTURE ONLY THROUGH WATER HARVESTING	sedentary livestock and rainfed agriculture	livestock and agriculture

Table 3. Climatic Zonation of the Tropical African Drylands (Source: GTZ, 1986)

Zone destination Jahnke (1978) FAO (1978)		Length of growing period (1978)	Approx. mean annual rainfall (mm) (a)	Approx. corresponding zone FAO (1976)	UNESCO (1977)
Arid	I	0 days	100-250	Saharan (b)	Hyperarid
	II	0-74 days	350-600	Sahelo-Saharan (b)	Arid
	III	75-89 days	500-800	Sahelian	
Semiarid	IV	90-119 days	600-900	Sahelo-Sudanian	Semiarid
	V	120-149 days	750-1000		
	VI	150-179 days	800-1400	Sudanian Guinean	Subhumid

(a) Found by comparison of iso-line
(b) Saharan and Sahelo-Saharan zones overlap

Source: World Bank Technical Paper No. 91, 1988

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Figure 1

Figure 2. Classification of Water Harvesting Systems According to Critchley
(Source: Critchley, 1987)

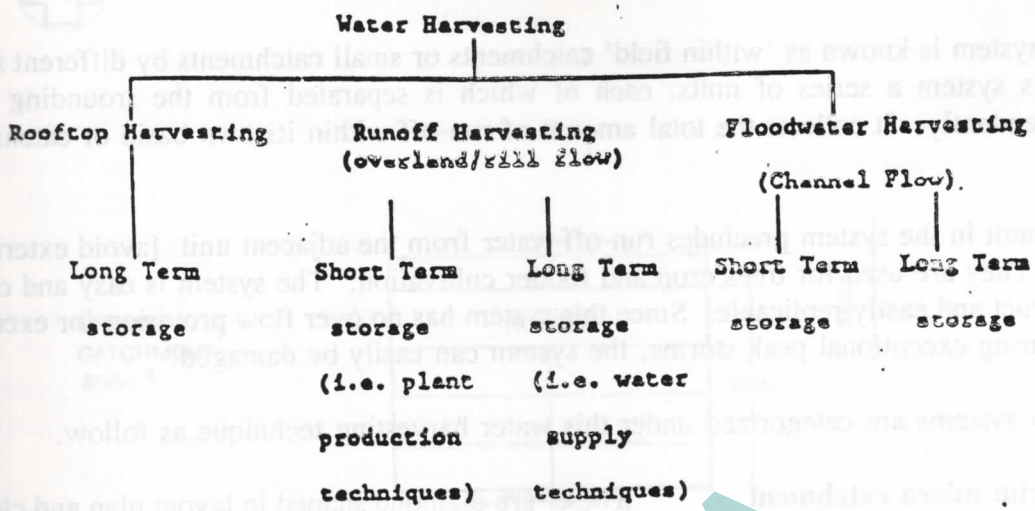
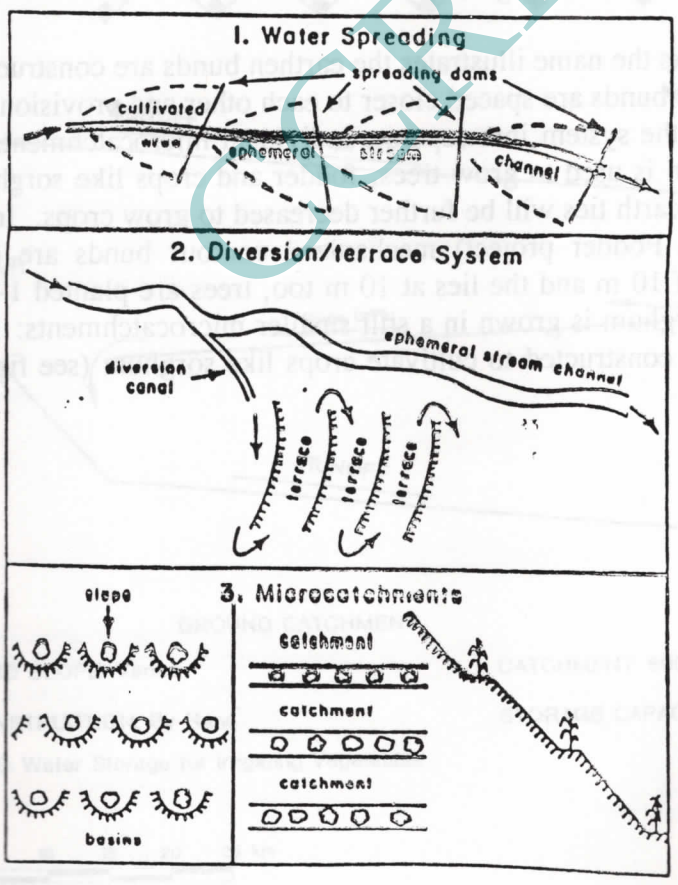


Figure 3. Main Types of Water Harvesting/Runoff Farming Systems According to Matlock and Dutt
(Source: Matlock and Dutt, 1986)



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Water Harvesting Systems for Different Use

Water harvesting techniques have been utilized as indicated above for centuries in various countries of arid and semi arid zones of the world for a number of different uses. These systems are indicated separately below.

Micro Catchment WH System

This system is known as 'within field' catchments or small catchments by different authors. In this system a series of units, each of which is separated from the srounding operate independently. It collects the total amount of run-off within its own basin or catchment or field.

Each unit in the system precludes run-off water from the adjacent unit [avoid external run-off]. They are used for trees crop and fodder cultivation. The system is easy and cheap to construct and easily replicable. Since this system has no over flow provision for excess run-off during exceptional peak storms, the system can easily be damaged.

A few systems are categorized under this water harvesting technique as follow.

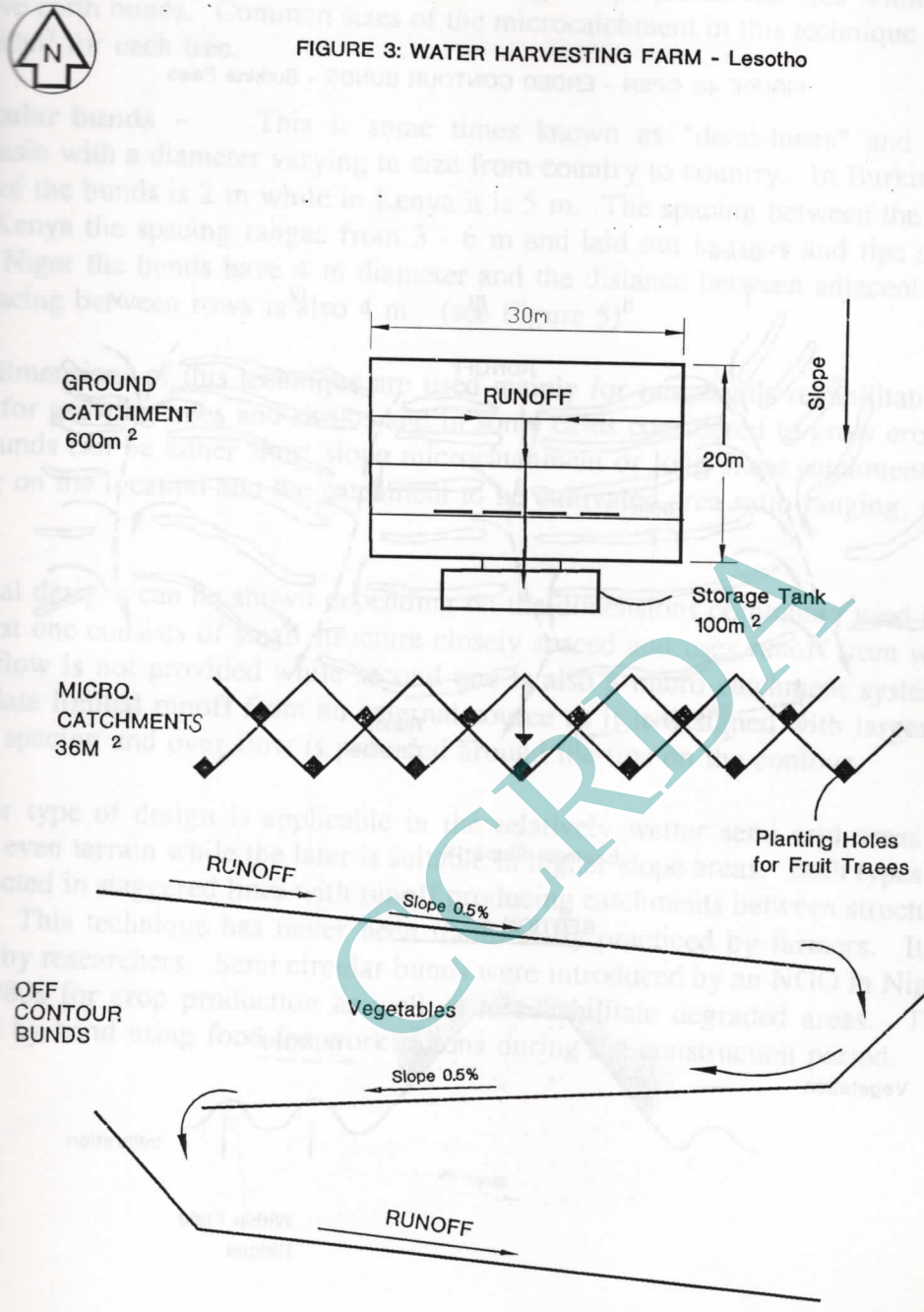
Negarim micro catchment - These are diamond shaped in layout plan and closed by small earthen bunds with an infiltration pit in the lowest corner of each . Run-off is collected within the basin and stored in the infiltration pit (see figure 3). Trees are mostly grown using this system where moisture deficit is prevailing. Negarim has been developed in the Negev and this technique is transferred to elsewhere of similar climatic situations (Neger in Hebrow means run off and then Negarim)

Contour Bunds As the name illustrates the earthen bunds are constructed following the same contour line. The bunds are spaced closer to each other and provision of perpendicular small earth ties divide the system into separate individual microcatchments. Contour bund water harvesting system is used to grow trees, fodder and crops like sorghum. The spaces between the bunds and earth ties will be further decreased to grow crops. In Kenya, Baringo district(fuel wood and Fodder project) mechanized contour bunds are established at an approximate spacing of 10 m and the lies at 10 m too, trees are planted 1-2 m apart infront of the bunds, while sorghum is grown in a still smaller microcatchments: 1.5 m - 3 m hand dug contour bunds are constructed to cultivate crops like sorghum (see figure)

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Figure 3

FIGURE 3: WATER HARVESTING FARM - Lesotho



GROUND CATCHMENT

LAND SLOPE: Varied

CONSTRUCTION: By Hand

USE: Water Storage for Irrigating Vegetables

CATCHMENT: 600m^2

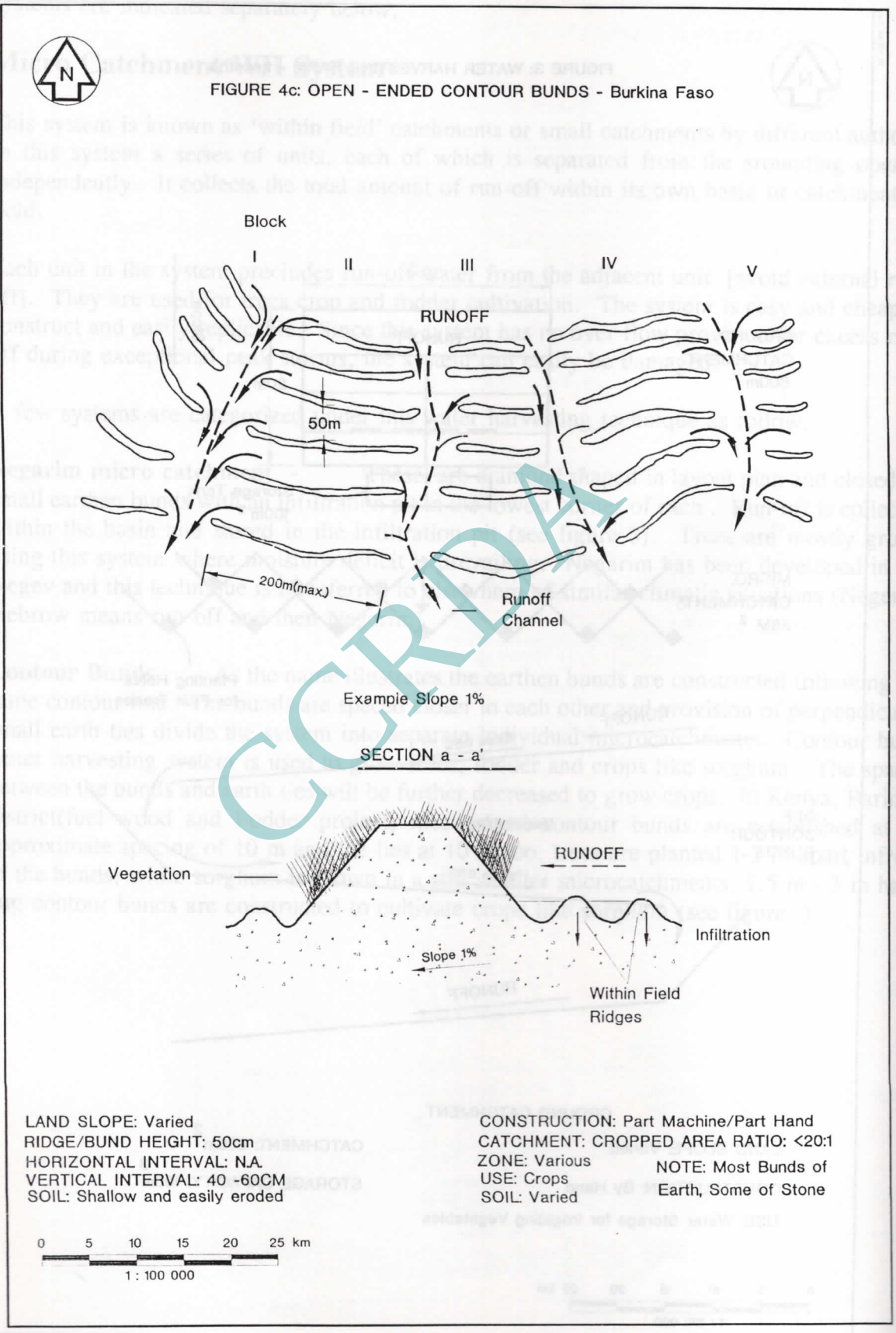
STORAGE CAPACITY: 100m^3

0 5 10 15 20 25 km

1 : 100 000

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Figure 4



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The overall network of contour bunds consists of parallel or nearly parallel constructed from soil excavated from adjacent parallel furrows on their upslope side approximately on the contour at a spacing of between 5 and 10 m. This system is more flexible as the catchment size can be easily changed by adding or removing the perpendicular ties within the fixed consecutive earth bunds. Common sizes of the microcatchment in this technique range from 10m^2 to 50m^2 for each tree.

Semi circular bunds - This is some times known as "demi-lunes" and have semi circular basin with a diameter varying in size from country to country. In Burkina Faso the diameter of the bunds is 2 m while in Kenya it is 5 m. The spacing between the bunds also vary, in Kenya the spacing ranges from 3 - 6 m and laid out in rows and tips on contour. While in Niger the bunds have 4 m diameter and the distance between adjacent bunds is 4 m and spacing between rows is also 4 m. (see Figure 5)

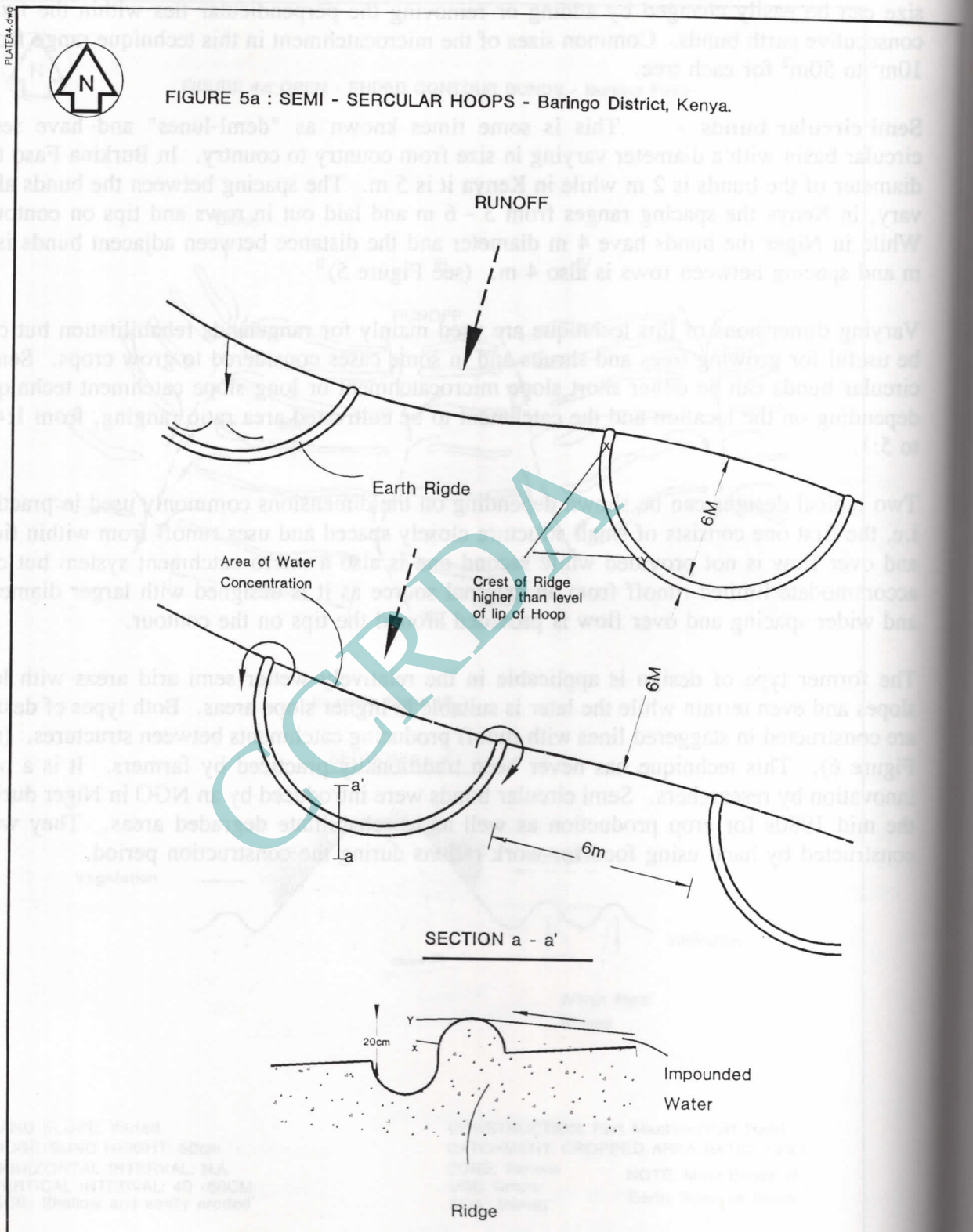
Varying dimensions of this technique are used mainly for rangelands rehabilitation but can be useful for growing trees and shrubs and in some cases considered to grow crops. Semi-circular bunds can be either short slope microcatchment or long slope catchment technique depending on the location and the catchment to be cultivated area ratio ranging, from 1:4:1 to 5:1.

Two typical designs can be shown depending on the dimensions commonly used in practice i.e. the first one consists of small structure closely spaced and uses runoff from within field and over flow is not provided while second one is also a micro catchment system but can accommodate limited runoff from an external source as it is designed with larger diameter and wider spacing and over flow is provided around the tips on the contour.

The former type of design is applicable in the relatively wetter semi arid areas with low slopes and even terrain while the later is suitable in higher slope areas. Both types of design are constructed in staggered lines with runoff producing catchments between structures. (see Figure 6). This technique has never been traditionally practiced by farmers. It is a new innovation by researchers. Semi circular bunds were introduced by an NGO in Niger during the mid 1980s for crop production as well as to rehabilitate degraded areas. They were constructed by hand using food for work rations during the construction period.

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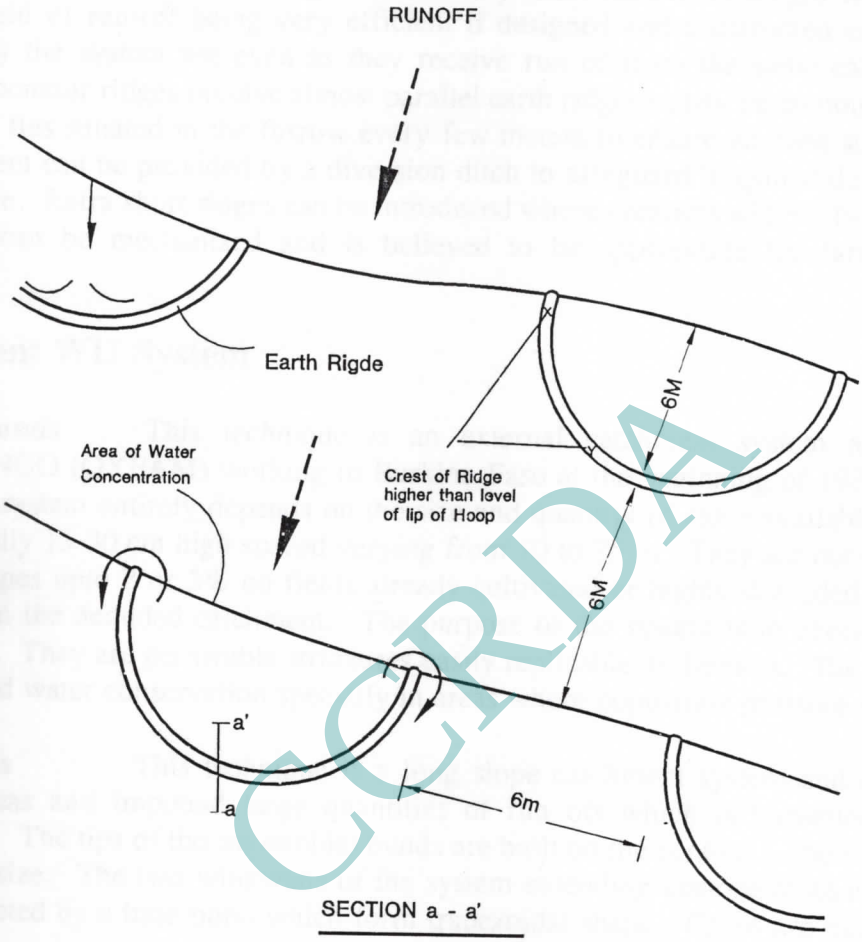
Figure 5



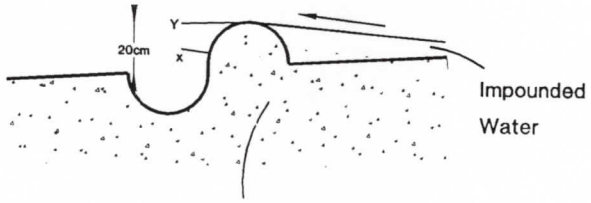
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Figure 6

FIGURE 5a : SEMI - SERCULAR HOOPS - Baringo District, Kenya.



SECTION a - a'



Ridge

SLOPE: < 2%
RIDGE/BUND HEIGHT: 20cm
HORIZONTAL INTERVAL: Varied
VERTICAL INTERVAL: N.A.
SOIL: Deep Fertile Alluvium

CONSTRUCTION: By Hand
CATCHMENT: CROPPED AREA RATIO: 2:1
ZONE: AEZ 5 / AEZ 6
USE: Grass / Fodder

0 5 10 15 20 25 km
1 : 100 000

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Contour Ridges Contour ridges are seldom called contour furrows and are suitable for crop production under a micro catchment technique. Ridges are spaced at 1 to 2m and follow contours. Ridges are constructed from borrows of furrows on the upslope. Runoff is collected from the un cultivated area and stored in the furrows. Crops are planted in by hand or machine and hence easily replicable.

Contour ridge system of water harvesting has relatively short catchment length which can produce better yield of run-off being very efficient if designed and constructed correctly. Plants growing by the system are even as they receive run of from the same catchment. Overall layout of contour ridges involve almost parallel earth ridges nearly on contour spaced closely with earth ties situated in the furrow every few meters to ensure an even storage of run off. The system can be provided by a diversion ditch to safeguard it against damage by runoff from outside. Extra short ridges can be introduced where contours widen. (see figure 7) The system can be mechanized and is believed to be appropriate for large scale implementation.

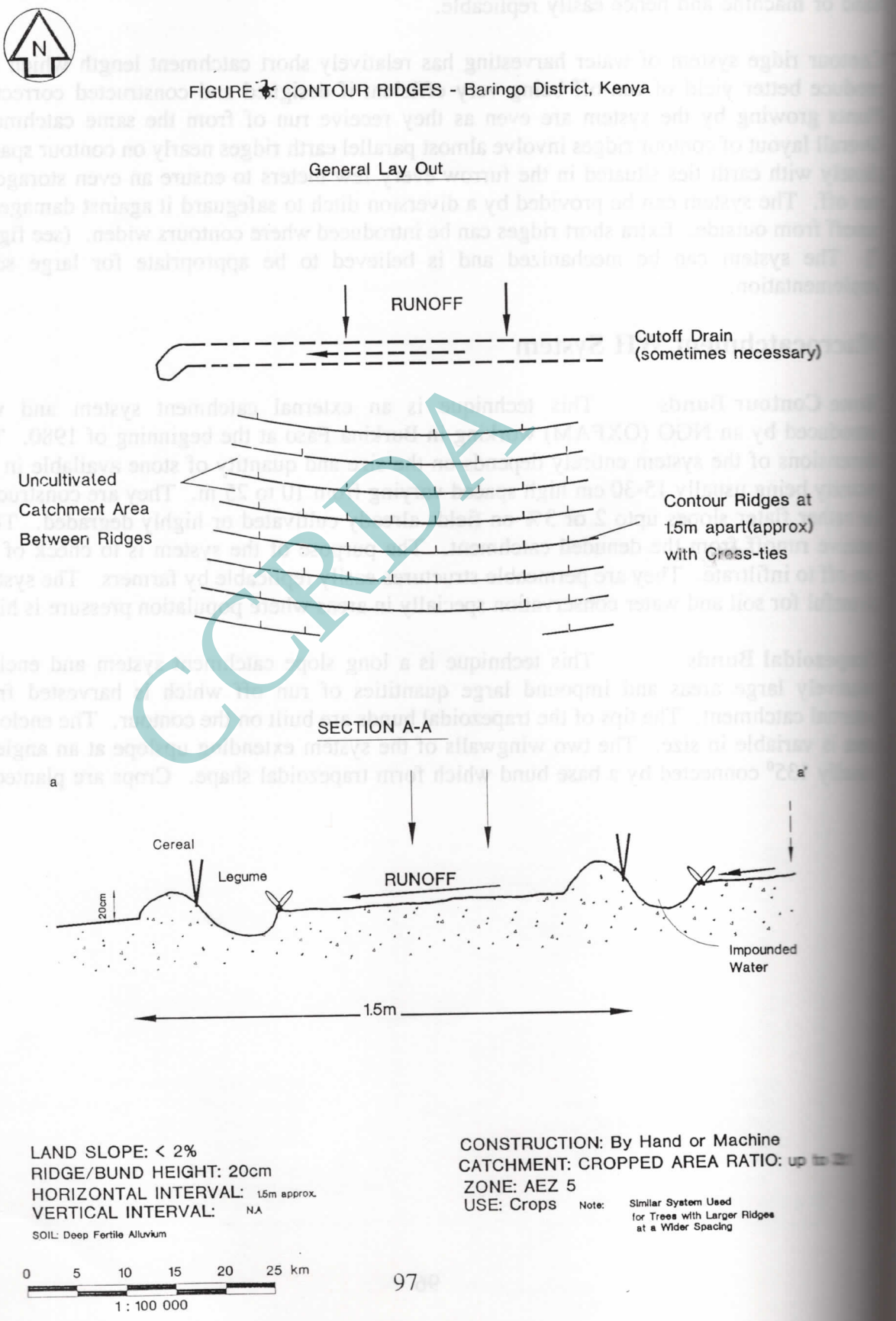
Microcatchment WH System

Semi Contour Bunds This technique is an external catchment system and was introduced by an NGO (OXFAM) working in Burkina Faso at the beginning of 1980. The dimensions of the system entirely depends on the size and quantity of stone available in the vicinity being usually 15-30 cm high spaced varying from 10 to 25 m. They are constructed on rather flater slopes upto 2 or 3% on fields already cultivated or highly degraded. They receive runoff from the denuded catchment. The purpose of the system is to check of the runoff to infiltrate. They are permeable structures easily replicable by farmers. The system is useful for soil and water conservation specially in areas where population pressure is high.

Trapezoidal Bunds This technique is a long slope catchment system and enclose relatively large areas and impound large quantities of run off which is harvested from external catchment. The tips of the trapezoidal bunds are built on the contour. The enclosed area is variable in size. The two wingwalls of the system extending upslope at an angle of nearly 135° connected by a base bund which form trapezoidal shape. Crops are planted in

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Figure 7



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the enclosed area varying from 0.1 to 1 ha. The bunds may be constructed as a single unit or in sets. In the later case the system is arranged in a staggered configuration; units in lower lines intercept over flow from the bunds immediately above them. The usual distance in between the tips of adjacent bunds within one row is 20 m while the space between the tips of lower row and the bunds of upper row is 30m. These spacings are not rigidly set but can be flexible according to site conditions with out increasing the number of rows in the unit so the additional row would receive less run off (see Figure 8).

Flood Water Farming System

This is a system of water harvesting where by farming is undertaken within the stream bed by blocking the water flow and concentrating the run-off. More water is utilized on the spot as opposed to the diversion of flood water off the main stream course. The stream bed can be either the valley bottom or the entire flood plain. Thus area can be inundated during peak flood flow. The technique employed under the system is by building permeable long but low rock dams across valleys. The structures can be considered as a form of terraced Wadi as used in more arid areas. Large amount of work is involved which makes labour intensive and needs large group of people in constructing and transporting the stone or earth.

Excess water overflows the stone dam and/or filter through the dam body. Gradually the sediment fills up the area behind the dam with fertile deposits which creates favourable condition for crop cultivation. Provisions of overflow is allowed with sort of spillway in case of building the dam with earth. However earth bund is usually damaged during peak flood flows. (see Figure 9)

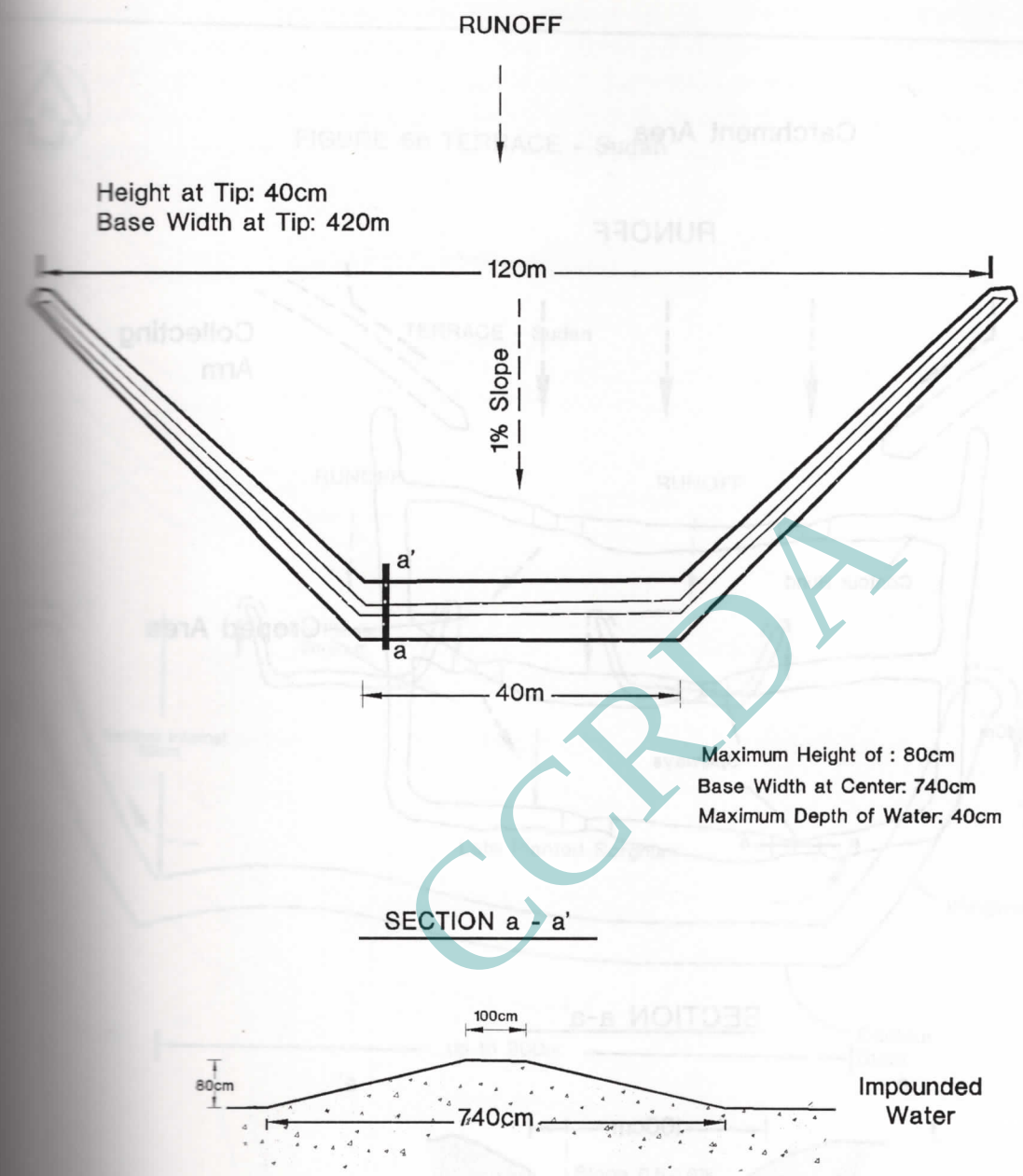
Flood Water Diversion System /spate irrigation/

The technique is a technique which forces the water to leave its natural course which can not be achieved without manipulation. As part of the system the diverted water from Wadis, perennial or seasonal streams is conveyed to a nearby suitable land for crop production and applied by means of channels or bunds. It is a water spreading technique in which the water flow passes through or zig-zags around structures. These structures are usually made of

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FIGURE 8: TRAPEZOIDAL BUD - Turkana District, Kenya



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LAND SLOPE: < 2%
BUND HEIGHT: 80cm (maximum)
HORIZONTAL INTERVAL:] Site Dependant
VERTICAL INTERVAL:]
SOIL: Varied

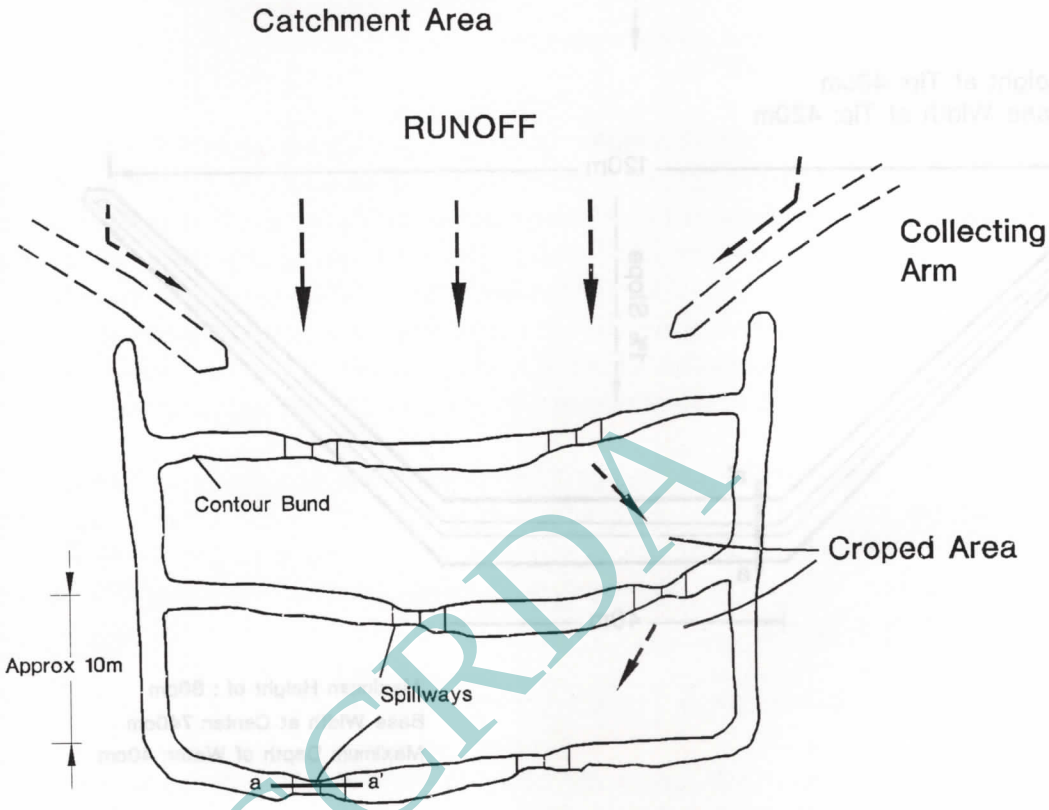
CONSTRUCTION: By Hand
CATCHMENT: CROPPED AREA RATIO: <20:1
ZONE: AEZ 6
USE: Crops
SOIL: Varied

0 5 10 15 20 25 km
1 : 100 000

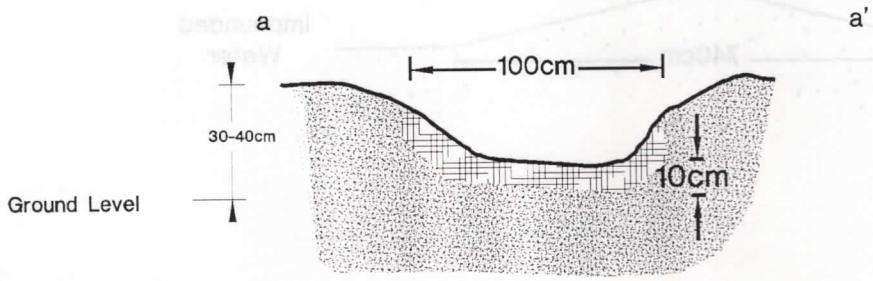
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FIGURE 8b : EXTERNAL CATCHMENT SYSTEM- Baringo District, Kenya



SECTION a-a'



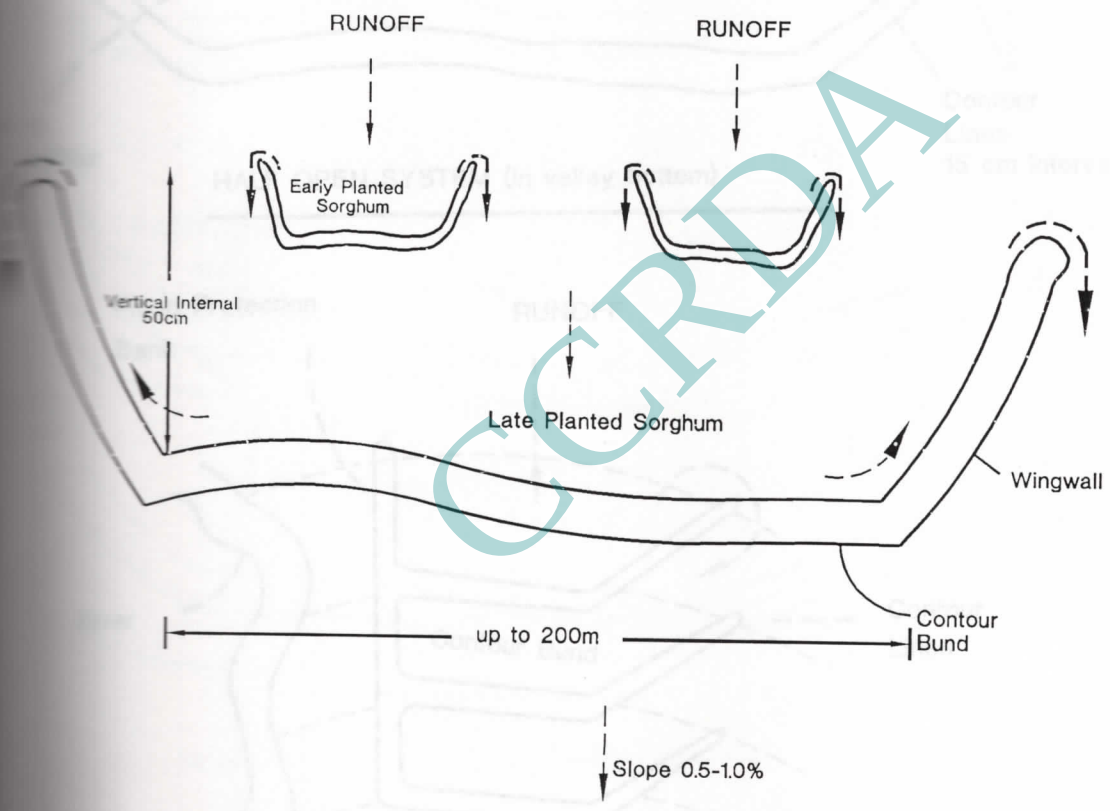
LAND SLOPE: < 2%
RIDGE/BUND HEIGHT: 40cm
HORIZONTAL INTERVAL: 10m
VERTICAL INTERVAL: N.A
SOILS: Deep Fertile Alluvium

CONSTRUCTION: By Hand
CATCHMENT: CROPPED AREA RATIO: 5:1 approx
ZONE: AEZ 5/AEZ 6
USE: Crops

0 5 10 15 20 25 km

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FIGURE 6b TERRACE - Sudan



SLOPE : 0.5 - 1.0%	CONSTRUCTION : By Hand
BUND HEIGHT : 75-100cm	CATCHMENT CROPPED AREA RATIO : ≈ 3:1
INTERVAL : N.A.	ZONE: N.A.
INTERVAL : 50cm to tips	USE: Crops

0 5 10 15 20 25 km
1 : 100 000

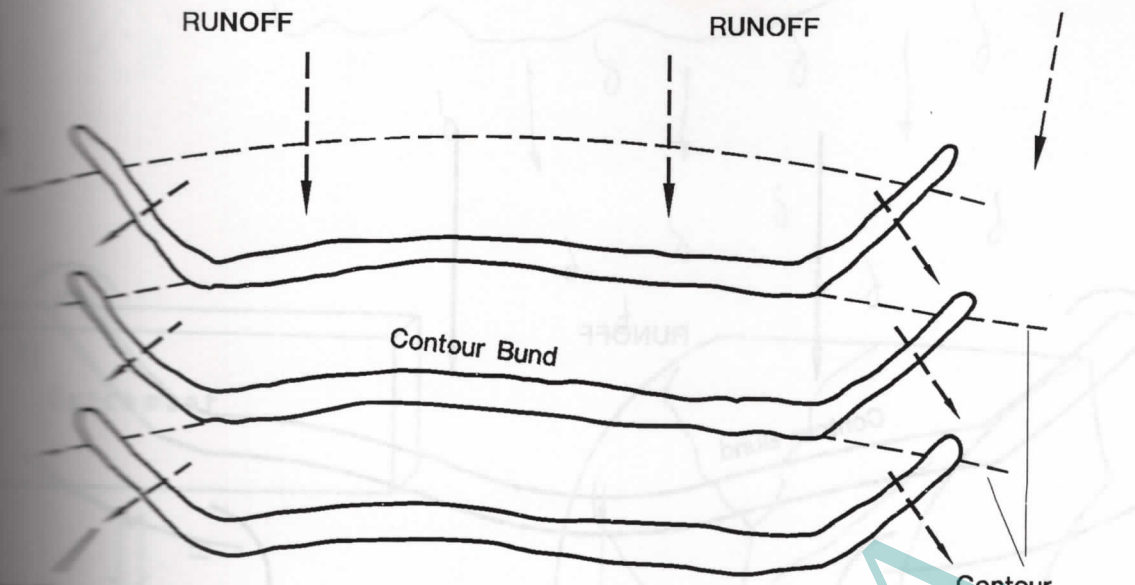
earth to slow down the flow and spread it over the land to be cultivated by allowing it to infiltrate. Here part of the wadi flow is diverted and impoundment is not required.

Two major components are important in the system. The main structure being the diversion dam/weir/with an overflow spillway (if required), and next one is water spreading bunds or channels used as water conveyance structures. This technique is very site specific. The land must be close to the floodwater diversion site, usually on a flood plain with alluvial soils and low slopes. Crops or fodder can be grown using this system between the water spreading bunds.(see Figure 10)

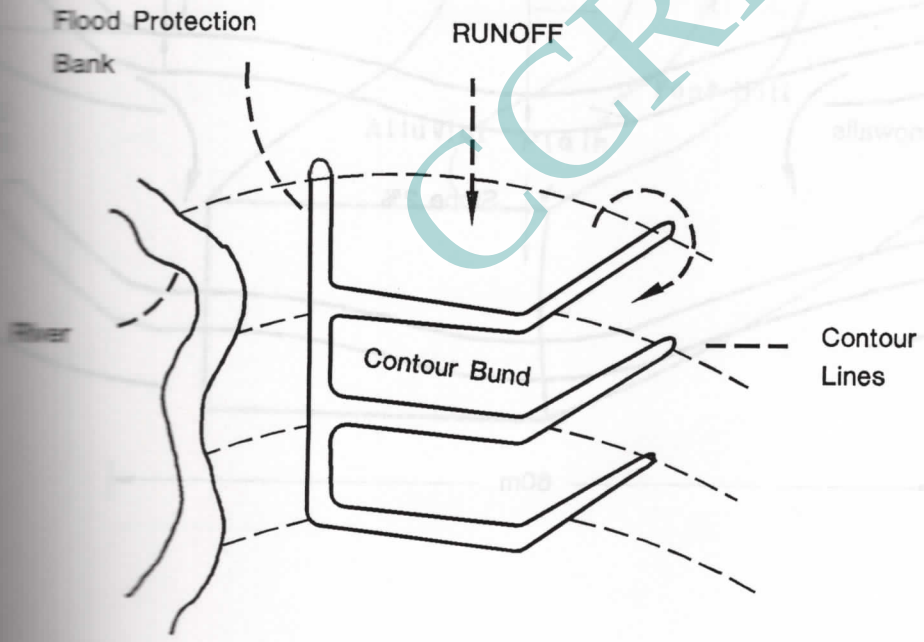
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FIGURE 4a: LOWLAND DEVELOPMENT SCHEMES - Burkina Faso

SIMPLE OPEN SYSTEM (in valley bottom)



HALF OPEN SYSTEM (in valley bottom)



LAND SLOPE: Low
RIDGE BUND HEIGHT: 50cm
HORIZONTAL INTERVAL: N.A.
VERTICAL INTERVAL: 15cm
SOIL: Varied

CONSTRUCTION: Part Machine/Part Hand
CATCHMENT: CROPPED AREA RATIO: Large
ZONE: Various
USE: Crops (mainly Rice)

0 5 10 15 20 25 km

1:100 000

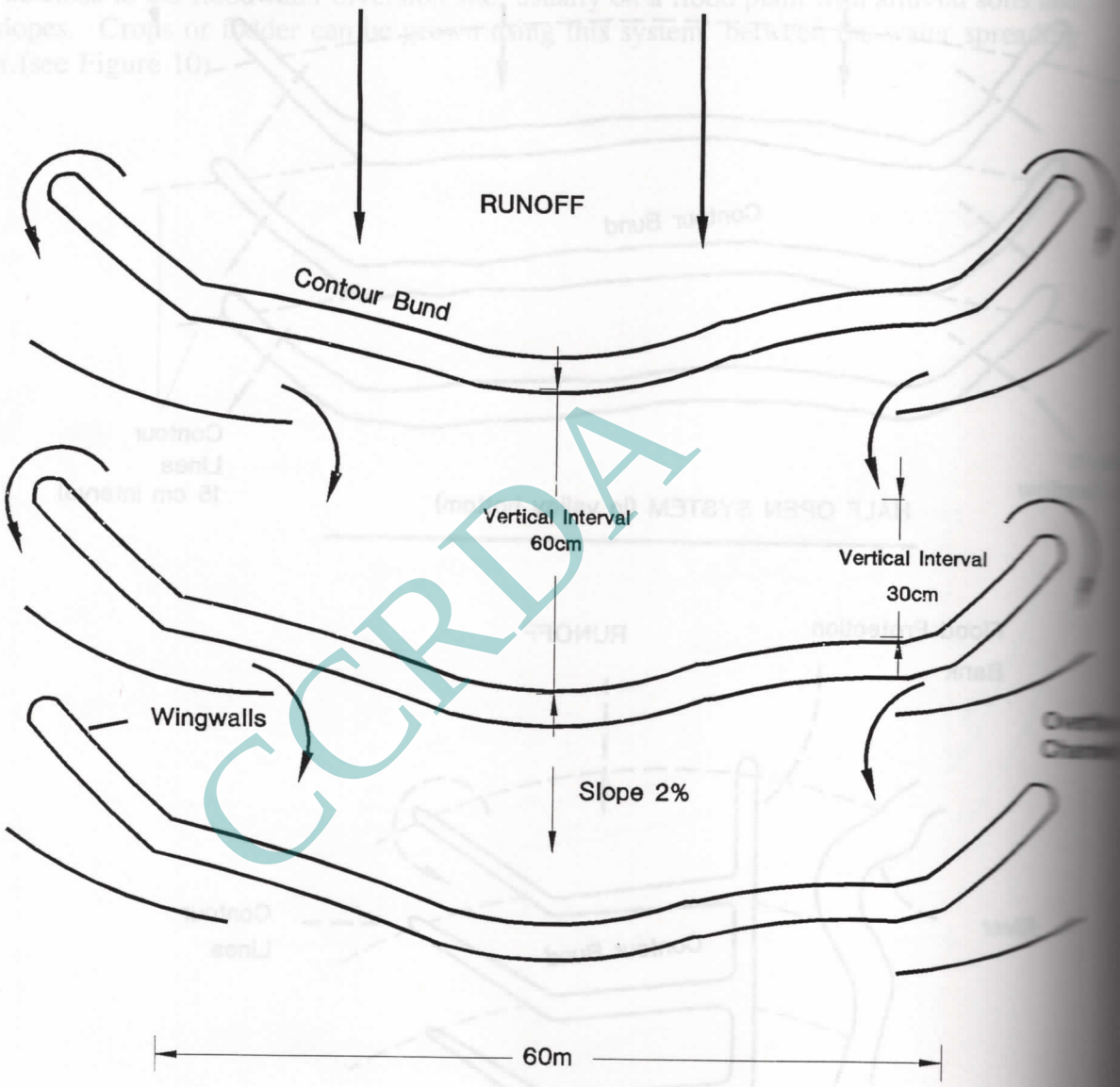
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FIGURE 4b:BUNDING - NWADEP Somalia



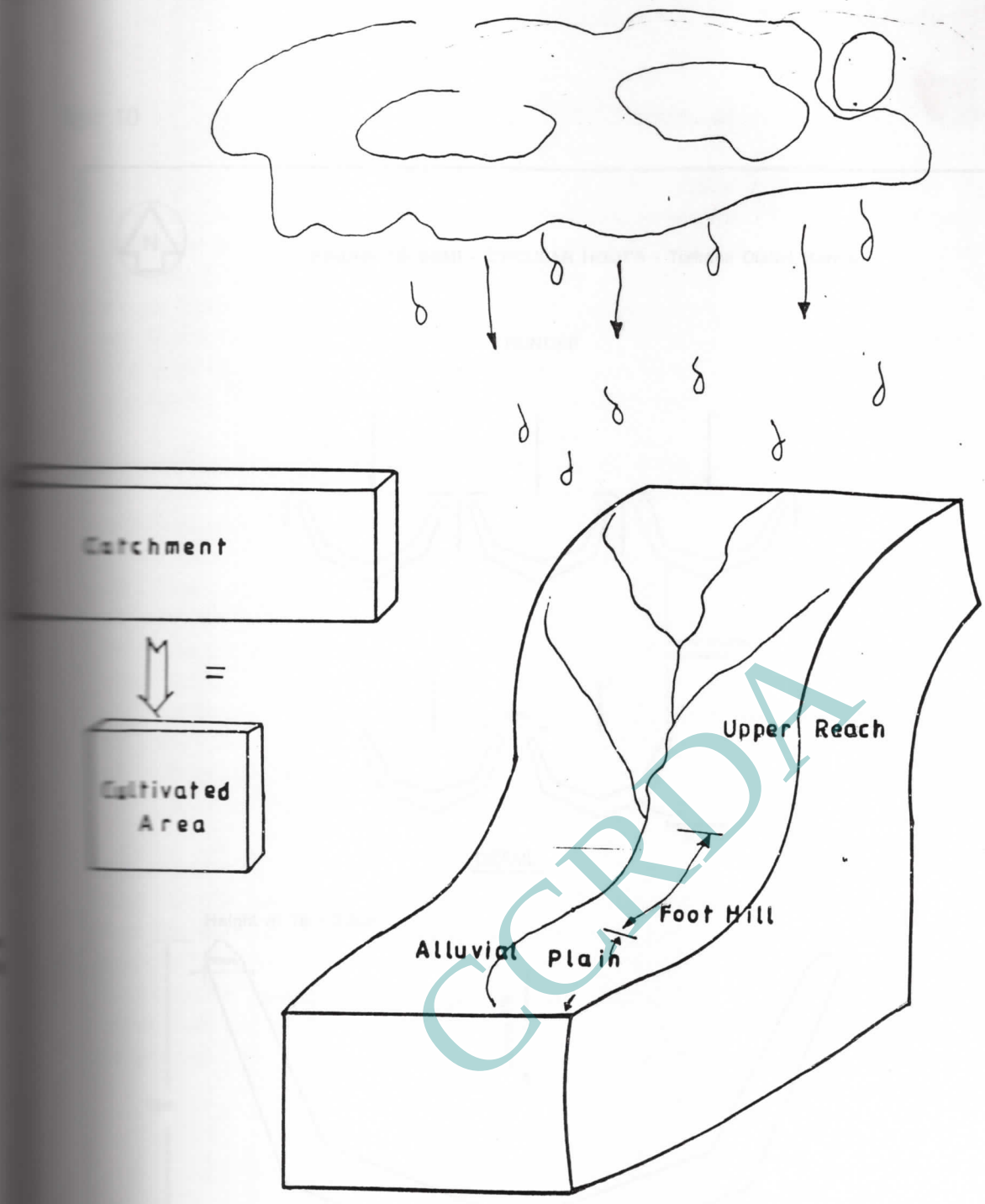
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LAND SLOPE: < 2% [typical]
RIDGE/BUND HEIGHT: 1m
HORIZONTAL INTERVAL: N.A.
VERTICAL INTERVAL: 60cm

CONSTRUCTION: Heavy Machinery
CATCHMENT: CROPPED AREA RATIO
ZONE: Semi - Arid
USE: Crops

0 5 10 15 20 25 km

1 : 100 000



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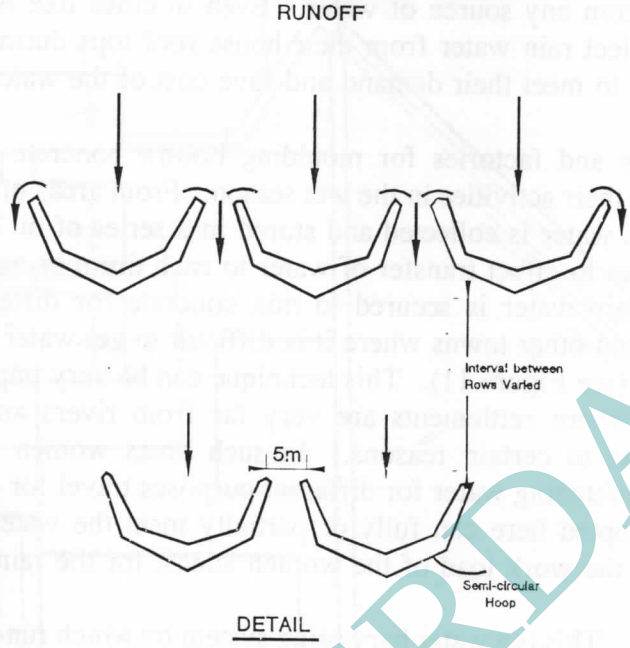
Pictorial Representation

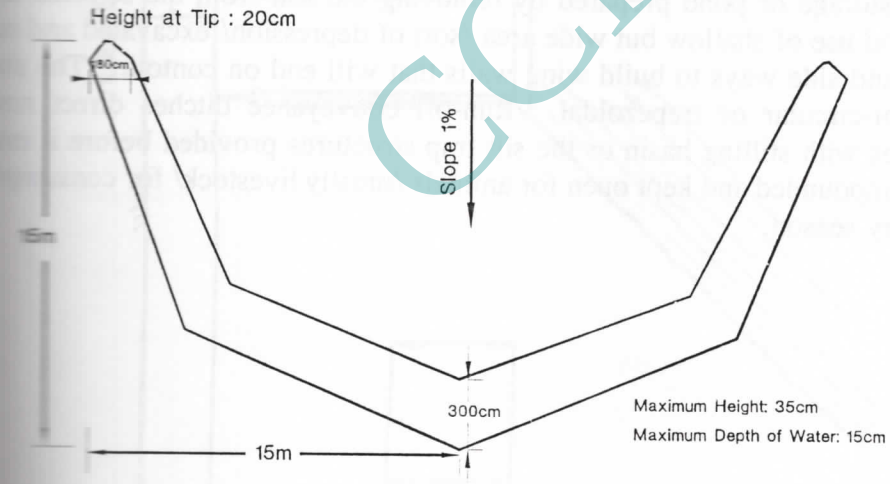
Of

Concept Of WH System

FIGURE 56: SEMI - CIRCULAR HOOPS - Turkana Distict, Kenya.







LAND SLOPE: <3%
RIDGE/BUND HEIGHT: 35cm (maximum)
HORIZONTAL INTERVAL: Site Dependant
VERTICAL INTERVAL:
SOIL: Varied

CONSTRUCTION: By Hand
CATCHMENT: CROPPED AREA RATIO: <20:1
ZONE: AEZ 6
USE: Fodder

0 5 10 15 20 25 km
1 : 100 000

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Rooftop Water Harvesting System

In many parts of Ethiopia even where rainfall is adequate rain water is collected from rooftops covered by galvanized corrugated iron sheets by means of gutters leading to down pipes and stored in oil drums or jars in both rural and urban areas for domestic purposes. Collection of rain water from roof covered by thatches is also practiced. This is common during rain seasons of the year in areas not provided with safe and enough water supply system and those area far from any source of water. Even in cities like Addis Ababa the majority of the dwellers collect rain water from their house roof tops during wet season to perform washing and others to meet their demand and save cost of the water in the system.

Contractors building houses and factories for moulding hollow concrete blocks take the advantage of this system for their activities in the wet season. From areas of house/building/ roofs a large volume of rain water is collected and stored in a series of oil drums /metal or plastic/ connected with pipes to effect transfer of water to each drum or barrel maintaining equal level. In this way rain water is secured to mix concrete for different uses in the periphery of Addis Ababa and other towns where it is difficult to get water supply from the main town supply net work (see Figure 11). This technique can be very important and more applicable in most places where settlements are very far from rivers and ground water potential is not feasible due to certain reasons. In such areas women (like elsewhere) traditionally responsible for fetching water for different purposes travel for hours. Roof top rain water harvesting if adopted here can fully or partially meet the water demand of the communities and minimize the work load of the women atleast for the rainy periods.

Dugouts or water ponds. This is a water harvesting system by which run-off is intercepted and channelled to a storage or pond prepared by removing the soil from the selected area. The traditional method use of shallow but wide area /sort of depression/ excavated and earth thrown down slope and side ways to build wing walls that will end on contour. The shape can be roughly semi-circular or trapezoidal. Run-off conveyance ditches direct runoff coming from hillsides with stilling basin or the silt trap structures provided before it enters the pond. Water is impounded and kept open for animals /mostly livestock/ for consumption during part of the dry season.

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Figure 11

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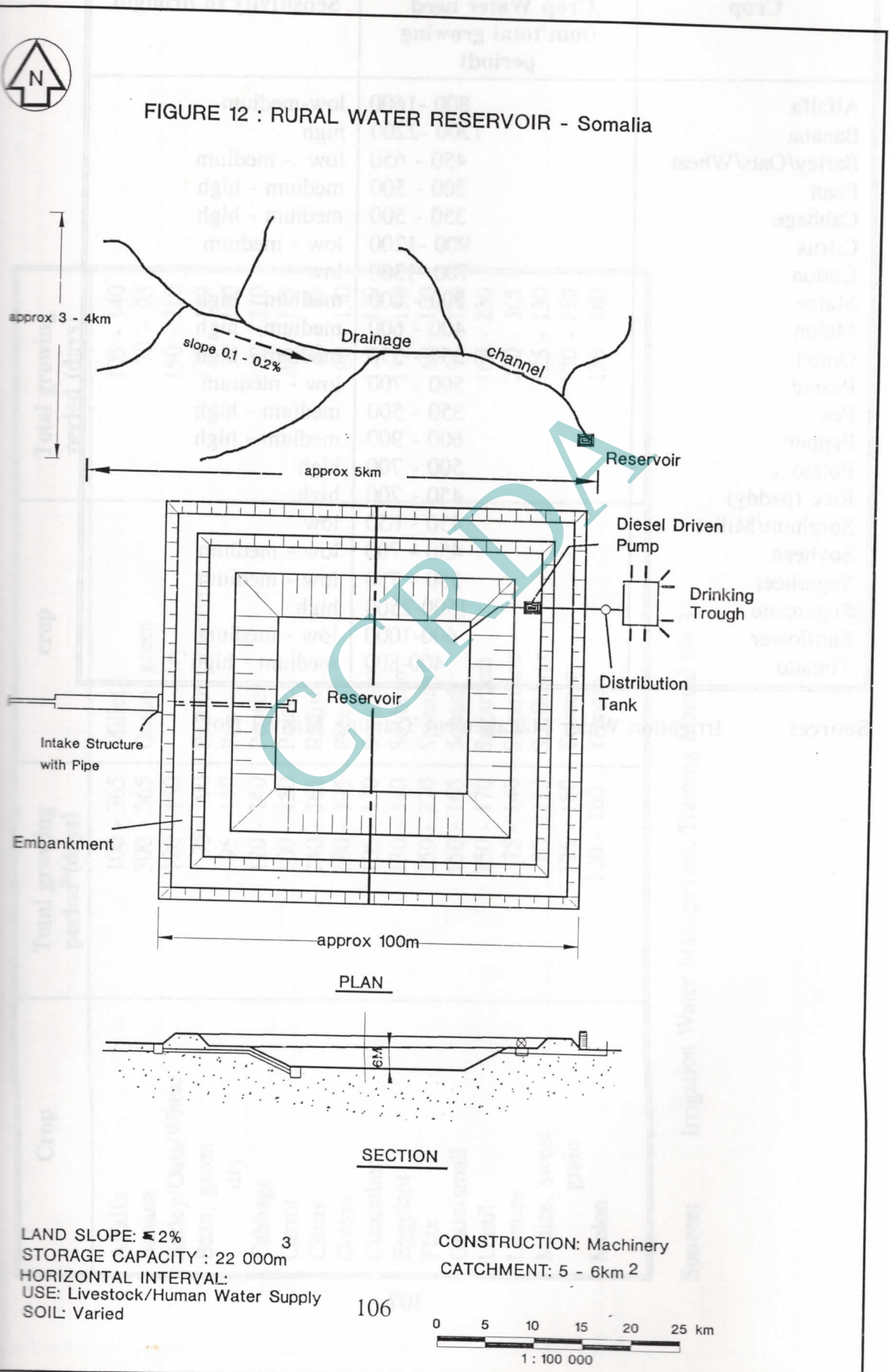
In some places this traditional technique has been improvised in such a way that excavation is done deeper but relatively on narrower area and the entire wall is lined with cement concrete. Improved stilling basin is provided that able to partially settle the sediment load (silt) carried along and trap trashes before entering the under ground storage reservoir. Water can be taken either by buckets or pumped out by means of power available .(see Figure 12)

Table 3.1 **Runoff coefficients.** (Hofkes, 1981: UNEP, 1983, Frasier, 1975 and Gould, 1983)

Type of catchment	Coefficients
Roof catchments	
- tiles	0.8 - 0.9
- corrugated metal sheet	0.7 - 0.9
Ground surface coverings	
- concrete	0.6 - 0.8
- plastic sheeting (gravel covered)	0.7 - 0.8
- butyl rubber	0.8 - 0.9
- brick pavement	0.5 - 0.6
Treated ground catchments	
- compacted and smoothed soil	0.3 - 0.5
- clay/cow-dung threshing floors (Botswana, Gould 1983)	0.5 - 0.6
- silicone-treated soil	0.5 - 0.8
- soil treated with sodium salts	0.4 - 0.7
- soil treated with paraffin wax	0.6 - 0.9
Untreated ground catchments	
- soil on slopes less than 10 percent	0.0 - 0.3*
- rocky natural catchments	0.2 - 0.5

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Figure 12



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Table 3: Indicative values of crop water needs and sensitivity to drought.

Crop	Crop Water need (mm/total growing period)	Sensitivity to drought
Alfalfa	800 -1600	low-medium
Banana	1200 -2200	high
Barley/Oats/Wheat	450 - 650	low - medium
Bean	300 - 500	medium - high
Cabbage	350 - 500	medium - high
Citrus	900 -1200	low - medium
Cotton	700 -1300	low
Maize	500 - 800	medium - high
Melon	400 - 600	medium - high
Onion	350 - 550	medium - high
Peanut	500 - 700	low - medium
Pea	350 - 500	medium - high
Pepper	600 - 900	medium - high
Potato	500 - 700	high
Rice (paddy)	450 - 700	high
Sorghum/Millet	450 - 650	low
Soybean	450 - 700	low - medium
Sugarbeet	550 - 750	low - medium
Sugarcane	1500-2500	high
Sunflower	600-1000	low - medium
Tomato	400-800	medium - high

Source: Irrigation Water Management Training Manual No 3

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Table 4 Indicative Values of the Total Growing Period

Crop	Total growing period (days)	crop	Total growing period (days)
Alfalfa	100 - 365	Millet	105 - 140
Banana	300 - 365	Onion, green	70 - 95
Barley/Oats/Wheat	120 - 150	dry	150 - 210
Bean, green	75 - 90	Peanut/Groundnut	130 - 140
dry	95 - 110	Pea	90 - 100
Cabbage	120 - 140	Pepper	120 - 210
Carrot	100 - 150	Potato	105 - 145
Citrus	240 - 365	Radish	35 - 45
Cotton	180 - 195	Rice	90 - 150
Cucumber	105 - 130	Sorghum	120 - 130
Eggplant	130 - 140	Soybean	135 - 150
Flax	150 - 220	Spinach	60 - 100
Grain/small	150 - 165	Squash	95 - 120
Lentil	150 - 170	Sugarbeat	160 - 230
Lettuce	75 - 140	Sugarcane	270 - 365
Maize, sweet	80 - 110	Sunflower	125 - 130
grain	125 - 180	Tobacco	130 - 160
Melon	120 - 160	Tomato	135 - 180

Source: Irrigation Water Management Training Manual No 3

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Table 4 **Suitable Factor for W/t system**

Classification	WM System	Mean annual (mm) rainfall	Topography and Land Slope (%)	Soil	Catchment to cultivated area ratio
Micro Catchment	Negarim Microcatchment	150	Need not be even ≤5%	1.5 - 2m deep	Variable
	Contour bund	200-750 arid-S.arid	Must be even free-of rills, gullies	1.5-2 deep	Variable
	Semi circular bunds	200-750 arid-S.arid	Even topo < 2%-5%	Not too shallow or saline	1.4:1 3:1 depend on design
	Contour ridges	350-750	flat - 5%	All agricultural soils not heavy soils	2:1 3:1
	Trapezoidal	250-500 Arid to S.arid	Within bund must be even 0.25-1.5% suitable <5%	Agricultural soils with good construction properties (clay content reasonable)	Upto 30:1 is sometimes used but 10:1 is recommended
External catchment	Contour Stone bunds	200-750 Arid-S.arid	Need not be even <2%	Agricultural soil good stone availability	Variable
	Permeable rock dams	200-750 Arid-S.arid	Wide shallow valley beds <2%	All agricultural soil	Not applicable
	Water Spreading bunds (spate)	100-350 arid	Even, <1%	Alluvial fans deep fertile soil	Not applicable
Root top	Root top	> 100 in all zones	-	-	N.A

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Table 3 Major Climatic Zones and Land Use in Africa

Climatic zone	Annual rainfall (mm)	Wet period (months)	Vegetation	
Desert	less than 100	0 - 1	little or no vegetation	Hunters, nomadic pastoralists, sedimentary irrigators around , no rainfed agriculture
Arid	100 - 400	1 - 3	Some shrubs and grassland	Extensive grazing, some millet and sorghum under flood irrigation (WH) in valley plains.
Semi Arid	400 - 600	3 - 4	Shrubs + bushes + grassland	Cultivators, mainly millet and sorghum also short corn pea phaseolus beans ground nut, no fodder or sown pasture , maize in cooler zone
Sub humid	600 - 1200	4 - 6	Bushes to wood and, grassland	Traditional nomadic pastoralist in dry season and drought years. Millet, sorghum Maize Ground nuts, Casana, Cornpeas, Cotton, Sweet potato, Tobacco, Soy bean, Down pasture etc.
Most sub humid	1200 - 1500	6 - 9	Forest and woodland	Transitory zone for agriculture. Too wet for seasonal crops, too dry for tree crops, Maize caravan jams, bananas, pineapple... in tropics winter rainfall-east African highland barely and wheat.
Humid	morethan 1500	9 - 12	Tropical rain forest	Tree crops oilpalon, cacao some sorghum, maize banana sugar cane rice. Some tropical hard wood

Source:

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Simple Surveying Techniques

Definitions of Termnologies used

Elevation is the height or vertical distance of a point or object from a known datum - sea level or a temporary bench mark (reference point)

Contour line is a line joining equal elevations or vertical distance on a topographic map.

Topographic Map is a map representing the natural and artificial feature of an area, i.e. ridges, depression, roads, swamps etc on a paper to the desired scale.

Slope is the ratio of a vertical distance to a horizontal distance represnted as percentage.

Surveying Techniques

In most cases and places surveying is carried out for different purposes using scientific instruments like levels, meodolites, RDs and recently the total which is aided by computers. These instruments are expensive to buy and need specialist skills.

For the purpose of this training introduction of use of simple instruments like the line level and the water tube level for simple surveying purpose is very important. These simple instruments are used to layout contours and also to layout graded contours and measure slopes using the former but is difficult using the later one. Procedure in under taking the job will given separately.

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Spate Irrigation

Definition

Spate irrigation is a water harvesting technique by which flood water is diverted from ephemeral streams, conveyed by forms of channel and spread over the alluvium plains to grow crops and/or pasture. This is effected traditionally by constructing earthen banks across the flood course (Wadi) to divert the total flow or by building rock fill spurs at an acute angle protruding into the flow to draw part of the spate. The diverted spate is guided by channel and spread on the cultivated field by means earthen bunds which pond up the flood for the desired infiltration in to the soil profile.

Like the rest of water harvesting techniques traditional spate irrigation has ancient history in Middle East. The traditional methods based on centuries farming populations old experience has been elementary and effective. In the Arabian Peninsula this technique involved building of deflectors and earthen banks named 'Oamas' across the wadis to divert part of the entire flow of spate to the adjacent fields. Medium to large flood flows frequently damaged the temporary structures. These structures were comparatively cheap to build but the cost of their maintenance and repair was high.

In the Ethiopian lowlands where rainfall is low and erratic for crop production some of the sedentary agriculturalists and rarely pastoralists use spate flows crudely to grow subsistence crops and pasture. It can be observed from reports that the whole valley floor in Tigray had been planted and flood from small catchments were spread over the valley bottom, however, lacked outlet for excess flood.

In the Eastern Catchment - part of the Awash River Basin small holder (family size) spate irrigation schemes are observed along the rail road between Mieso and Erer towns. The numerous ephemeral streams dissecting alluvial plains in the catchment originate from the eastern high lands and carry flood flows to alluvial fans and finally braid away without reaching the Awash river. Farmers living at the foothills have practised spate irrigation for

over 30 years. They grow maize, sorghum and sweet potatoes. In this area near by Mullu town (train substation next to Mieso), there is an abandoned spate diversion /weir/ structure across Koran Gogoga stream, which was originally built by an Italian investor who used to cultivate vegetables. This man was known to export large tonnes of vegetables to Djibouti from his 40ha spate irrigation land. This scheme is believed to have been destroyed after the 1974 revolution and the Italian farmer evacuated.

The main problems reported in this area similar to else where practicing spate irrigation are frequent destruction of the temporary weirs, large quantity of sediment load uncertainty of occurrence of spate which lead to total crop failure and labour availability.

Physical Characteristics of Spate

Climate - Spate irrigation is of most interest in the arid and semi-arid areas where rainfed agricultural production is limited by low and erratic rainfall. The terms arid and semi-arid are used by most authors as indicated earlier for region where potential evaporation is much higher than the precipitation.

Rainfall - Arid zones are characterized largely by sudden winds and convective type cloud mechanisms which usually result in short duration storms of relatively high intensity and limited in areal extent. Low intensity frontal type rains experience in areas where rainfall season is in winter (Jordan, Iraq, Negev Desert etc) and aridity is up to 250 mm of rainfall annually. In areas where rainfall occurs during summer as in the Sahel (Ethiopia is part of it) aridity ranges from 300-400 mm rainfall per year. In Africa, the Sahelian rainfall is influenced by the Inter Tropical Convergence Zone (ITCZ) where (See Figure 13)

Run-off Precipitation in arid regions is not sufficient to cause floods, the low rain that falls is infiltrated or evaporated and induces little run off over the ground surface. Spates in this zones rise from well defined run off generating areas (catchments). They occur as short isolated 'flow periods' separated by longer periods of little or zero flow. This gives rise to the ephemeral characteristics of the streams in the arid zones. Flows in the wadis are

usually seasonal. Prolonged base flows occur from springs or in channels outside of the region. The peak discharges in a short duration are caused by sporadic, high intensity rainfall occurring within a short time and by the catchment characteristics-steep rocky or denuded landscape etc.

High sediment load and transmission loses are also main characteristics of spates in the arid zones. High range of sediment size, from silt to boulders as well as other debris are carried along. The sediments usually deposit behind head work structures, in the conveyance channels and onfarm land.

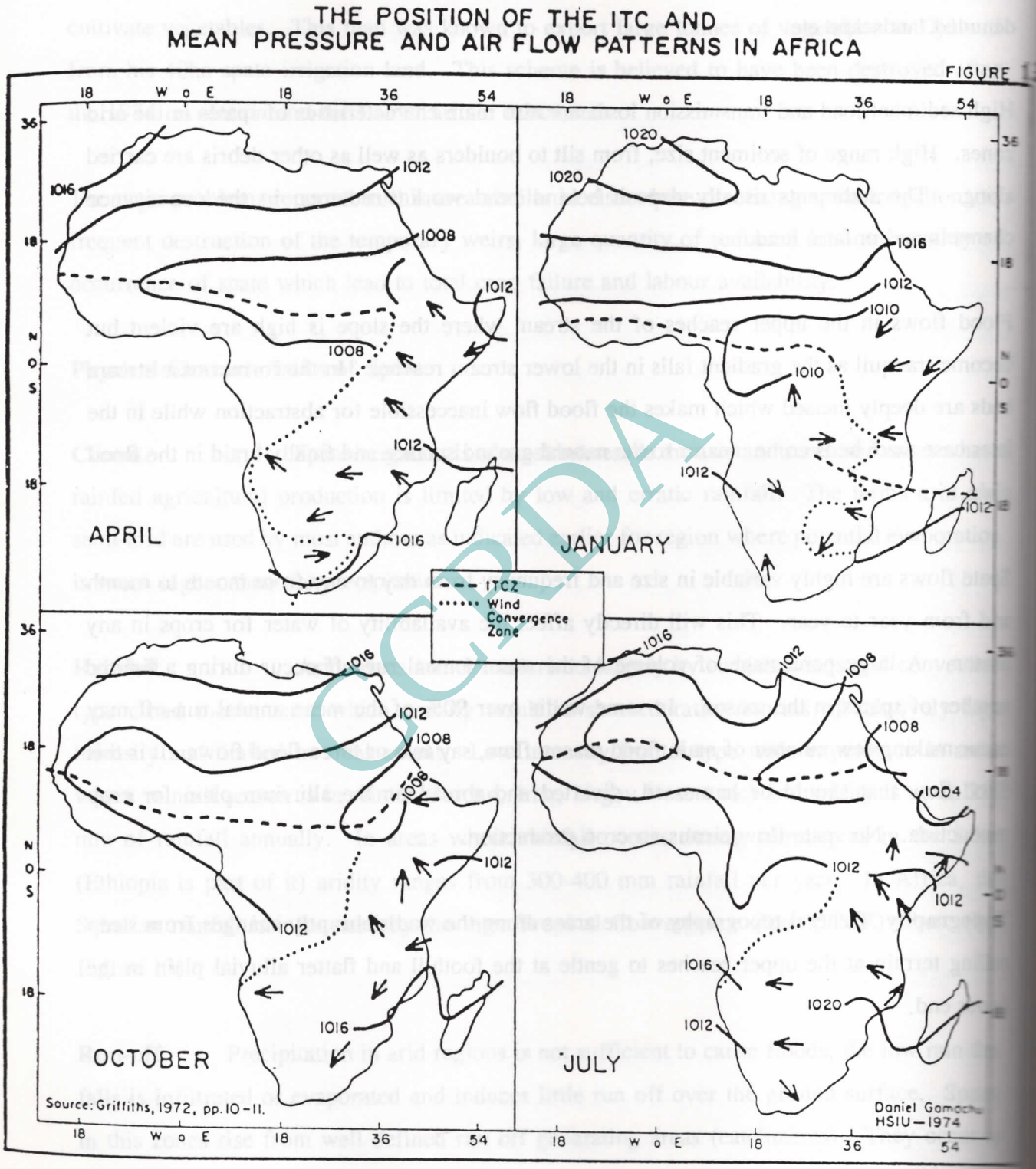
Flood flows in the upper reaches of the stream where the slope is high are violent but become tranquil as the gradient falls in the lower stream reaches. In the former case stream beds are deeply incised which makes the flood flow inaccessible for abstraction while in the latter case wadi beds come nearer to the natural ground surface and finally braid in the flood plain.

Spate flows are highly variable in size and frequency from day to day from month to month and from year to year. This will directly affect the availability of water for crops in any season. A large percentage of volume of the mean annual run-off occur during a limited number of spates in the season. In some wadis over 90% of the mean annual run-off may occur making few number of main flood season flow, say two or three flood flows. It is this flood flow that should be harnessed, diverted and spread on the alluvium plain for crop production. No spate flow means no crop production.

Topography General topography of the areas along the wadis abruptly changes from steep rolling terrain at the upper reaches to gentle at the foothill and flatter alluvial plain in the lower end.

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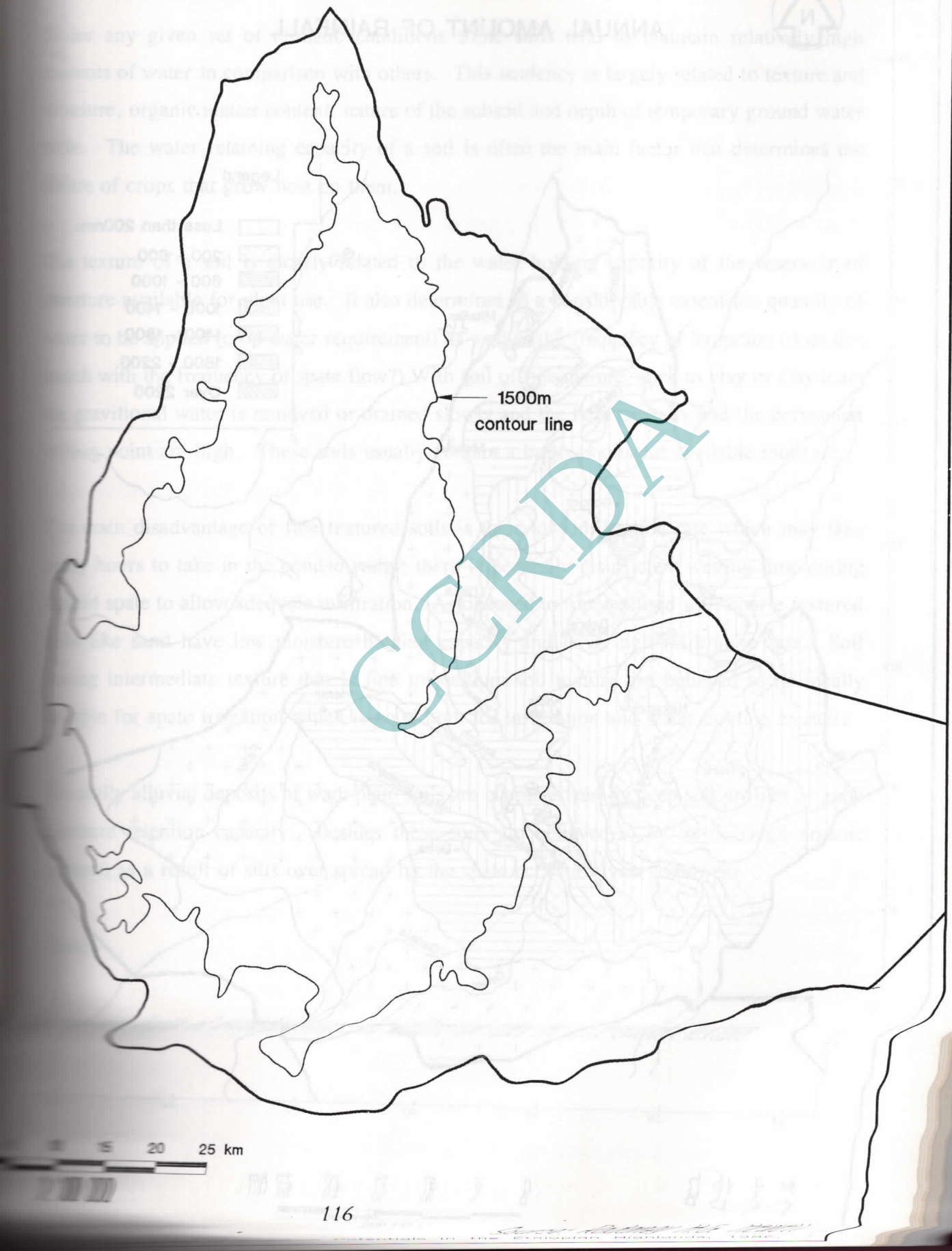
Figure 13



Source: Daniel Gamachu, 1977, Addis Ababa University Press

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Figure 15a : High and Lowland Location Map



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PLATEA4.dwg

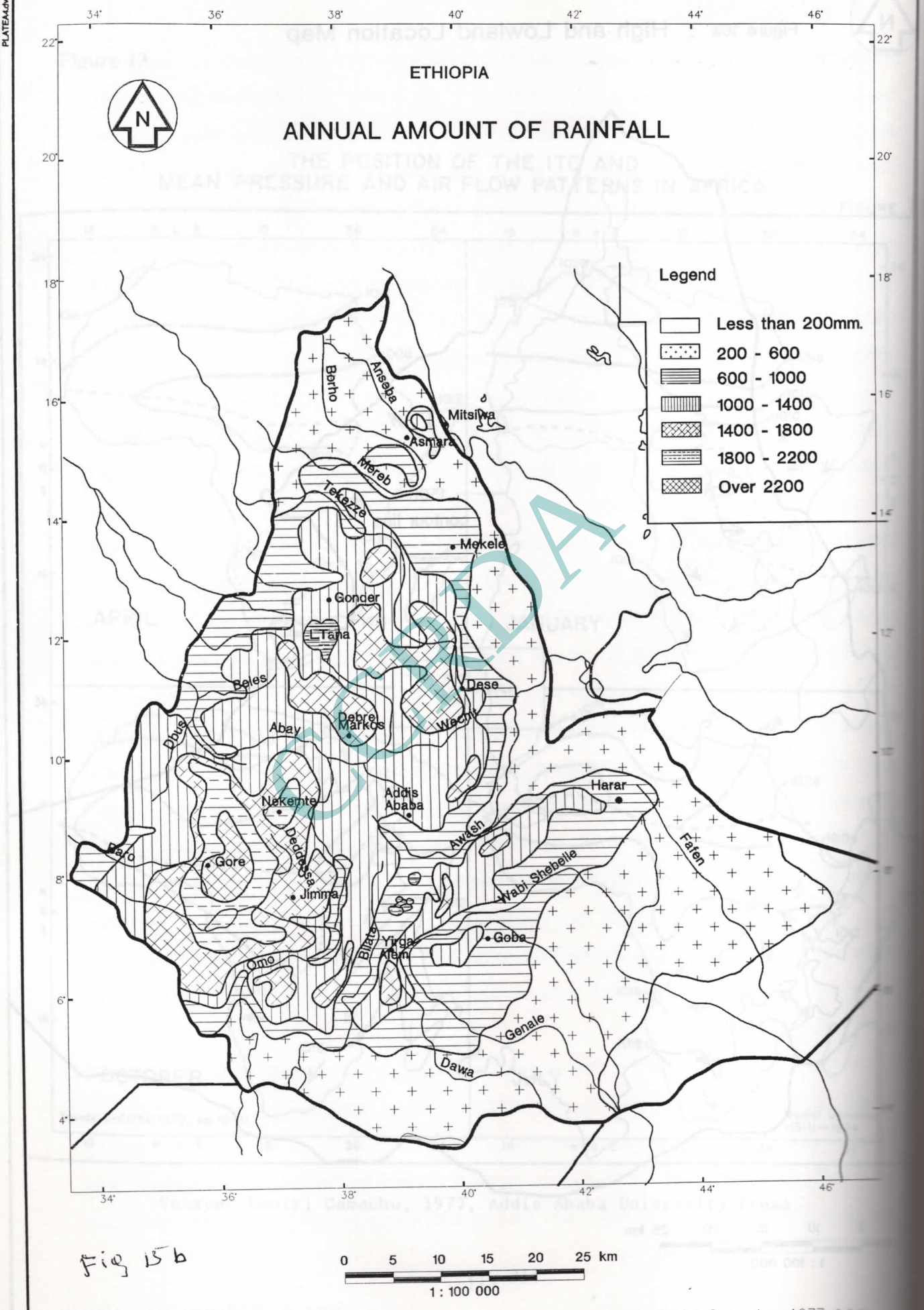


Fig 15b

source Daniel Gamachu, 1977

Soils and Land Capabilities

Under any given set of climatic conditions some soils tend to maintain relatively high contents of water in comparison with others. This tendency is largely related to texture and structure, organic matter content, nature of the subsoil and depth of temporary ground water table. The water retaining capacity of a soil is often the main factor that determines the nature of crops that grow best on them.

The texture of a soil is closely related to the water holding capacity of the reservoir of moisture available for plant use. It also determines to a considerable extent the quantity of water to be applied (crop water requirement) as well as the frequency of irrigation (does this match with the frequency of spate flow?) With soil of fine texture, such as clay or clay loam the gravitional water is removed or drained slowly and the field capacity and the permanent wilting point are high. These soils usually contain a large amount of available moisture.

The main disadvantage of fine textured soils is their low infiltration rate which may take many hours to take in the ponded water; there is generally insufficient wetting time during rapid spate to allow adequate infiltration. As opposed to fine textured soils coarse textured soils like sand have low moisture holding capacity and have high infiltration rate. Soil having intermediate texture that is fine to medium soil texture are believed to be ideally suitable for spate irrigation which is good both for infiltration and water holding capacity.

Generally alluvial deposits of wadi plain soils are characterized by deep soil profiles of good moisture retention capacity. Besides these soils are believed to be fertile (high organic content) as a result of silts over spread by the spate occurring year after year.

Table:-

Approximate depth of available water and infiltration rates for different soil texture

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Soil texture	infiltration rate cm/m	Available water capacity cm/m
Sand	2.5 - 25	7 - 10
Sandy loam	1.3 - 7.6	9 - 15
Loam	0.8 - 2.0	19 - 19
Clay loam	0.25 - 1.5	18 - 23
Silty loam	0.03 - 0.5	20 - 25

Source Irrigation Principles and Practices, Israelsen

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Evolution of Spate Irrigation

Since the beginning of human kind's effort to use spate flow for productive purpose, though gradually, remarkable improvements have been achieved. Diversion and distribution systems of the technique have been improvised eventually. Initially earthen banks were constructed fully or partially across the ephemeral streams to divert the required flow on the adjacent land under concern. This became very difficult if not impossible as a result of frequent destruction of structures sediment deposition in and around intakes and canals and the wadi beds were scoured and incised. Raising of the low spate flows to the level of canal full supply level became crucially important. This noble concept solved the problem of access to low level flows. Yet the problem of easily destroyability of the earthen embankment and deposition of sediment in the system lasted for centuries.

Recently modernization of this technique received attention by Governments, Funding Organizations and Engineers concerned in these areas and improvements were made by introducing conventional method of designing weir, intake structures and provided sediment exclusion as to match with the traditional ones.

Traditional Spate Irrigation Technique

As discussed earlier in the arid zones agriculture is impossible without irrigation. In most of these areas where water resource is the limiting factor (no perennial rivers) spate irrigation is the only option for crop production.

Irrigation has been practised by farmers in these areas by harnessing the flood occurring at any time by building wadi material across the dry stream bed or constructing spurs (structures producting into the wadi) in order to fully or partly divert the spate on to the cultivated land. These structures being usually earthfill embankments were amenable to frequent distraction /wash away/ by medium to large spates.

Destruction of the headwork sometimes occur before the desired volume of water is diverted even at the beginning of flow diversion. So diversion becomes impossible before the next

reconstruction of the temporary weirs. More labour cost and dry period is required. Hence crop production is postponed for the next season. Further more life and property is lost. Maintenance cost of the system is very comparable to the cost of building new structure.

Once the spate is diverted it makes its way through the main channel until it reaches the targeted land. The channels besides carrying along high discharge the system is required to cater for the very high sediment land. This characteristics demands higher flow velocities and steeper gradient of canal bed as compared to clear water flow.

Suspended sediment in the canal are usually welcomed by farmers and allowed to spread over their plots as a source of fertility. But this deposition of silt in the field eventually result in an uneven topography and consequently difficulty in commanding by the existing canal alignment system. There is not any provision of permanent spate flow control system in the traditional spate irrigation technique. That is, off-takes to the fields are made from the main canal. Fields are bounded by basin ridges (earth bunds) of reasonable height. Water is allowed to fill up the baisn and released to the next down stream plot when the approximate required depth of flood is believed applied. Therefore, water distribution is plot-to-plot system.

Modernization of Spate Irrigation System

As opposed to the temporary structures incorporated, uncontrolled flow system, today this technique involves the design of permanent weirs across the ephemeral streams including canal head regulator and sediment excluders. The modern design incorporates also the improvisation of the canal network and the water distribution systems similar to the conversational irrigation system though spates are unreliable. In modernization of spate irrigation system the objective is diversion of controlled flow with minimized sediment load and reduction of uncertainty of the spate availability to the cultivated land. Thus thorough investigation of factors that are favourable for the success and sustainability of the system is very important. These factors involve spate hydrology, soils and land capability, land tenure and water rights and the socioeconomic aspect of the area under consideration.

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As the objective of building permanent diversion structure for spate irrigation system is to secure the diversion of the spate flow, this concept with no doubt required high construction cost; skilled labour, cement and sometimes foreign currency component. In order to minimized such costs and win the acceptability of the technique by the beneficiaries, the idea of improving traditional deflectors through bed stabilization has led engineers to consider gabion mattress for the permanent silt flushing system to intercept the lowflows and direct it to the canal intake.

The choice of gabion is determined by a number of factors. Materials used to fill the gabion boxes are locally available, from research it is proved that gabion can withstand effect of impact, abrasion and distortion. The most important factor is that farmers can participate in the construction and may develop sense of ownership and responsibility for the maintenance of the structure, and obviously it creates employment opportunity for the local labourers at least during construction period. Gabion structures are also cheaper than the conventional concrete and masonry weirs.

The design of canal network must be flexible so as to accommodate the varying spate flows as opposed to the steady flow state in the conventional ones, careful consideration ought to be given to the transport of highly variable sediment load without significant scour. This is important in the determination of the canal bed slope.

The main types of control structures used in this technique are: weirs to raise and divert spate flow with the offtake and head regulator to control discharge entering the main canal.

Sediment exclusion is effected by provision of sluice way between the weir and the canal head regulator. The sluice way gives good scouring action around the approach to the head regulator and interceptes a large proportion of sediment load. (see Figure 12, Recommended layout of flood weir, sluice and offtake channel)

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Possible Potential Sites for Spate Irrigation

As made clear in the previous notes and lectures the arid and semi-arid zones in Ethiopia fall in the lowlands below the altitude of 1500 meters above sea level. The high lands in this country stretch from north to south and from west to east mostly occupying the central part while the low lands cover most of the peripheral land around the territorial boundary as well as some low lands (pockets) in the high lands and the rift valley system.(see figures 14 and 15)

These places in the lowlands with low and erratic rainfall characteristics, reasonable spate flow occurrence, suitable and deep soil, acceptable slope and an undulating topography, available labour for construction and maintenance of the system is ideally the best potential site for sustainable spate irrigation development. To mention few places: the valley floors of Tigray, the foothills in Afar regions and the alluvial fan of the eastern catchment and the rift valley basin etc. are potential sites. With regard to site for diversion structure, its stability and efficiency of diversion should receive proper consideration. The intake structure should be preferable at a bend with the canal offtake at the lower end of the outer side of the bank.

This is because sediments tend to be deposited in the inner side of the bend and deeper flood water pool will be maintained at the convex as in the case of conventional design of river flow diversion structure for irrigation.

Approach of Introducing Spate Irrigation in Potential Areas

In general terms irrigation is a new concept among the vast Ethiopian peasant population. Corp production is achieved using rainfall in the high lands. However recently small and micro scale irrigation schemes are flourishing since the government and the people embanked on the development of this alternative to fight against food self-insufficiency as a result of the recurrent drought. Some schemes were observed to suffer failure as a result of lack of experience and policy constraint of previous government.

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Introduction of spate irrigation in the potential areas may be more difficult and would require a carefully planned approach to enhance its chance of success. The best approach, enter-alia, would be by providing credit and extension services, initiating or involving the beneficiaries as to participate from the outset of the scheme, providing basic infrastructure where they are nonexistent, providing market outlets, providing external assistance (both technical and financial).

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Sustainability of Spate Irrigation

Sustainability of a system is the degree to which it continuous to function throughout its life period. To maintain the spate irrigation system operating at its best requires that the farmers must have understanding and control over the system at every stage. In other words the technology should be easily managable by the farmers. 'Farmers managed' explains that operation, adjustment, maintenance and construction of the system is undertaken by the farmers themselves under minimum supervision which later be managed on their own.

Spate irrigation in particular and water harvesting systems in general have to meet certain conditions in order to be sustainable.

- The product of the scheme (i.e crops, vegetables, fodder, livestock) should be one or more of what the local people have been used to produce traditionally or that has higher demand if cash crop.

- The technology to be employed has to match with the farmers organizational capacity level.

- The technology has to correspond to the financial capability level to acquire the necessary means and instrument of production to implement and operate the system. Intensive labour is the most favoured input in case of adequate labour. Farmers usually draw labour from their won family. Extra labour during the peak requirement must be within what they can buy.

- The technology has to match with farmers knowledge of construction, operation, maintenance of the system. The technique has to be easily replicable and adaptable by the farmer. After the minimum supervision from external source, the construction of the diversion structures and others in the system should be taken over by the farmers themselves. The problem as well as the benefits of the system has to be realized by the beneficiaries. Training must be given on practical demonstration farm.

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To minimize the unreliability of occurrence of spate which largely contribute to the total failure of crops the development of conjunctive use of spate and ground water resources where available is very important. While diverting and spreading the spate considerable volume of water percolates to the ground water which eventually increases the level of the ground water. The stored water in the ground can be pumped to augment the spate irrigation.

This method is very important to sustain the crop production during the period the spate fails to avoid the dissatisfaction and loss of confidence and finally non-acceptance of the system by the beneficiaries. Therefore it is highly recommendable to integrate the development of both resources.

Diversification of means of income greatly assist the livelihood of the people depending on the limited resource. To minimize the risks of starvation and migration farmers have to distribute their investment and participation on versalite farming activities such as livestock development and intercropping where possible and crafting, etc, to generate income.

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Water Harvesting System Design

The technique of collecting rain water occurring in any form and using it for traditional productive purpose has been and is likely to be of increasing importance in the future within the arid and semi-arid areas of sub saharan Africa. For this increasing significance appropriate system design is required if the system has to be acceptable.

The most important factors that need be considered among others are: the socio-economic factors of the community concerned; agronomic options and the engineering alternatives.

1. Socio-economic considerations

The success or failure of water harvesting system will ultimately rely on it acceptance by the target community. Therefore, at the time the scheme is conceptualized the beneficiaries must be consulted. The problems and needs of the community need clearly be understood and fully provided for in planning and design process. It is a regrettable and serious mistake to impose a scheme upon the community without their willingness and participation. The failure of some irrigation schemes and soil and water conservation projects in various parts of this country are few to mention from our recent memories.

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Similarly, after the need assessment priorities have to be established in regard to planning to minimize or solve the problems in the potential areas. Though it is obvious that food shortage is the critical problem in the arid and semiarid, the community may give priority to water supply for their own and their cattle to be very important. If a project concentrates on crop production while the community views this as a secondary priority, there will be little support to the project and then low return. In this regard the planners are required to seek solutions for community's top priority.

The introduction of new technology into a community can not be an isolated development. Its successful acceptance by the community will depend to the extent to which it is technically effective, corresponding with the level of skill of the local people, economically efficient and applicable to the agro-ecological environment. For example a water harvesting

project which increases moisture availability for crops must also improve the standard of crop husbandry in order to achieve its full potential.

is very important to compare design alternatives using cost benefit analysis. Simple and small structures which can be constructed from local materials and require a minimum labour supervision are ideal for water harvesting technique structures, however, must be designed for soundness and avoid frequent failures. This is particularly essential to win confidence of the community. On the other hand the system has to prove benefitable to the farmers.

Agronomic Factors

Water harvesting techniques are intended to increase the availability of water to plants grown in situations where moisture is the primary constraining element. These areas are usually defined on the basis of climatic conditions that is ratio of precipitation to potential evapotranspiration. As discussed earlier in the arid and semi arid zones rainfall is much lower than evaporation. Here different crops respond to different moisture regimes which will affect yield eventually.

Calculation of the season water requirement of the selected crop type is a valuable tool in the design of appropriate systems of water harvesting. The water requirement for maximum yield per land unit under optimum conditions is given as follows:-

$$ETcrop = Kc\ ETo$$

where ETcrop = crop water requirement mm/day
Kc = crop coefficient
Eto = Reference evapotranspiration mm/day

Suitable type of soil at various places for different purposes is very important for the success of water harvesting system. The different purposes are: suitability for runoff generation in catchment either, by sealing or crust formation, suitability for crop/fodder production in cultivated area i.e, should be deep and capable to hold moisture so that the run-off can be stored with the profile.

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Construction of bunds and ridges for the various water harvesting technique requires suitable type of soil: soils which lose their structural integrity on drying can lead to breaches of the bund structures. Black cotton soils (vertisols) are not good for construction of such structures.

Soil fertility is an essential component of a successful system. Crops need the necessary nutrients for optimum growth equally as they need water.

- Another important factor for a successful water harvesting system is selection of type of crop in regard with resistance against drought (moisture stress) tolerance to water logging and maturing earlier. (see table 3 and 4) Crops like sorghum and pearl millet are drought resistant. Moreover pearl millet can not tolerate water logging. Maize requires more water and also is not tolerant to water logging. Generally a research need be carried out before any type of crop is chosen to be adapted.

- Timing in planting, spacing between plants, crop rotation, intercropping in order to use extra moisture and proper weeding are essential factors to be considered in crop husbandry aspect like the conventional agronomic requirement for better yield per unit of land.

Design and System Selection

Appropriate engineering criteria cannot be developed in different to the intended end use of the proposed system or from socio economic consideration. In this regard water harvesting structures should be designed to solve problems imposed by these factors and should meet the following requirement as much as possible.

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Versatility: The techniques employed should involve flexible design and hence be useful for variety of purposes over a range of conditions and be readily replicable.

Simplicity: Construction of the structures employed in the technique should be geared more to labour intensive method than mechanization.

Durability: Structures should be reasonably durable and require minimum repair and maintenance may be preferred to minimize the risk of breaching which will automatically increase the labour required to build them. However care must be taken to avoid high cost over design.

Design parameters: Fundamental to water harvesting technique is the catchment to cultivated area ratio as illustrated in the previous discussion is presented as follow:-

(1) Water harvested = extra water (runoff)

(2) Water harvested = catchment area x design rainfall x runoff coefficient x efficiency factor

(3) Extra water required = cultivated area x (crop water requirement - design rainfall)

By substitution in equation (1) we obtain

Catchment area x Design Rainfall x Runoff coefficient x Efficiency factor = Cultivated area x (crop water requirement - design rainfall)

Rearranging

$$\frac{\text{Catchment Area}}{\text{Cultivated Area}} = \frac{\text{Crop water Requirement - Design Rainfall}}{\text{Design Rainfall x Runoff coefficient x Efficiency water}}$$

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Important parameters involved in the above formula are:-

Crop Water Requirement: This as hopefully covered in the previous sessions is the total amount of water(mm) needed by the crop over its growing period to produce the maximum yield per unit of land. The amount depends on certain conditions like type of crop to be grown and climatic conditions.

Design Rainfall: It is the amount of seasonal rainfall (mm) at which or above which (minimum) the system is designed to provide enough runoff to meet the crop water requirement. Moisture stress will cause crop failure if the rainfall in a season is below the design rainfall and on the contrary if it is above the design rainfall excess runoff will breach the bunds.

Run-off Coefficient: This is the percentage of rainfall which flows along the catchment as a runoff. The amount of runoff depends on slope, soil type, vegetation cover, soil saturation level due to previous rainfall, rainfall intensity and further more on length of catchment (conveyance loss). The coefficient ranges from 0.1 to 0.5 usually.

Efficiency factor: This factor takes into account the in-efficiency of un even distribution of the runoff within the field as well as losses due to evaporation and deep percolation. For example where the cultivated area is levelled and smooth efficiency is higher. Microchachment water harvesting system have relatively higher efficiencies as runoff is usually less ponded. The factor normally ranges from 0.5 to 0.75 depending on experience (judgement) of the designer.

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Water Harvesting Excercise

Your organization has planned to assist the seminomadic agriculturalists near Jijiga town located in a semiarid area. In most years when the rainfall is in adequate to rainfed agriculture the farmers grown drought resistant cereals, and fodder crops, but crop yields are very low on crop failure occurs usually.

You are sent by your organization to the area for selecting the proper water harvesting technique to assist the farmers to cultivate crops. After arriving at the area, you have held several meeting with them and demorcated the boundary of the holdings of the community.

For selecting the suitable type of water harvesting technique you sent out serveyors to the field, who surveyed the land and produced a topo-map at a contour interval of one meter covering 80 ha.

In one of the meetings you held with the farmers, you have learned that they were divided into three groups as to what their immediate priorities are. Some want to grow sorghum; other are interested in growing fodder for the young calves and need water for their cattle and their own, the third group wanted to plant trees to provide sheds for their animals.

In response to the priorities of the farmers, you are required to: a) select the proper type of water harvesting techniques using the topo-map and the availble data. b) Make the outline layout and prepare the outline of explanation you use for convincing the farmers to accept the technique and participate in the construction works. Calculate the labour required to implement the system. Estimate the cost in Birr. Available data

	Jan	Feb	March	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	-	-	-	50	75	100	110	125	40	-	-	-
	250	250	225	210	200	180	150	125	150	125	220	240

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Annual rainfall	=	500 mm		
Annual evaporation	=	2375mm		
Soil type	area	A	B	C
	depth(cm)	40	110	150
	texture	sand	clay	loam

Peak runoff = 90 - 95m^3/sec

Runoff coefficient 0.2, efficiency factor 0.5

trees to be planted - acacia

Crop dwarf - sorghum

Fodder

Labour cost Birr 10/day

farmers want to cultivate each area as follows

Area A	=	trees
Area B	=	sorghum
Area C	=	rehabilitate area for fodder production
Population	=	20
No of cattle	=	60

average water consumption including cattle = 100 l/day/head

Check whether the crop water requirement is meet by the annual rainfall

Assume the area is divided among the three groups by the two main gullies.

1) calculate the average slope for each subaria.

Area 'A'

Slope

Area 'B'

Slope

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Area 'C'

Select the proper technique for each type of crop and tree

Area 'A'

possible techniques

Area 'B'

possible techniques

Area 'C'

possible techniques

For preparing layout

Use the same dimensions of the figures in the handouts.

Size of Negarim microcatchments =		10 x 12m
Contour bunds for trees	-	use 10 m^2 for each tree
Contour ridges for crops	-	spacing 2m
Trapezoidal bunds	-	use the same dimension in the figure in the note.
		The tips should be located on the same contour line.
Water spreading	-	Graded bunds with a single up slope wing should be used as the slope of load is greater than o.5%.
Semicircular bunds	-	Use type 'b' for short slopes and some dimensions as in the figure in the notes

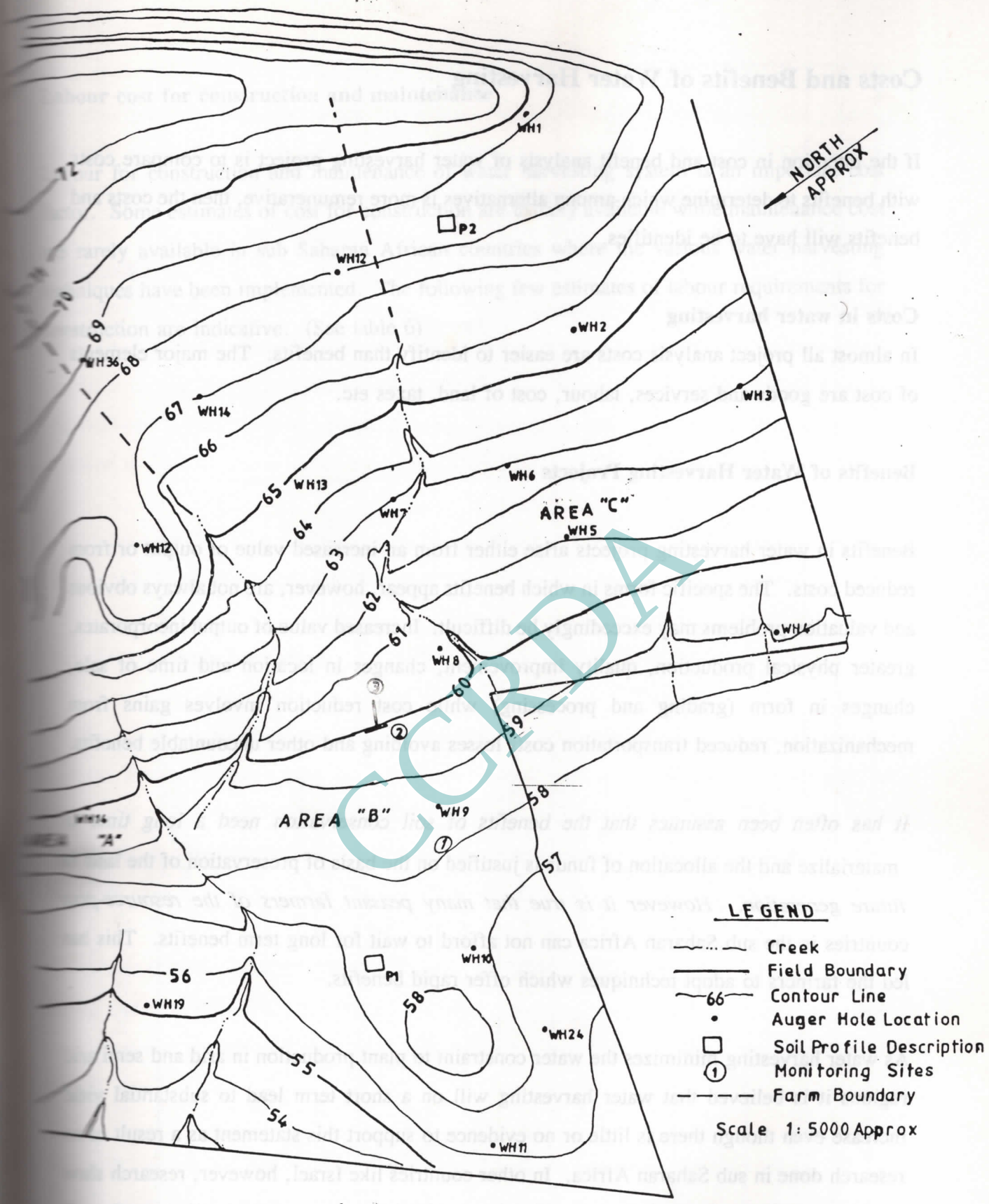
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4. What is the catchment to cultivated area ratio for prefered technique.

5. What is the maximum storage volume for the pond (reservoir) for the option of water supply for the people and cattle in part of the area under consideration? How does this with the demand of water? Assume evaporation and other loses for this exercise only.

6. The Peasant Association Leader's house roof is covered by courgated iron sheet with surface area of 200m^2. The roof is provided by sutters surcum scribing the entere edge and connected to what volume a down pipe of rain water can be collect in the rainy season shown above. 10% of the rain droping on the roof is lost.

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WATER HARVESTING PILOT SCHEME
REDUCED AREA

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Costs and Benefits of Water Harvesting

If the intention in cost and benefit analysis of water harvesting project is to compare costs with benefits to determine which among alternatives is more remunerative, then the costs and benefits will have to be identifies.

Costs in water harvesting

In almost all project analysis costs are easier to identify than benefits. The major elements of cost are goods and services, labour, cost of land, taxes etc.

Benefits of Water Harvesting Projects

Benefits in water harvesting projects arise either from an increased value of output or from reduced costs. The specific forms in which benefits appear, however, are not always obvious and valuation problems may exceedingly be difficult. Increased value of output incorporates, greater physical production, quality improvement, changes in location and time of sale, changes in form (grading and processing) while cost reduction involves gains from mechanization, reduced transportation costs losses avoiding and other uncountable benefits.

It has often been assumes that the benefits of soil conservation need a long time to materialize and the allocation of funds is justified on the basis of preservation of the land for future generation. However it is true that many peasant farmers of the resource-poor countries in the sub Saharan Africa can not afford to wait for long term benefits. This has led the farmers to adopt techniques which offer rapid benefits.

As water harvesting minimizes the water constraint to plant production in arid and semi arid regions it is believed that water harvesting will on a short term lead to substantial yield increase even though there is little or no evidence to support this statement as a result of no research done in sub Saharan Africa. In other countries like Israel, however, research show that the system can be made more profitable by selecting best crop species that can best fit in to the environment.

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Labour cost for construction and maintenance

Labour for construction and maintenance of water harvesting system is an important cost factor. Some estimates of cost for construction are usually available while maintenance cost are rarely available in sub Saharan African countries where the various water harvesting techniques have been implemented. The following few estimates of labour requirements for construction are indicative: (See table 6)

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Table 6

Country	W.H system	Description	Labour input	Cost/ha
Kenya	Conventional tillage		50 man days/ha	
	Contour ridges	Earth bund, 0.2m high, 1.5m horizontal interval	90 md/ha* 50 md/ha**	
	Semicircular hoops	Earth bund, 0.2m high 5-6m raduis appx.18m apart	0.1 md/unit appx = 10 md/ha	
	Semi circular hoops	Earth bund, 0.35m high 15m radius 35m apart	25 md/unit	
	V-shaped microcatchment	Earth bund 0.3m high 10 x 10m length	1 md/unit	
	Contour terraces	Earth bund 0.5m high 1m vertical interval	185 md/ha on 20% slope	
	Trapezoidal bunds		380 md/3200 m^2 impounded	
Burkina Faso	Demi-lunes	Earth bund 0.2 - 0.25m high (m radius (= 625 units/ha)	50 - 60 md/ha	
	Stone contour bunds	0.50 - 0.3m high 10 - 25 horizontal distance (400-1000m/ha	50 - 60 md/ha (Yatenza) 150 md/ha (Sanmatonga)	
	Rock dams	0.7 - 3m high 300 - 400m long 75 - 200m horizontal distance		
Niger	demi-lunes	0.2 - 0.3m high 2m radius, 313 units/ha	8 units/md =40-80md/ha	
	Contour terraces	earth bund reinforced with rocks 0.5 - 0.6m high 250m/ha	90 - 110 md/ha (on 2% slope	

Note 1 Monday = 4 work hours per day in Kenya
= 5 work hours per day in Burkina Faso

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Use of machinery is un avoidable in areas where population density is low without which it is virtually impossible to treat a substantial area. Heavy duty equipment (bulldozers, graders, tractors) is usually used to the work of rough shaping of bunds and terraces. This input is not considered as the cost can be retrieved from else where (conventional).

Costs per hectare (1 ha = 10,000m^2)

Different authors had different cost observations in areas where water harvesting was practiced. In Kenya the construction of three water harvesting projects (water spreading) was reported to cost on average US$ 820 per hectare in 1985 and 1986. In Burkina Faso the Agro-Forestry project costed about US$ 1714 per ha at the beginning of the project and reduced to US$ 38 and US$ 30 per ha in 1987, 1985 and 1987 respectively.

In Ethiopia cost of diversion weir, canal network and 45 ha terraces is exceptionally high about US$ 900,000 according to Benett (1985).

Benefits of Water harvesting

As there are a few water harvesting projects under implementation, only few data as yet support the presumption that use of this technique in the arid/semi-arid areas leads to significant and sustainable yield increase and hence substantial benefit. There is doubt of whether the initial high yields in few projects would continue in similar production per unit of land or not.

In Somalia three projects in 4 years showed an increase in yields in the range of 55% to 75% on bunded land (World Bank 1984). An other report indicated that 1.8 ton/ha of sorghum and maize was harvested from bunded areas while 1.2 ton/ha was the yield from non bunded areas.

In Kenya the Baringo plot semi arid area project produced sorghum yields an average of 2.8 times greater than an adjacent control plot. On the other hand the contour ridges and macro catchments in Kitui district did not perform better than the adjacent control plots. In Niger 250 kg/ha and 600 kg/ha were produced in poor rainfall and in normal years respectively on

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fields where rainfed agriculture was not feasible at all. Flood diversion scheme in Tigray (Ethiopia) produced yields of 3 - 3.5 ton/ha in 1983 and 1984 where local rainfed crops totally failed because of the drought (Benett, 1985).

In conclusion scarcity of data for dependable costs and benefits for water harvesting technique is very important factor which constrain assessment of the two potential of the technique in sub Saharan Africa. A considerable cost range is observed among which some techniques are relatively cheaper. More research and implementation of monitoring and evaluation is needed to overcome the constraints already pointed out.

Calculation of benefit-cost ratio

comparison of investments alternative naturally involves cost and benefits as discounted to the present value of the future years amount of money. This is to say present worth of benefits is compared with present worth costs presented as:

$$\text{Benefit - cost ratio} = \frac{\text{present worth of benefits}}{\text{present worth of costs}},$$

which calls for table of discount rates. For the purpose of this training programme the benefit is assumed to be obtained in the same year and is simplified as follows:

$$\text{Benefit - cost ratio} = \frac{\text{Benefit stream}}{\text{Cost stream}},$$

if the rafw is greater than 1, the scheme is assumed to be profitable.

Cost and Benefit of WH

Exercise

The Mulu area farming community depend on the spate flow coming down Koran Gogoga dry water course generated from the highlands of the eastern catchment. Three out of four years the spate flow is dependable and last year the farmers diverted adequate flow and spread it over 40 ha. There are 40 family heads and each family has land holding of one ha. Every year the temporary structure (earth reinforced with tree branches) are breached and before the next rain reconstruction of the weir and maintenance of the channel is carried out.

Each family head of 3 members hires five additional labourers from outside at the rate of Birr 6 per day to reconstruct the weir and Birr 5/day to maintain the channel. Three days are enough to finish the weir construction and two days for the maintenance. The rest of the work is believed to be done by the families only.

Fortunately enough the yield of crops that year was good as follow:

Crop	Cropping pattern (% of area)	Yield ton/ha	Price Birr/qt
Maize	40	0.4	90
Sorghum	40	0.5	80
Sweet potato	20	2	100

The local government announced that the farmers should pay tax of 5% of their product as harvest was attractive.

What is the benefit - cost ratio at the end of the year. How do you evaluate the spate irrigation scheme? is it benefitable?

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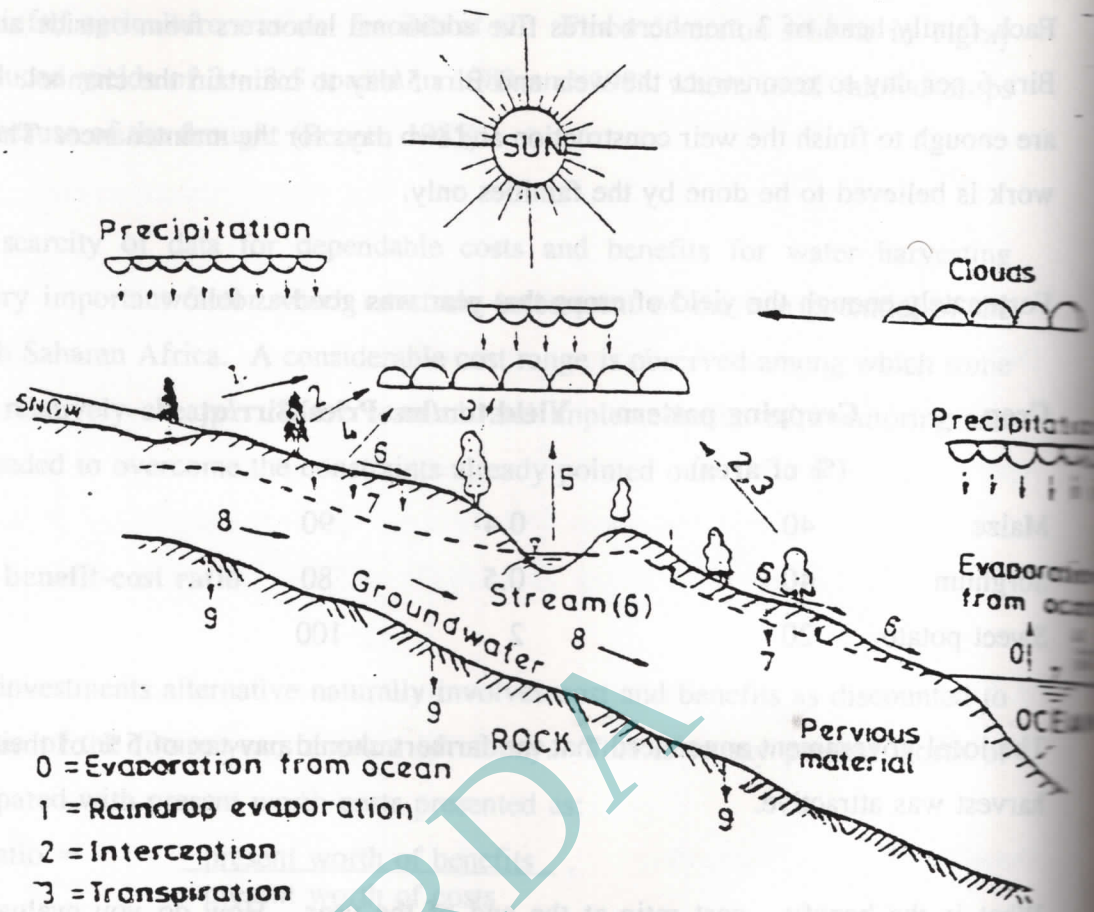


Fig. 1.1 The hydrologic cycle

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Precipitation - Rain, Snow, drizzle, glaze, sleet and hail

Rain — Water drops, sizes > 0.5 mm, max, size = 6 mm

— Intensity Classification of rain

1. Light rain - trace to 2.5 mm/hr
2. Moderate rain -2.5 to 7.5 mm/hr
3. Heavy rain > 7.5 mm/hr

Measurement

— In terms of depth to which rainfall water would stand on an area if all the rain were collected on it. Units - mm, cm.

— Raingauge

1. Non-recording (see fig 2.5)
2. Rcording gauge - A continous plot of rainfall against time (see fig. 2.6)

Fig. 2.5 Nonrecording raingauge (Symons' gauge)

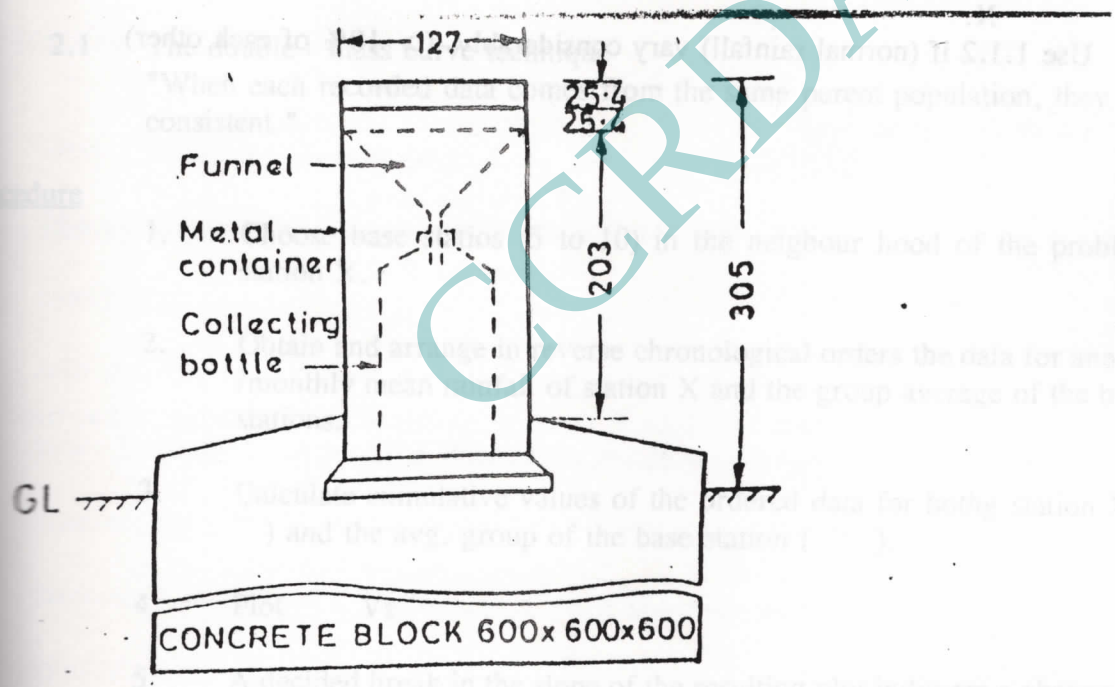


Fig. 2.5 Nonrecording raingauge (Symons' gauge)

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Preparation of Rainfall Data:

Checks for continuity and consistency :

1. Continuity

1.1 Estiamtin of Missing data

1.1.1 Arithmetic avrage procedure $Px = 1/M [P1 + P2 + \ldots + Pm]$

- Use 1.1.1 if "normal rainfall" defined as the average over 30 years of the stations considered are within 10% of each other and station X.
- P1, P2, ... Pm rainfall values over period analysed. (monthly, yearly, ...)
- Px = Rainfall value missing at station X.
- M = No. of neigbouring stations whose P1, P2, ... Pm are used to estimate Px.

1.1.2 The Normal Ratio Method.

$Px = Nx/M [P1/N1 + P2/N2 + ... + Pm/Nm]$ - N1, N2, ... Nm = Normal rainfall at each of the M neigbouring stations. Nx = Ditto at station X.

- Use 1.1.2 if (normal rainfall) vary considerably. (> 10% of each other)

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Fig. 2.6 Recodrding from a natural syphon-type gauge (schematic)

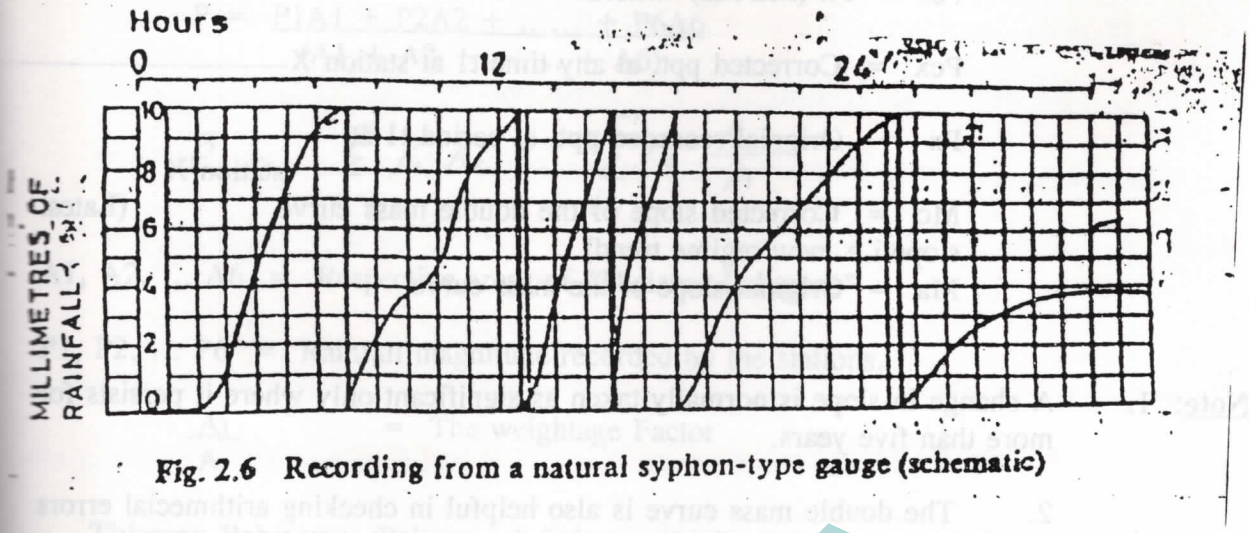


Fig. 2.6 Recording from a natural syphon-type gauge (schematic)

2. Consistency

2.1 The double - mass curve technique

"When each recorded data comes from the same parent population, they are consistent."

Procedure

1. Choose base statios (5 to 10) in the neigbour hood of the problem station X.

2. Obtain and arrange in reverse chronological orders the data for annual /monthly mean rainfall of station X and the group average of the base stations.

3. Calculate cumulative values of the ordered data for bothg station X ( ) and the avg. group of the base station ( ).

4. Plot Vs .

5. A decided break in the slope of the resulting plot indicates a change in the precipitation regime of station X.

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6. Correct the preciptation values at station X beyond the period of change of regime by using the relation.

Pcx = Px (Mc/Ma) where

Pcx = Corrected ppt. at any time t1 at station X

Px = Orignial recorded ppt. at period t1 at station X

Mc = Corrected slope of the double mass curve (Latest slope i.e. new regime trend)

Ma = Original slope of the mass curve

Note: 1. A change in slope is normally taken as significant only where it persists for more than five years.

2. The double mass curve is also helpful in checking arithmecial errors in transferring rainfall data from one record to another.

Presentions of Rainfall Data:

- Mass curve of Rainfall -
  - A plot of the accumulated ppt. against time.
  - Recording raingage
  - Useful in extracting duration, magnitude and intensitus of storms.

- Mean Precipitation Over an area:

To convert "Point rainfall" data at varions staions into an average value over a satement the following three methods are in use:

1. Arithmetical mean method
2. Thiessen - Polygon mehtod and
3. Isolyetal method

1. Arthmetic mean method

$$P = \frac{P1 + P2 + ... + P5 + P6 ..... + Pn}{N}$$

P1, P2, ... Pn = rainfall values in a given period in N stations.

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Comment :- Rarely used when variation is assumed little.

2. Thiessen - Mean Method

$$P = \frac{P1A1 + P2A2 + \ldots\ldots + P6A6}{(A1 + A2 + \ldots\ldots + A6)}$$

$$\bar{P} = \sum_{i=1}^{M} P_i A_i = \sum_{i=1}^{M} P_i \frac{A_i}{A}$$

A1, A2, ... A6 = Respective areas of "Theissen Polygons"

P1, P2, ... P6 = Rainfall magnitude recorded by the stations.

$\frac{Ai}{A}$ = The weightage Factor

Thiessen Polygon :- Polygons defining areas closest to a network of station points.

Construction of Thiessen Polygons :-

- Draw catchment area to scale
- Plot in station points including points neighbouring the catchment.
- Join station points to form a network of triangles
- Draw bisectors to each of the sides of the triangles. These bisectors form the "Theissen Polygons". The boundary of the catchment, if it cuts the bisectors is taken as the outer limit of the polygon.

Comment : This method is superior to the arithmetic - mean method.

Isohyetal Method

Isohyet is a line pointing points of equal rainfall mngitude.

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$$\bar{P} = \frac{a1\ \frac{(P1 + P2)}{2} + a2\ \frac{(P2 + P2)}{2} + \ldots + An\text{-}1\ \frac{(Pn\text{-}1 + Pn)}{2}}{A}$$

P1, P2, ... Pn = Values of Isohyets. P = Mean ppt. over the catchment

A1, A2 ..... An-1 = Inter Isohyet areas; bounded by catchment whenever they go out of the boundary.

Construction of Isohyets:

- Draw catchment area to scale
- Plot in station points including points neigbouring the catchment .
- Classify ppt. data over unform interval
- Plot contours for class boundaries. Interpolate linearly for class boundaries. The contours of the class boundaries are the Isohyets.

Comment : The Isohyet method is superior to the other two methods especially when the staions are large in numeber.

Frequency of Point Rainfall :

The rainfall at a place is a random hydrologic process and the rainfall data at a place when arranged in chronological order constitute 'time series.'

- Let P be the probability of occurence of an event (e.g. rainfall) whose magnitude is equal to or in excess of a specified magnitude. X.

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The recurrence interval (return period) is then

$T = 1/P$ T represents the average interval between the occurence of a rainfall of magnitude equal to or greater than X. (N.B. Periodicity is not implied in T).

If the possiblity of an event occuring is P, the probability of the event not occuring in a givne year is of = 1 - P.

The "binomial distribution' can be used to find the probability of occurence of the event R times in N successive years. Thus

$$Pr_1n = {}^{n}C_1P^{r}f^{n-r} = \frac{n!}{(n-r)!\ r!}P^{r}f^{n-r}$$

Where Pr_1n = Probability of a random hydrologic event (rainfall) of given magnitude and exceedence probability P occuring r time in n succeisive years.

The possibility of an event occuring at least once in n seccessive years
Pf = 1-fn = 1-(1-p)n
Pf [at least once] + Pf [Not occuring] = 1
['at least once' is the complement of 'Not occuring']

Probability of exceedince by emprincal mehtod.

Plotting Position:

- Arrange given data (time series) in decreasing (descerding) order of magnitude.
- Assign order number m : i.e. 1st entry m=1, 2nd entry m=2, last event m = N where N = number of perid of record.
- The probability P of an event equalled to or exceeded is then given by empirical formuale known as "Plotting Position".

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Plotting Position Formulate

Method	p
California	m/n
Hazen	(n-0.5)/N
Weibul	m/(N+1)
Chegodayev	(m-0.3)/(N+0.4)
Blom	(m-0.44)/(N+0.12)
Gringorten	(m-3/8)/(N+1/4)

N.B. Weibul's formula $P = m/N+1$ is the most popular.

P is found means T is found ($P = 1/T$ $T=1/p$).

* If the data series is plotted against T on a semi-log or log-log paper, by extrapolation the rainfall magnitude of specific duration for any recurrence interval can be estimated.

N.B The errors increase with the amount of extrapolation.

* Analyticel methods to determine probability of exceedence.
(Not appropriate for this course!)

Intensity - Duration - Frequency Relationship :

The interdependency between the intensity duration and return period (T years) is commonly experessed in a general form as

$$i = \frac{KT^x}{(D + a)^n}$$, K, X, a, n -> Constrants for a given catchment

ABSTRACTIONS FROM PRECIPITION:

EVAPORATION:- "The net escape of water molecules from the liquid state to the gaseous state."

-depends on
1. Vapour pressure at the water suface (ew) and air above (ea).
2. air and Water tempratures
3. Wind speed

4. Atmospheric Pressure

5. Quality of water

6. size of the water body

- The amount of water evaporated from a water surface is estimated by the following method:

1. Using evaporation data

2. empirical evaporation equations

3. Analytical methods

1. Evaporimeters.

- Class A evaporation pan

- Pan coefficient, Cp : The evaporation observed from a pan has to be corrected to get the evaporaion pan from a lake under similar climatic and exposure conditons.

Lake evaportion = Cp X Pan evaportion.

Class A land Pan - Cp avg. = 0.70
(Range = 0.60 to 0.80)

Emprical Evaporation Equations :-

Dalton Type - $E_L = K f(u) (ew-ea)$

E_L = Lake evaproation, ew = saturated vapour pesure at the water surface temprature in mm of mercury.

e_a = Actual vapour pressure of overlying air at a speicfed hight in mm of mercury, F(u) = Wind speed correction funciton and K = a coefficient.

Meyer's Formula

$E_L = Kh (ew-ea) (1 + ug/16)$, For data's of wind speed (u) at varying hight (h) use the relationshop $Uh = Ch^{1/7}$. That is determine C for the available data and apply on the required data.

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- Analytical mehtods of evaportion equations
  - Water budjet = 'Continuity equation' (hydrological)
  - Energy budget = 'Law of conservation of Energy'
  - Mass transfer = 'Mass Water vapour transfer from surface to atmosphere.'

(Skipped for this course)

Methodes available for Reduciton of Evaportion Losses:

1. Reduction of surface area of deep reservoirs in place of wider ones, elimination of slallow areas.

2. Mechanical covers - roof over reservoirs- permanent
   - temporary
   - Floating -> rafts, floating porticles
     For small water bodies

3. Chemical Films: Certain chemicals such as cetyl alcohol (hexade canol) and stearyl alcohol (Octa decanol) form monomolecular layers on a water surface. These layers act as evaporation inbibitors by preventing the water molecules to escape past them. The thin film formed has the following desirable features:

   1. The film is strong and flexible and does not break easily due to wave action.
   2. If punctured due to the impact of rain drops or by birds, insects, etc, the film closes back soon after.
   3. It is pervious to oxygen and carbondioxide; the water quality is therefore not affected by its presence.
   4. It is clourless, odorless and nontoxic.

EVAPORATION: -> Evaporation + Transpiration

- If sufficient moisture is always available to completely meet the needs of vegetation fully covering the area, the resulting evaporation is called Potential evaporation (PET). The real evapotranspiration occuring in a specific situation is called actual evapotranspiration (AET). The Field Capacity is the maximum quantity of water that the soil can retain against the zone of gravity.

Permanent Wilting Point is the moisture content of a soil at which the moisture is no longer avaialble in sufficient quantity to sustain the plants.

The filed capacity - the permanent witting point = the available water (moinsture available for plant growth)

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- Measurement of Evaporations

Evaporation = Ppt + Irrigation Input - increase in soil storage - deep percolation

Comment: Time consuming & expensive operation; for research

(2) Field Plots -> Similar concept but without tank. Measurement done on a plot laid out to facilitate mesurements.

Evapotranspiration = Ppt + Irrigation Input - Increase in soil storage
Deep percolation cannot be measured in here. Keep condition of the plot at field capacity.

Evapotranspiration Equations:

PENMAN'S EQUATION:- -> Widely used; [A combination of the Energy balance & Masstransfer Approach].

$PET = \frac{AH_n + Ea_r}{A + r}$

- PET = daily potential evapotranspiration in mm/day

A = Slope of the saturation vapour pressure Vs temprature, in mm of mercury per ^{0}C. (see table 3.3)

H_n = Net radiation in mm of evaporable water per day

Ea = 0.35 (1 + U2/160) (ew - ea)

r = Psycrometric constant

= 0.49mm of mercury/^{0}C.

U_2 = mean wind speed at 2m above ground in Km/day

e_w = Saturation vapour pressure at mean air temprature in mm of mercury (table 3.3)

e_a = Actual vapour pressure in the air in mm of mercury

H_n = $Ha\,(1-r)\,(a + bn/N) - \sqrt{Ta^4}\,(0.56 - 0.092\sqrt{ea})\,x\,(0.10 + 0.90\,n/N)$

H_a = incident solar radiation outside the atmosphere on a horizontal surface, expressed in mm of evaporable water per day (it is a function of the latitude and period of the year as indicated in table 3.4)

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r = reflection coofficient (Albedo). Usual ranges of values of r are:

Surface	r
Close ground crops	0.15 - 025
Bare Lands	0.05 - 0.45
Water surface	0.05
Snow	0.45 - 0.90

a = 0.29 cos ϕ, ϕ = Latitude of the locality

b = o.52 , n = actual duration of bright sunshine hours.

N = Max. possible hours of bright sunshine (See table 3.5 , a function of latitude)

σ = Stefan - Boltzman constant = 2.01×10^{-9} mm/day

Ta = mean air temprature in degrees Kelvin = 273 + $-^{0}C$

For the computation of PET, data on n, ea, U_2, mean air temprature and nature of surface (i.e. value of r) are needed. [obtainable from actual observation or through available meteorlogizal data of the locality.

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TABLE 3.3 SATURATION VAPOUR PRESSURE OF WATER

Temperature (°C)	Saturation vapour pressure e_w (mm of Hg)	A (mm/°C)
0	4.58	0.30
5.0	6.54	0.45
7.5	7.78	0.54
10.0	9.21	0.60
12.5	10.87	0.71
15.0	12.79	0.80
17.5	15.00	0.95
20.0	17.54	1.05
22.5	20.44	1.24
25.0	23.76	1.40
27.5	27.54	1.61
30.0	31.82	1.85
32.5	36.68	2.07
35.0	42.81	2.35
37.5	48.36	2.62
40.0	55.32	2.95
45.0	71.20	3.66

TABLE 3.4 MEAN MONTHLY SOLAR RADIATION AT TOP OF ATMOSPHERE, H_a IN mm OF EVAPORABLE WATER/DAY

North latitude	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0°	14.5	15.0	15.2	14.7	13.9	13.4	13.5	14.2	14.9	15.0	14.6	14.3
10°	12.8	13.9	14.8	15.2	15.0	14.8	14.8	15.0	14.9	14.1	13.1	12.4
20°	10.8	12.3	13.9	15.2	15.7	15.8	15.7	15.3	14.4	12.9	11.2	10.3
30°	8.5	10.5	12.7	14.8	16.0	16.5	16.2	15.3	13.5	11.3	9.1	7.9
40°	6.0	8.3	11.0	13.9	15.9	16.7	16.3	14.8	12.2	9.3	6.7	5.4
50°	3.6	5.9	9.1	12.7	15.4	16.7	16.1	13.9	10.5	7.1	4.3	3.0

TABLE 3.5 MEAN MONTHLY VALUES OF POSSIBLE SUNSHINE HOURS, N

North latitude	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0°	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1
10°	11.6	11.8	12.1	12.4	12.6	12.7	12.6	12.4	12.9	11.9	11.7	11.5
20°	11.1	11.5	12.0	12.6	13.1	13.3	13.2	12.8	12.3	11.7	11.2	10.9
30°	10.4	11.1	12.0	12.9	13.7	14.1	13.9	13.2	12.4	11.5	10.6	10.2

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Empirical Formula for the Estimation of PET:

Blaney - Criddle Formula:

The potential evapotranspiration in a crop - growing season is given by $ET = 2.54\ KF$ and $F = P_h \bar{T}_f/100$ where

E_T = PET in a crop season in cm, K = an empirical coofficient, depends on the type of the crop, F = Sum of monthly consumptive use factors for the period

P_h = monthly percent of annual day time hours, depends onthe latitude of the place (Table 3.6) and

$\bar{T}_f$ = mean monthly temprature in ^0F. Values of K depend on the month and locality. Average value for the season for selected crops is given in table 3.7.

Comment: The Blancy criddle formula is largely used by Irrigation Engineers to calculate the water requirements of crops, which is taken as the difference between PET and effective precipitation.

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TABLE 3.6 MONTHLY DAYTIME HOURS PERCENTAGES, p_h, FOR USE IN BLANEY-CRIDDLE FORMULA (EQ. 3.16)

North latitude (degrees)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	8.50	7.66	8.49	8.21	8.50	8.22	8.50	8.49	8.21	8.50	8.22	8.50
10	8.13	7.47	8.45	8.37	8.81	8.60	8.86	8.71	8.25	8.34	7.91	8.10
15	7.94	7.36	8.43	8.44	8.98	8.80	9.05	8.83	8.28	8.26	7.75	7.88
20	7.74	7.25	8.41	8.52	9.15	9.00	9.25	8.96	8.30	8.18	7.58	7.66
25	7.53	7.14	8.39	8.61	9.33	9.23	9.45	9.09	8.32	8.09	7.40	7.42
30	7.30	7.03	8.38	8.72	9.53	9.49	9.67	9.22	8.33	7.99	7.19	7.15
35	7.05	6.88	8.35	8.83	9.76	9.77	9.93	9.37	8.36	7.87	6.97	6.86
40	6.76	6.72	8.33	8.95	10.02	10.08	10.22	9.54	8.39	7.75	6.72	6.52

TABLE 3.7 VALUES OF K FOR SELECTED CROPS FOR USE IN EQ. (3.16)

Crop	Value of K	Range of monthly values
Rice	1.10	0.85–1.30
Wheat	0.65	0.50–0.75
Maize	0.65	0.50–0.80
Sugarcane	0.90	0.75–1.00
Cotton	0.65	0.50–0.90
Potatoes	0.70	0.65–0.75
Natural Vegetation:		
(a) Very dense	1.30	
(b) Dense	1.20	
(c) Medium	1.00	
(d) Light	0.80	

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Initial Loss

1. Interpretation - Interception Loss -> retained by surface of vegetation & lost to the atmosphere by evaporation [10 to 20%] of total rainfall.

   Through fall - Part dropping off the plant leaves

   Stem flow - Part flowing down the stem of the plant

2. Depression Storage - Lost to rainoff through infiltration and evaporation

   - 0.50 cm is sand, 0.4 cm in loan & o.25 cm in clay representative for depression storage loss during intensive storms

Infiltration

Infiltration capacity:- the maximum rate at which the ground can absorb water (fc)

Field capacity:-the volume of water that can be held against gravity drainage (percolation)

F_c (Infiltration capacity): $f = f_c$ when $i > f_c$

$f = i$ when $i < f_c$

Where i = intensity of rainfall & f = the actual rate of infiltration

Factor affecting: 1. Characteristics of soil- texture

- structure
- permeability
- under drainage

2. Surface of entry - vegetal cover
- exposed soil

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3. Fluid characteristic - turbidity of the water

- temprature of the water (Viscosity)

- dissolved salts

Infiltration Model --> (See fig. 3.9)

Variation of Infiltration capacity --> (See fig. 3.12)

Typically a bare, sandy area will have f_c = 1.2 cm/hr, a bare, clay soil will have f_c = 0.15 cm/hr

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Fig 3.9 An infiltration model

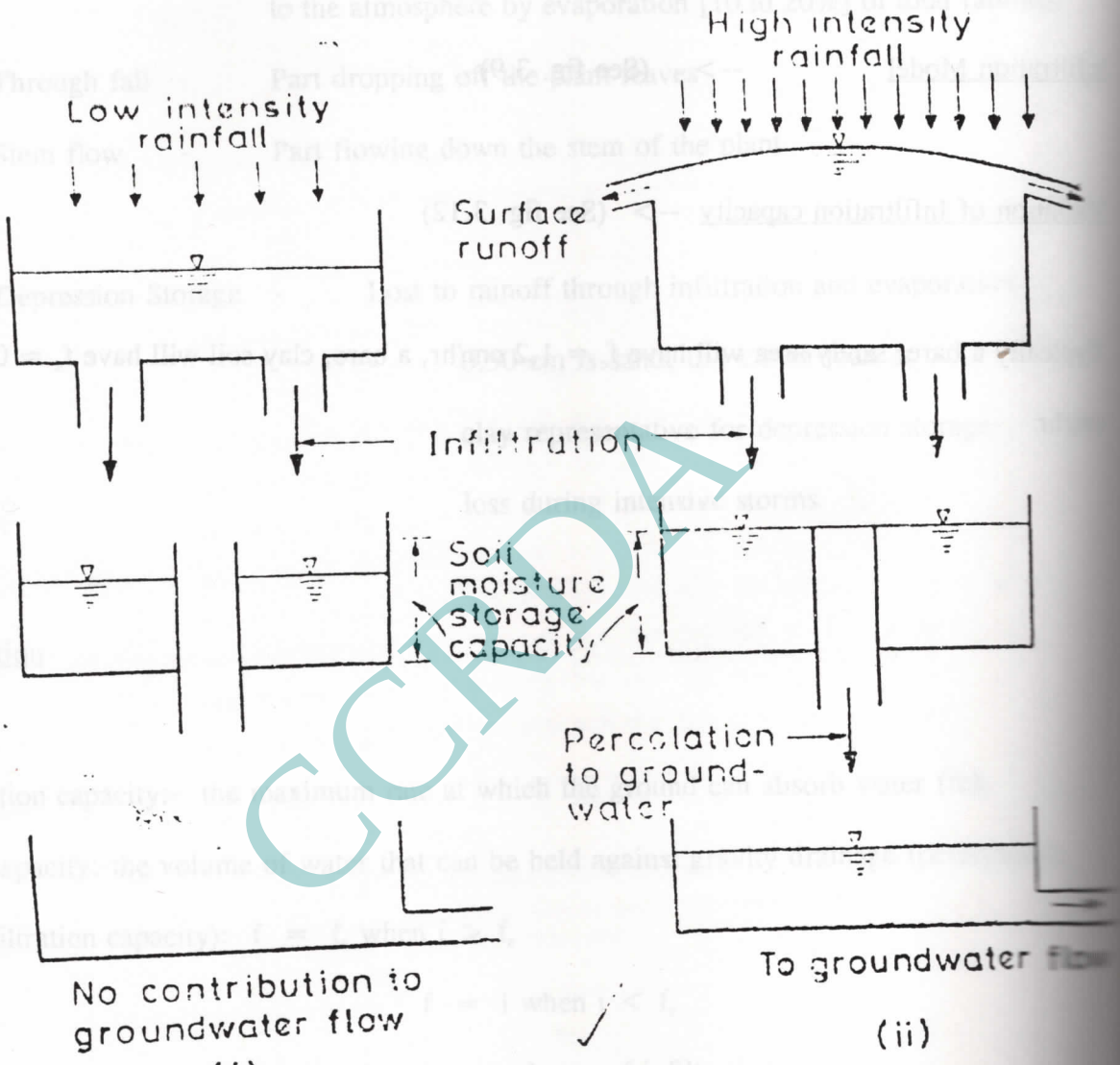


Fig. 3.9 An infiltration model

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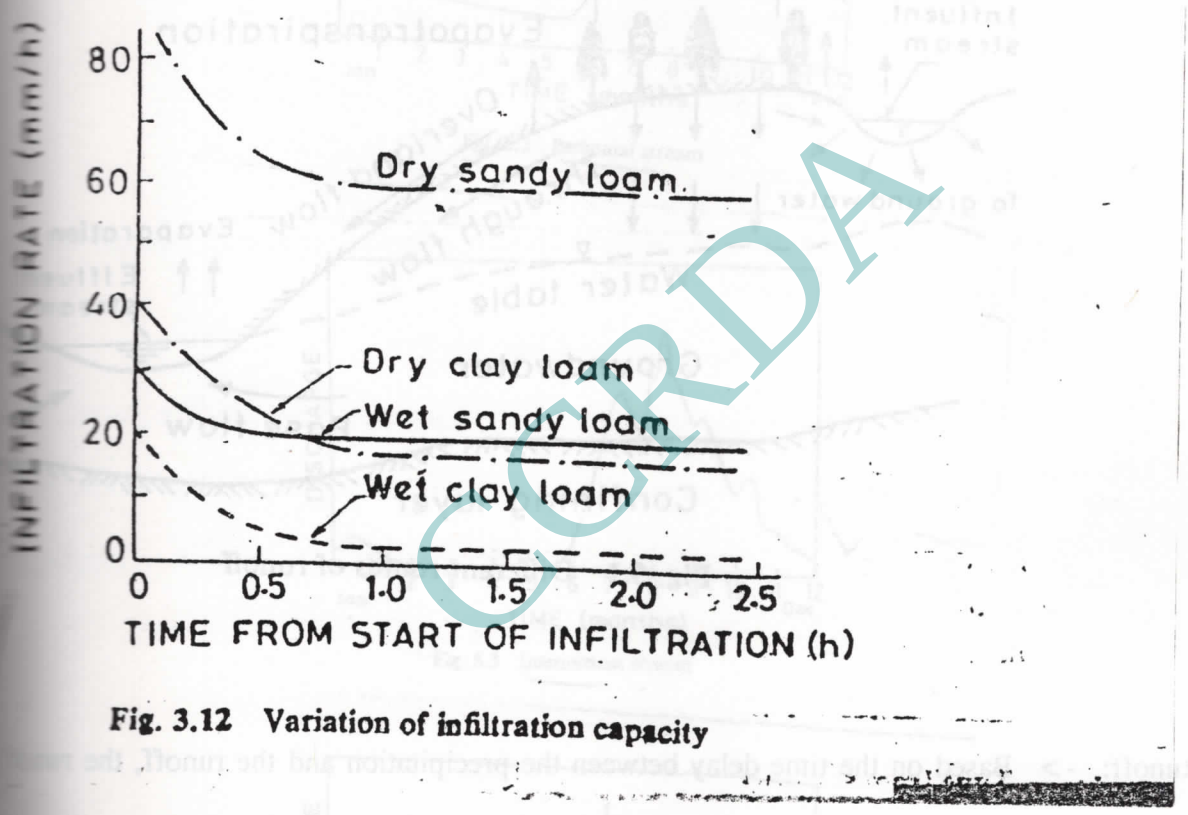


Fig. 3.12 Variation of infiltration capacity

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Fig 5.1 Different notes of runoff

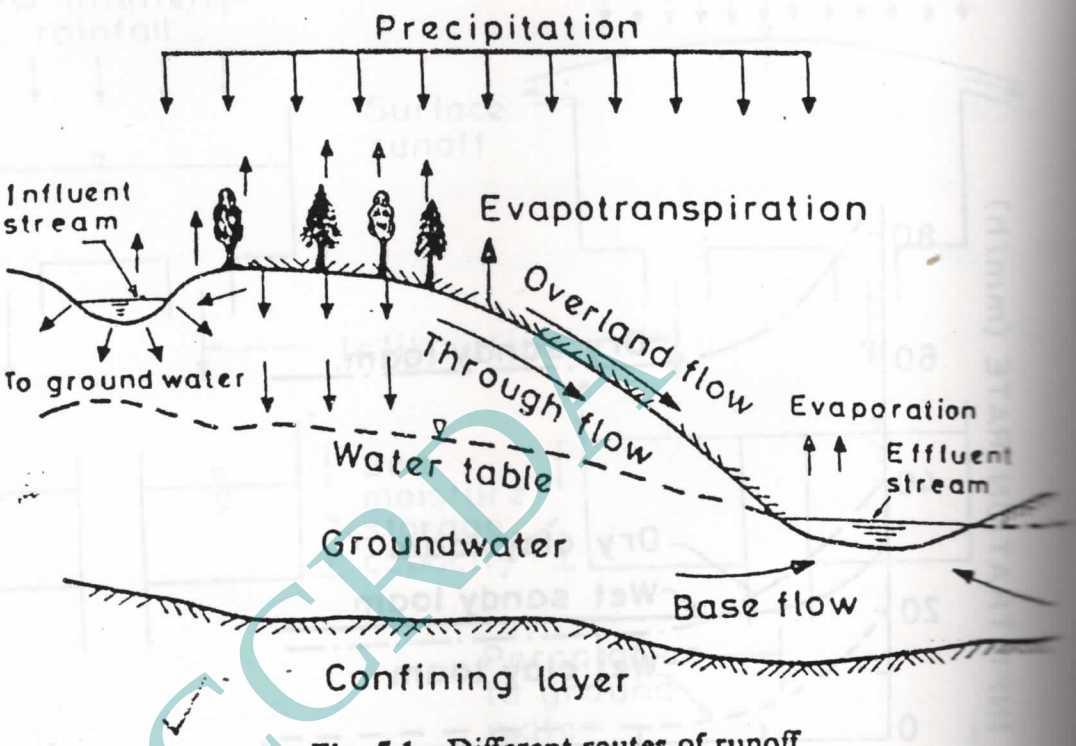


Fig. 5.1 Different routes of runoff

Runoff: -> Based on the time delay between the precipitation and the runoff, the runoff is classified in to two categories; as 1. Direct Runoff , 2. Base flow

- Direct Runoff = Suface runoff + Interflow + Precipitation on channel surface

  of surface runoff = overland flow + chemical flow

- Base flow = The delayed flow that reaches a stream essentially as ground water flow

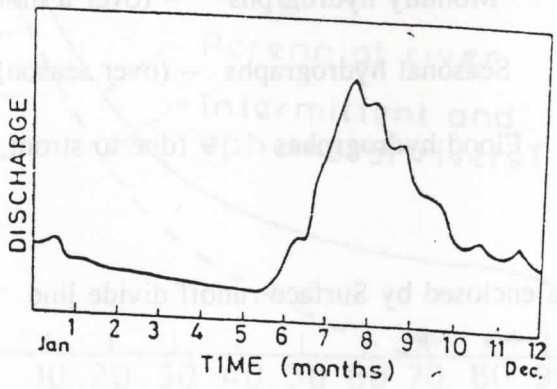


Fig. 5.2 Perennial stream

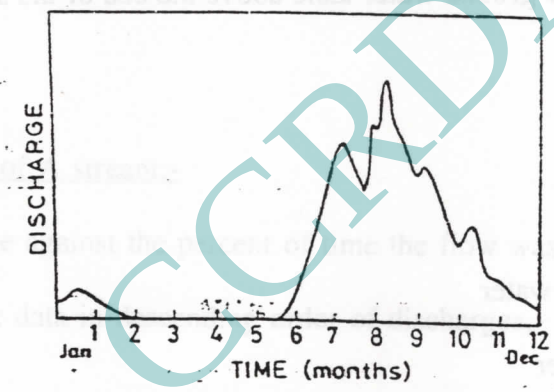


Fig. 5.3 Intermittent stream

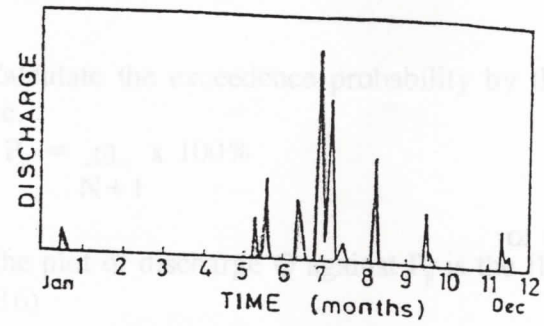


Fig. 5.4 Ephemeral stream

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Hydrograph = A plot of the discharge in a stream plotted against time

Chronologically eg. Annual hydrographs-- (over a year)

Monthly hydrogrphs -- (over a month)

Seasonal hydrographs -- (over season)

Flood hydrogrphas -- (due to strom, shorter)

Catchment = Area enclosed by Surface runoff divide line

Runoff characteristics of streams:

A perennial stream --> The ground water table above the bed of the stream through out the year

An intermittet stream

-> During dry seasons the water table drops to a level lower than that of the stream bed and stream dries up.

An ephemeral stream

-> Flash flows in response to storms. No base flow throughout the year.

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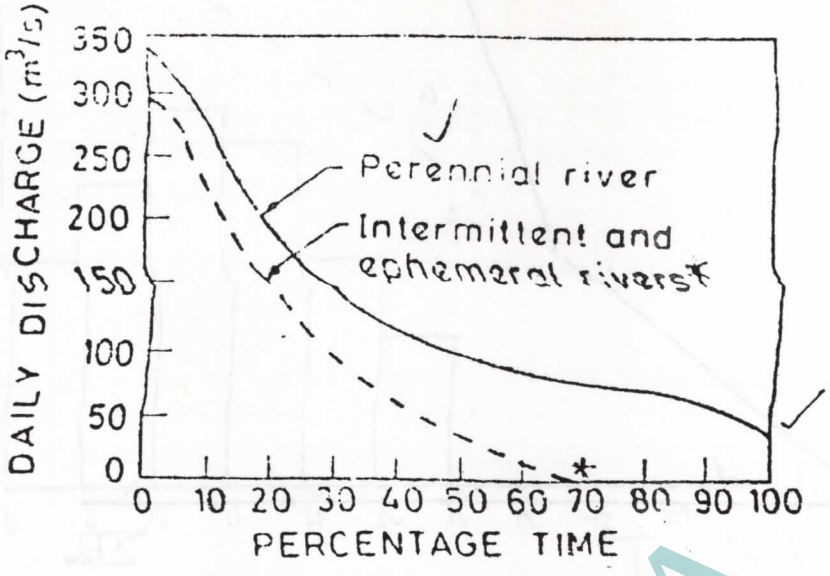


Fig. 5.6 Flow duration curve

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Flow Duration Curve of A stream:-

-> A plot of discharge against the percent of time the flow was equalled or exceeded.

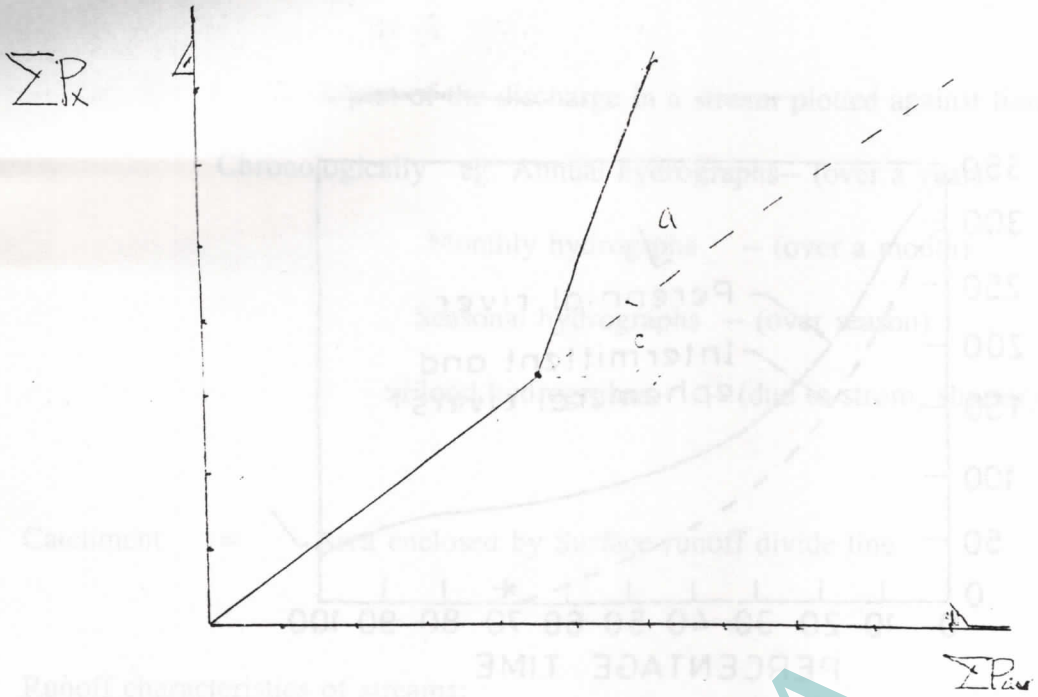
Procedure: - Arrange data in descending order of discharges,- Give (Assign) ranks 'm' to all the N data (data can be treated in classes but the rank considered is the cumulative rank of the lowest in the class)

- Calculate the exceedence probability by the ploting position method i.e.

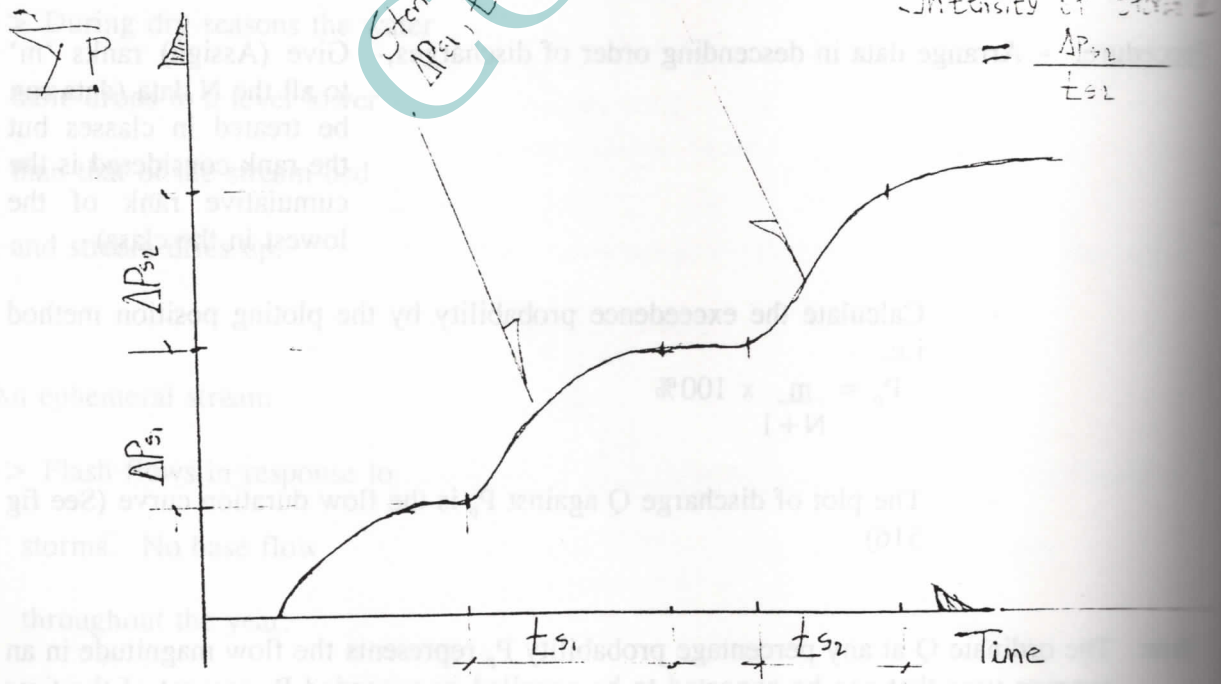
$$P_p = \frac{m}{N+1} \times 100\%$$

- The plot of discharge Q against P_p is the flow duration curve (See fig 516)

Note: The ordinate Q at any percentage probability P_p represents the flow magnitude in an avarage year that can be expected to be equalled or exceeded P_p percent of the time and is terned as P_p % dependable flow

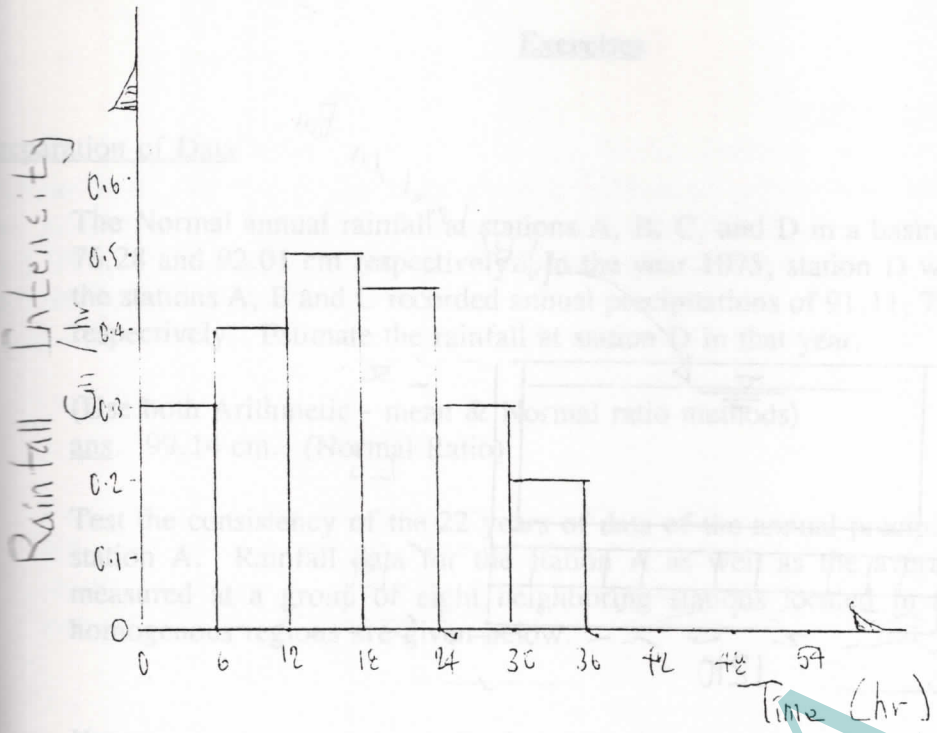


2-1 The Double Mass Curve Technique

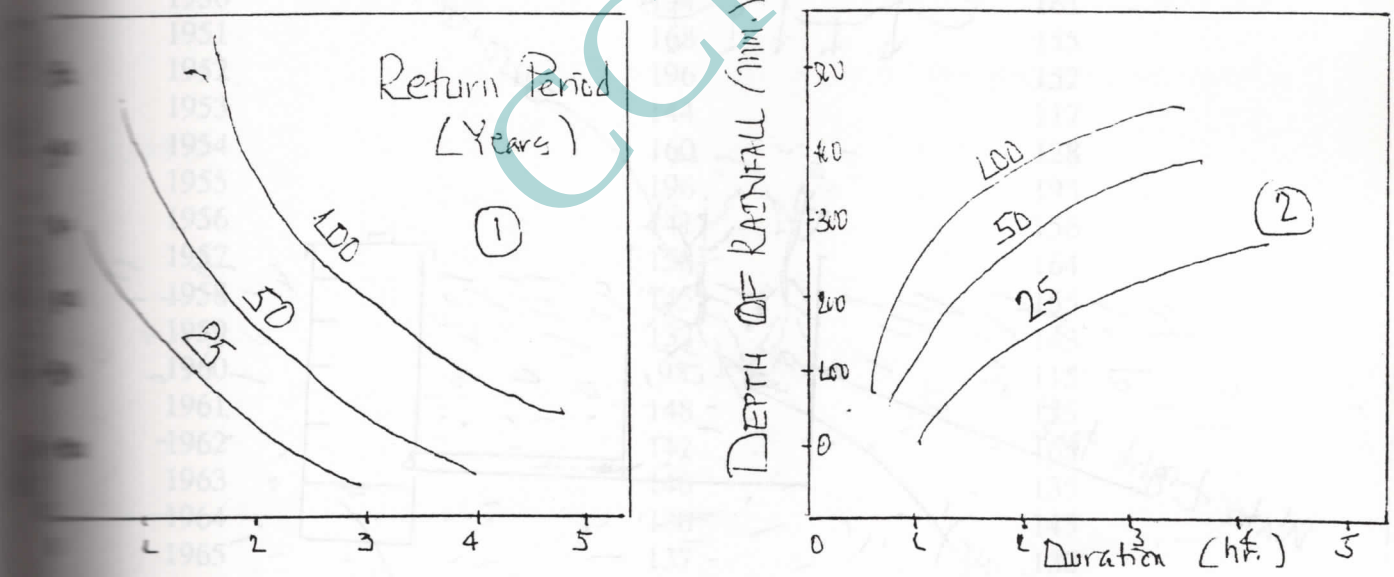


Mass Curve of Rainfall

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HYETOGRAPH OF A STORM



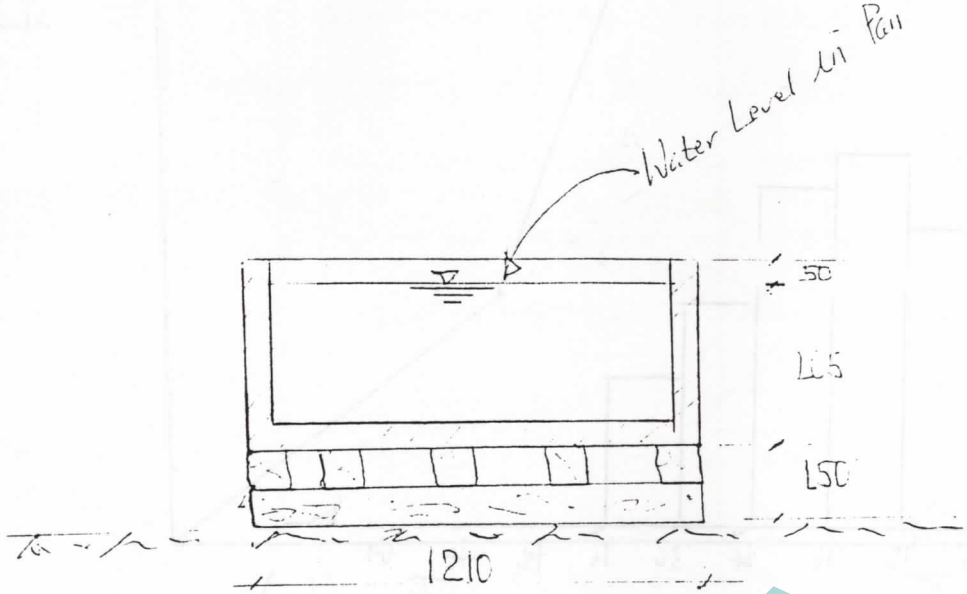
① INTENSITY - DURATION - FREQUENCY RELATIONSHIP

② DEPTH - DURATION - FREQUENCY CURVES

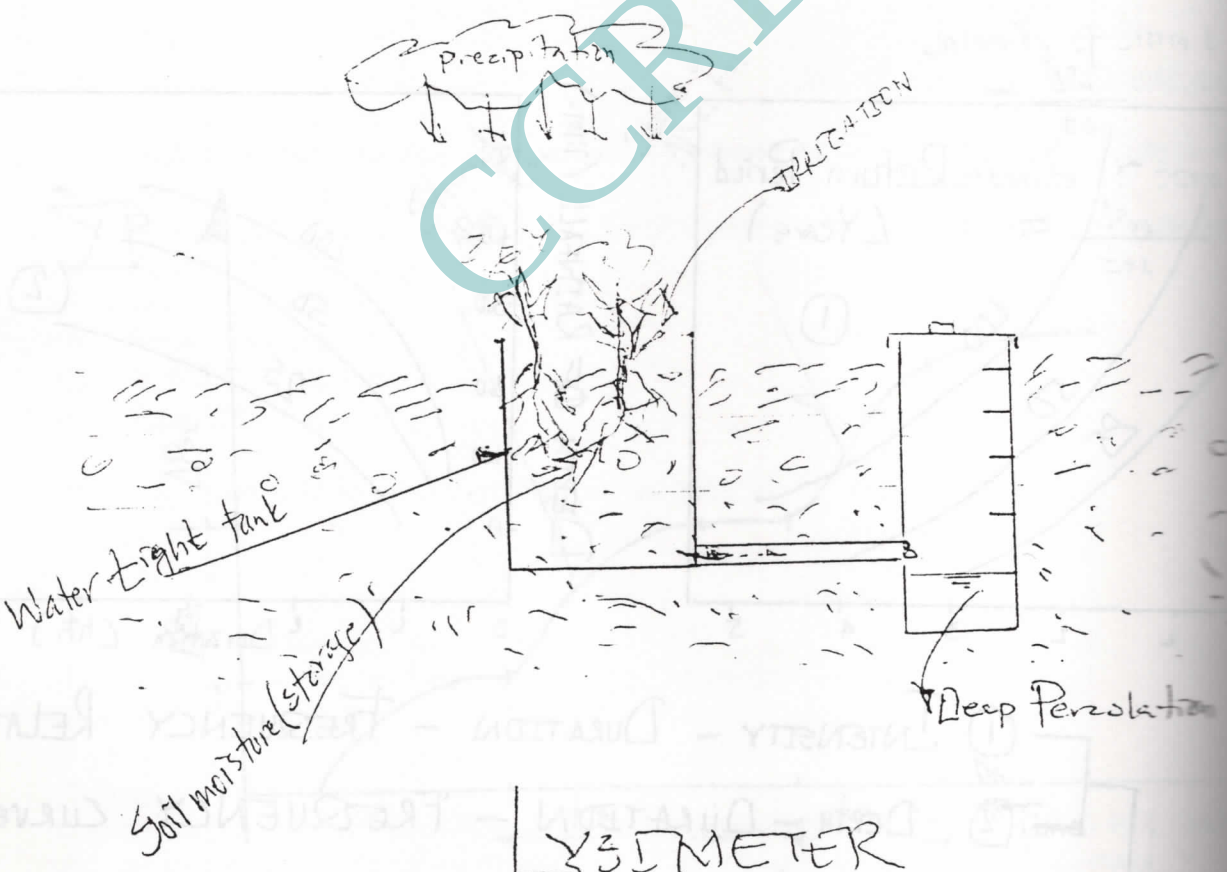
(SCHEMATIC)

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Exercises

Preparation of Data

1. The Normal annual rainfall at stations A, B, C, and D in a basin are 80.97, 67.59, 76.28 and 92.01 cm respectively. In the year 1075, station D was inoperative and the stations A, B and C recorded annual precipitations of 91.11, 72.23 and 79.89 cm respectively. Estimate the rainfall at station D in that year.

   (Use both Arithmetic - mean & Normal ratio methods)
   ans. 99.14 cm. (Normal Ratio)

   Test the consistency of the 22 years of data of the annual precipitation measured at station A. Rainfall data for the station A as well as the average annual rainfall measured at a group of eight neighboring stations located in a meteorologically homogenous regions are given below.

Year	Station A (cm)	8 Station avg. (cm)
1946	177	143
1947	144	132
1948	178	146
1949	162	147
1950	194	161
1951	168	155
1952	196	152
1953	144	117
1954	160	128
1955	196	193
1956	141	156
1957	158	164
1958	145	155
1959	132	143
1960	95	115
1961	148	135
1962	142	163
1963	140	135
1964	130	143
1965	137	130
1966	130	146
1967	163	161

   a. In what year is a change in regime indicated?
   b. Adjust the recorded data at station A and determine the mean annual precipitation.

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Exercise 2

Presentation of Rainfall Data

1. In a catchment area, approximated by a circle of diameter 100 km, four rainfall stations are situated inside the catchment and one station is outside in its neighborhood. The co-ordinates of the center of the catchment and of the five stations are given below. Also given are the annual precipitation recorded by the five stations in 1980. Determine the average annual precipitation by the Thiessen - mean method.

   center: (100,100) Diameter: 100 km

   Distances are in km

Station	1	2	3	4	5
Coordinates	(30,80)	(70,100)	(100,140)	(130,100)	(100,70)
Precipitation (cm)	85.0	135.2	95.3	146.4	102.2

ans. 121.84 cm

2. The Isohyets due to a storm in a catchment was drawn and the area of the catchment bounded by Isohyets were tabulated as below:

Isohyets (cm)	Station-12.0	12.0-10.0	10.0-8.0	8.0-6.0	6.0-4.0
Area (km^2)	30		140	80 180	20

Estimate the mean precipitation due to the storm

ans P = 8.84 cm

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Exercise 3

1. Analysis of data on maximum one-day rainfall depth at Nazareth indicated that a depth of 280 mm had a return period of 50 years. Determine the probability of a one-day rainfall depth equal to or greater than 280 mm at Nazareth occurring (a) Once in 20 successive years (b) two times in 15 successive years and (c) at least once in 20 successive years.

ans. a. $P1.20 = 0.272$
b. $P2.20 = 0.0292$
c. $P_1 = 0.332$

2. For a station A, the recorded annual 24 hr. maximum rainfall are given below. (a) Estimate the 24 hr maximum rainfall with return periods of 13 & 50 years. (b) What would be the probability of a rainfall of magnitude equal to or exceeding 10 cm occurring in 24 hr at station A.

Year	Rainfall (cm)
1950	13.0
1951	12.0
1952	7.6
1953	14.3
1954	16.0
1955	9.6
1956	8.0
1957	12.5
1958	11.2
1959	8.9
1960	8.9
1961	7.8
1962	9.0
1963	10.2
1964	8.5
1965	7.5
1966	6.0
1967	8.4
1968	10.8
1969	10.6
1970	8.3
1971	9.5

Ans. Rainfall
T = 13 , 14.55 cm
T = 50 , 18.00
For Rainfall = 10cm, T = 2.4

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Exercise 4

Evaporation

1. A reservoir with a surface area of 250 hectares had the following average values of parameters during a weak: Water temperature = 20°c, relative humidity = 40%, wind-velocity at 1.0m above ground = 16Km/hr. Estimate the average daily evaporation from the lake and the volume of water evaporated from the lake during that one week.

   (Use Meyer's formula)

   Ans. E_L = 8.97 mm/day
   In 7 days, evaporated volume = 157,000m^3

2. Calculate the potential evapotranspiration firm an area in the month of November by Penman's formula. The following data are available: Latitude: 280 4' N, Elevation : 230 mash
   Mean Monthly temp: 19°c , Mean relative Humidity: 75%
   Mean observed sunshine hours : 9hr , Wind velocity at 2 m height : 85 km/day

3. Estimate the PET of an area for the season November to February in which wheat is grown. The location is at a latitude of 30° N with mean monthly temperatures as below:

Month	November	December	January	February
Temp °C	16.5	13.0	11.0	14.5

Use the Balance Criddle formula

Ans. E_T = 2.54 x 16.26 x 0.65

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Exercise 5

Flow-Duration Curve

1. The daily flows of a river for three consecutive years are shown in the table below. For convenience the discharges are shown in class intervals and the number of days the flow belonged to the class is shown. Calculate the 50 and 75% dependable flows for the river.

Daily mean discharge ($m^{3/5}$) in each class interval	No. if days of flow 1961-62	1962-63	1963-64	1	2	3	4
140-120.1	0	1	5				
120-100.01	2	7	10				
100-80.1	12	18	15				
80-60.1	15	32	15				
60-50.1	30	29	45				
50-40.1	70	60	64				
40-30.1	84	75	76				
30-25.1	61	50	61				
25-20.1	43	45	38				
20-15.1	28	30	25				
15-10.1	15	18	12				
10-5.1	5	-	-				
Total					365	365	366

Ans. Q_{50} = 50% dependable flow = 35 $m^3/5$
and Q_{75} = 75% dependable flow = 26 $m^3/5$

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OPERATION OF WATER HARVESTING

Background

The operation of a system is a series of functions of a system established to operate under a given set of conditions. This paper tries to look at those major water harvesting techniques that could be applicable to Ethiopian semi-arid or arid condition.

In the identification of the water harvesting technique due consideration has been given for those water harvesting system that are relatively simple to construct and readily adoptable by Ethiopian farmer.

The technique of water harvest is a prominent exercise in areas where the availability of water for crop growth, for domestic use and for livestock is under frequent strained condition.

Understanding the technique of water harvesting is therefore an essential practice for those communities whose livelihood is heavily relying on water stressed environmental circumstances.

There are basically two ways of improving the availability of water and or soil moisture for an intended purpose.

1. Water conservation and,
2. Water harvesting and use

1. Water Conservation - It refers to ways and means of increasing the amount of water stored in the soil profile by trapping or holding rain where it falls, or where there is some small movement as surface run-off.

2. Water Harvesting & Use - technique refers to a situation where surface run-off is collected and stored in dams, tanks, or cistern, for later Use.

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One should note that the division of the methods into these two types is arbitrary. So cross - reference of the two types is essential at all stages of use.

An attempt have been made to identify a number of water conservation and harvesting techniques that could be suitable to most conditions of lowland Ethiopia which are also by and large susceptible to moisture deficiency.

The operations of each of the selected water conservation and harvesting technique are briefly described for some degree of apprehension. The descriptions of the techniques by no means are not exhaustive and complete. The user of this paper is then adviced to do more of personal effort to upgrade whatever degree of knowledge he/she has been absorbed from the reading and the one hour lecture deliberations.

I. Water Conservation

Under this category two methods of water conservation is thought to be feasible for classification. The classification is suggested to be based on comparison of the rainfall with crop requirements.

The following are conditions:

A. **Where precipitation is less than crop requirements.**

The strategy in here demands land treatment to increase run-off onto cropped areas, fallowing for water conservation and the use of drought tolerant crops with suitable management practices.

B. **Where precipitation is equal to crop requirements.**

The strategy in this case include local conservation of precipitation, maximizing storage within the soil profile, and storage of excess run-off for subsequent use.

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Methods for cropland

The techniques which shall be described in this heading all involve some re-shaping of the soil surface, and so require substantial inputs of energy.

1. **Broad Bed and Furrow System (BBF)**

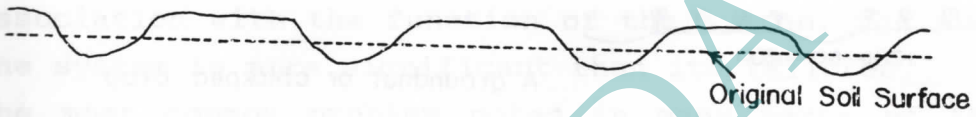
The objectives of this system normally include:

- to encourage moisture storage in the soil profile. This is often notable in deep vertisols which has good soil moisture storage to support plants.
- to dispose safely of surplus surface run - off without causing erosion.
- to provide a better drained and more easily cultivated soil in the beds.

Broad Bed and Furrow System is suitable for vertisols. Areas with dependable average annual rainfall of 750 mm or more on deep black soils are said to be best for the technique. The preparation of BBF to change the soil surface is not a difficult task.

It can be prepared manually and or with oxen drawn tools. Furrows can be established using the farmers' ploughs when the option of the land preparation is to utilize only hand labour. Under the Ethiopian's farmers stituation hand labour could be the most common practice. Animal drawn implements for this purpose are not common. A simple ox-drawn ridger developed at ILCA are not easily available. Until implements which are suitable for the construction of BBF the farmers shall be forced to depend on their hand labours and simple technique. Schematically the Broad Bed and Furrow system can have the following feature.

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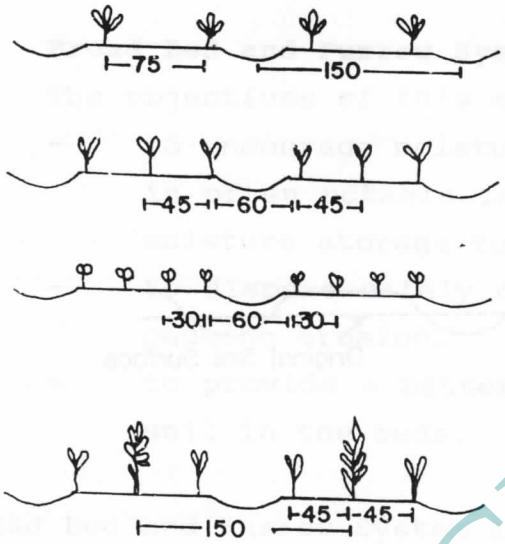


(a) Broad bed and furrow

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Depending on the choice of crop type to be used there are a number of alternative crop and row arrangements that could easily be adapted to a farming condition.



Broad beds and furrows are adapted to many row spacings
A maize crop

A sorghum or millet crop

A groundnut or chickpea crop

A pigeonpea/sorghum intercrop or a pigeonpea/maize intercrop

Fig. 1.2 Alternative crop and row arrangements on broad beds

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2. Ridging and Tied Ridging

The principle in this technique is to increase surface storage by first making ridges and furrows, then damming or blocking the furrows with small mounds, or ties.

The preparation of ridging and tied ridging require high labour. machinery as well as hand labour can be used for the construction. The hand - made ridges usually are said to be less efficient. The high labour requirement of the structure usually makes the technique unpopular with subsistence farmers.

Though there are reports of problems and failures faced in association with the function of the system, the success of the system is more significant than its failures.
The most common problem noted in many parts of the world include:

- Water logging developing into an anaerobic conditions in the rooting zone.
- Excessive fertilizer leaching, and
- Water table rise in lower slope areas. This problem is apparent, during high rainfall years or in a relatively long periods within the rainy season are very wet. The sum-total effect of all the above noted problem is a reduction in yields.

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Suitable conditions for tied ridging

- deep soils with good infiltration and permeability.
- furrows should be a gentle grade to assist run-off if the ties fail.
- the ties should be lower in height than the ridges so that the ties fail along the furrows before the ridges fail down the slope,

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Building tied ridges

World wide the construction of tied ridges is mainly associated with mechanized farming because of the high labour requirement. Ethiopian farmers in the southern part of the country have demonstrated the possibility of doing the structure by hand labour. The system in the local condition is simple. In the case of Ethiopia's experience the ridges and ties are made by piling up lines of sorghum residues and roots and soil.

Schematic presentation in the following would make the description clear.

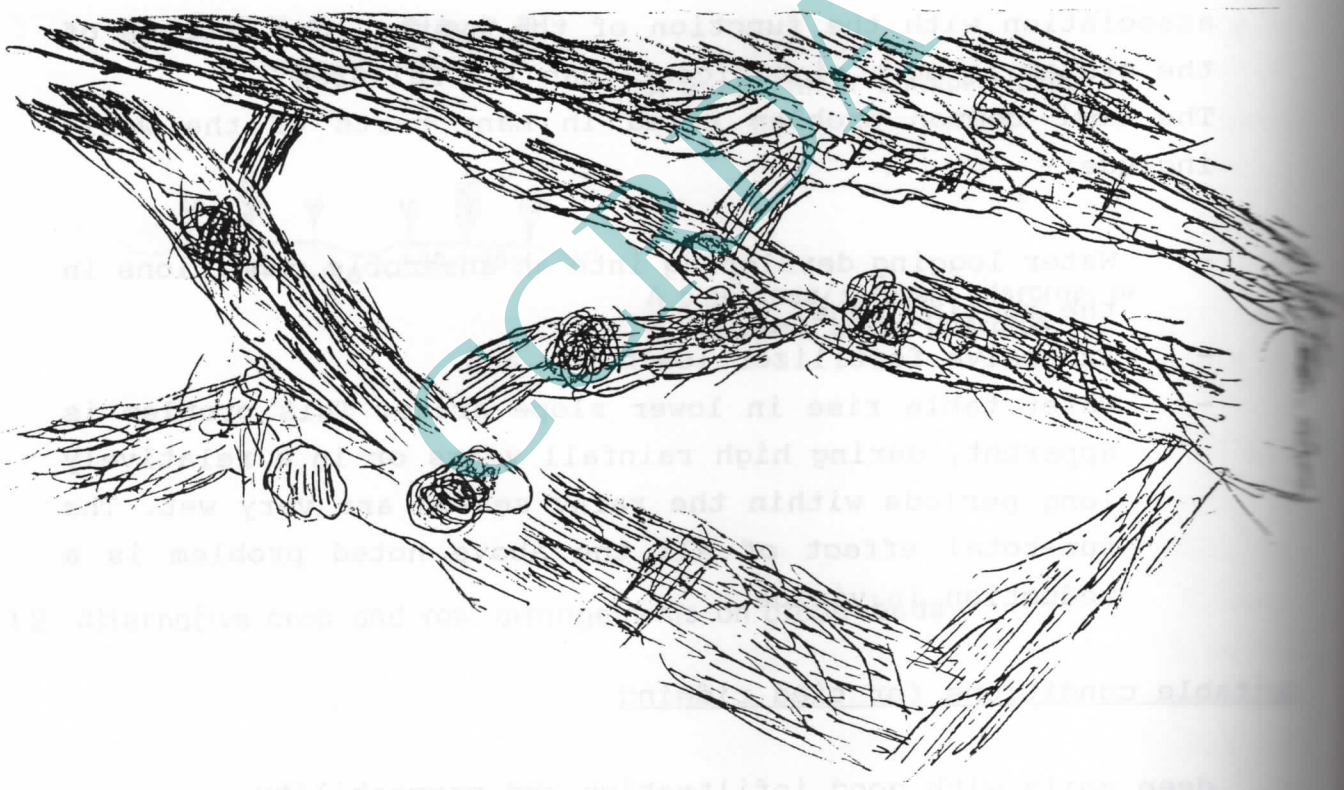


Figure 2·1

Building ridges and ties from crop residues, roots and soil,

3 . Level Bunds with run - off / run - on areas

The main principle in the technique is to create a combination of run - off and run - on system. Therefore, the runoff from an uncultivated part of the land is diverted on the cultivated part. By so doing, the cultivated part of the land receives more water directly than it does from rain. The overall function of the system is known by a term **'rainfall multiplier'**.

The ratio of area yielding run - off (catchment area) to the area receiving run - on (cultivated area) varies according to the variations of soil and crop requirements. The deeper the soil and its infiltration, the higher the water storage capacity and the possibility to increase the ratio according to crop requirements.

For mean seasonal rainfall (cropping season) of 300 - 500 mm, the best ration could be 1:1, 1.5:1 or 2:1. Optimum ratio could only be found through experience depending on the locality and cropping system.

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Construction

- the soil bund should be very well compacted and covered with stones (it available) or vegetated with appropriate vegetation.
- the height of the bund is 50 - 75 cm, the length vary from 80 to 100 meters and the width 1.5 - 2 meters. The bund has lateral wings as long as the width of the cultivated area which is 15 meters.
  The lateral distance between two bunds is 5 meters. (see the figure of the technique).

Arrangement of the bunds

To secure efficiency in the operation of the structure the bunds have to be staggered alternatively.

the arrangement of the structure in the staggering pattern would assist the structure from being damaged in the event of heavy and destructive showers are eminent.

The drawing in the following exhibits the main features of the structure.

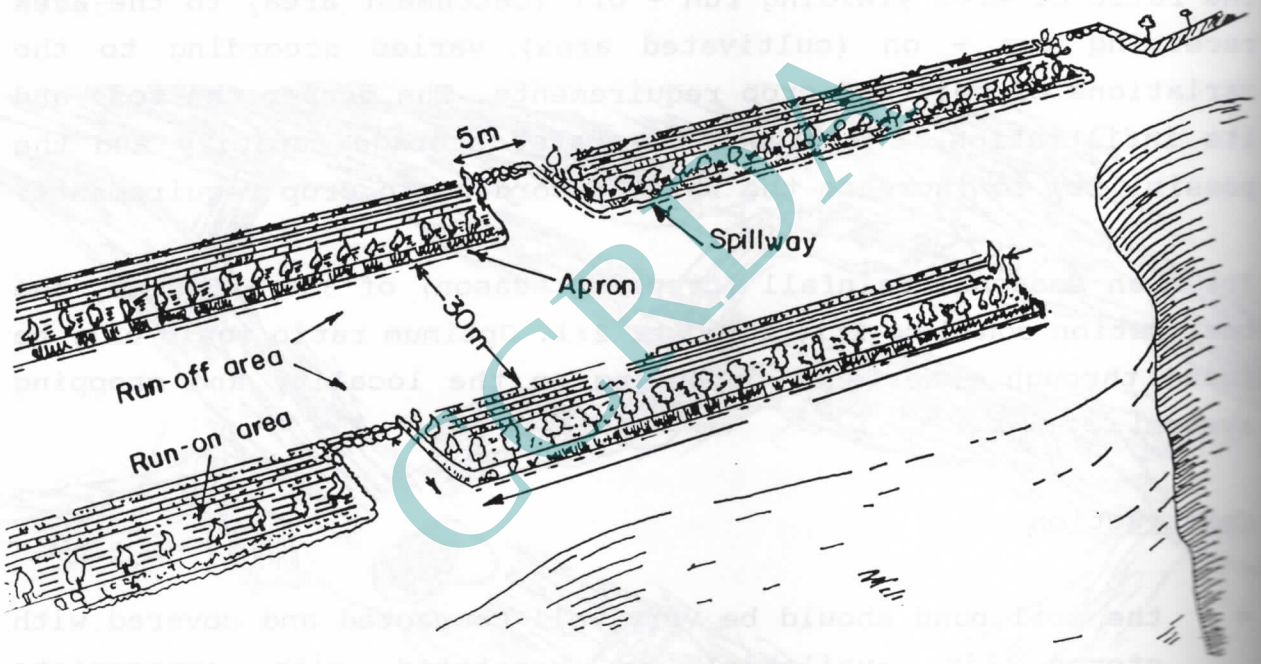


Figure 31 Level bunds with run-off / run-on areas

4. Conservation Bench Terrace

This is another type of rainfall multiplier, using part of the land surface as a catchment to provide additional run - off on to level terraces on which crops are grown.

Deep soils and good permeability are required so that flood water can be absorbed so quickly. A small embankment has to be constructed at the edge of the terrace at a height of 20 - 30 cm and width of 30 cm.
The run-on area can have a width of 10-30 meters.

- Should there be a risk that run - off from the catchment area will be in excess of absorption capacity of run - on area outlets at the end of terrace should be arranged to discharge into safe disposals.
  The system is most suitable on general slopes of 0.5 - 1.5 percent. But there are reports that indicate the experience of the system being practiced on areas of up to slope of 6 percent. But this requires more earth moving work.

- The bench terrace should usually be level along its length, however a gradient of 0.25% is allowed to encourage safe disposal of excessive run - off.

- The ratio of catchment to terrace may range 0:1 to 2:1.
  In general the lower the mean annual rainfall the larger will be the required catchment area to provide sufficient moisture of the crop.

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For more elaboration of the system the rain fall multiplier effect of the system is given in the following table.

The rainfall multiplier effect of conservation bench terrace assuming 500 mm of water is required for a sorghum crop.

Catchment Ratio	Catchment Ratio.	Run-off coeff.c%	Run-on (MAR X Ratio) X C	Total
MAR = 250 mm	2	40	200	450
	2	50	250	500
	3	30	225	475
	3	40	300	550
	4	30	300	550
MAR = 350 mm	2	20	140	490
	2	25	175	525
	3	10	105	455
	3	15	157	507

The drawing below illustrates what a simple conservation bench terrace would look like.

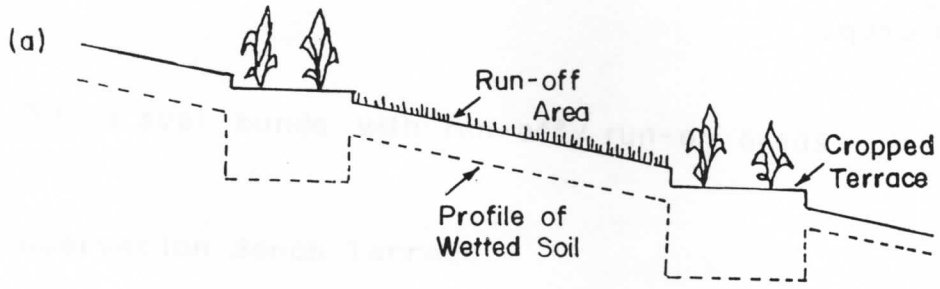


Figure 4·1

(a) conservation bench terraces increase soil moisture storage under the terrace

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5. Contours furrows

It is a system where the soil surface or the surface is prepared to contain a series of ridge like and furrow structure across the general slope direction of a given land .

The difference between this system and the system number three described earlier is that in here the soil surface is shaped differently to encourage the generation of run - off.

The shaping of the soil surface can be achieved by ploughing with oxen using tool bars or even by hand. It must be noted that the system is a bit labour demanding venture. The furrows part which are part of the system need to be fitted with low cross ties.

Mulching with crop residues in the cropped area assists to intensify infiltration.

When the whole of the soil surface is shaped, the ratio of run - off area to run - on area is governed by the configuration as shown in the following figures.

CCRDA

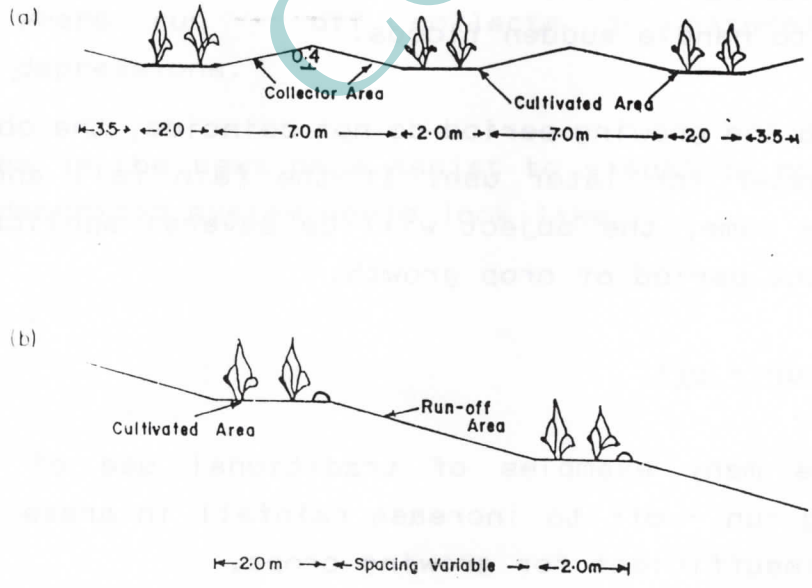


Figure 5.1
Shaping the whole soil surface into run-off and run-on areas ;
a) on level ground; b) on gently sloping ground

In low rainfall areas a large ratio of catchment to cropped area is required, but it is not easy to design a system which will give the best result for all variations of annual rain fall.

6. Water Spreading (use of run - on areas)

There are a wide variety of methods for different conditions as in the situations described earlier.
The soil type influences the method in many ways. Clay soils have low infiltration rates and high moisture storage capacity, so they are suitable for deep flooding with subsequent cropping sandy soils have quicker infiltration and lower storage which tends to go with the diversion schemes. A deep soil can absorb larger amounts of water, while shallow soil may need the provision of overflow outlets to avoid drowning the crop.

In the low lands of Ethiopia the rain fall occurs with high intensity producing floods. The methods to pursue should then focuss on how to handle sudden floods.

If the rain and the growing period do not coincide, the object will be to store water for later use. If the rain fall and growing period are the same, the object will be several applications of water during the period of crop growth.

a) Natural Run - off

There are many examples of traditional use of naturally occurring run - off to increase rainfall in areas where the rain is insufficient for growing crops.

This kind of practice may have not been widely used locally, but the system has a high potential to be suited to several conditions of the country.

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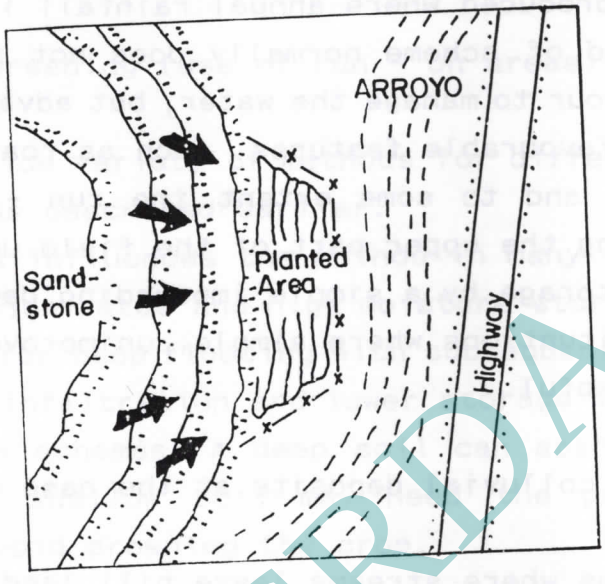
Run - off water can easily be collected to water alluvial soil at the base of the hills. Good crops of maize, sorghum or others could be produced where annual rainfall is only 300 - 400 mm. This kind of scheme normally does not require high investment of labour to manage the water, but advantages could be taken of any favourable features, such as roads to act as collector drains and to some extent the run - off may be managed by leaving the upper part of the field unplanted, or increasing the storage by a simple impounding dam.
There are four situations where simple, unimproved run - off farming may be useful.

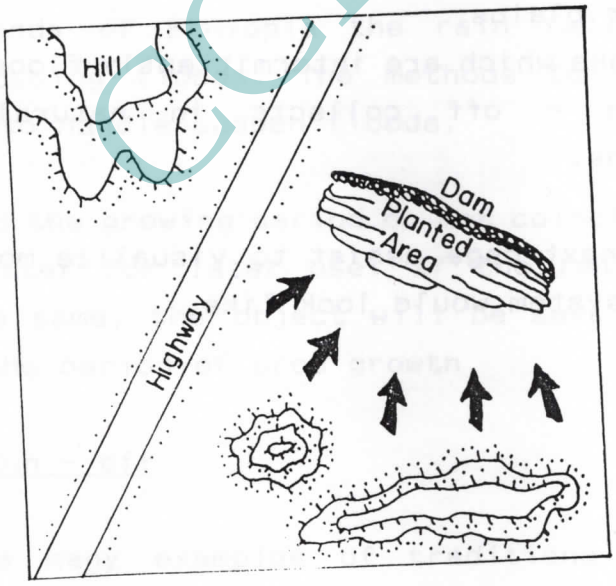
- alluvial or colluvial deposits at the base of ridges or escarpments;
- alluvial fans where streams leave hill land and flow on to flatter plains;
- stream banks which are intermittently flooded naturally;
- where run - off collects in naturally occurring depressions.

The figures in the next page assist to visualize more clearly of what the described system would look like.

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(a) Farming with natural floodwater, a sandstone ridge.





(b) Planting after floodwater has been retained by a low dam

Figure 6·1 Floodwater farming

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b) Inundation Methods

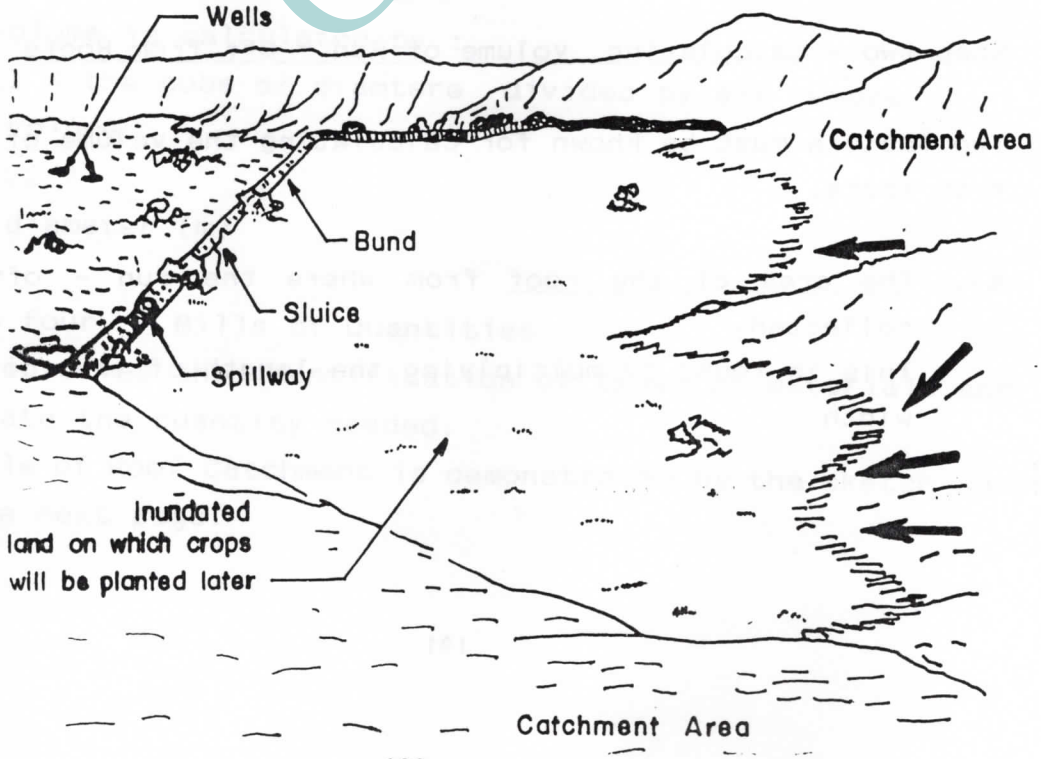
The system deals with flood waters where they are impounded and retained long enough to saturate the soil so that a crop can be grown on moisture stored in the soil.

On gently sloping land embankments collect and hold surface run - off, and after the water has soaked into the soil a short duration crop is planted and matures in a few days.

The system is largely used in semiarid areas of India & Pakistan at a very large scale.

As it was briefly described the system does not seem to be difficult to be adopted in the country.

Construction of contour bunds with a manageable size could help to try the system before a large scale venture is initiated.
The sketch prepared for this purpose would make the system more understandable.



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II. Water Harvesting and Use Technique In Moisture Stressed Area

7. Roof Catchment

It is a system of collecting rainfall water from a roof or roofs of a house or houses and storing them in water tanks that would be established in the scheme.

As long as there is required labour and some materials are available the system can not be difficult to be applied in the rural areas of the country.

There are a number of steps that one has to follow in order to apply the system.

Step one - Calculating the Users demand

- estimate the average daily consumption of water from the tank per person (or livestock).
- determine the number of days in the dry season; and
- estimate numbers of people (or livestock) using the tank.
- the demand then is equal number of days multiplied by number of liters taken multiplied by number of people.

Step two - Calculating Volume of Run - Off from Roofs

Two factors must be known for calculating the volume of run - off from roofs.

a). The area of the roof from where the run - off will be collected.
This is found by multiplying the length of the roof with the width.

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b). The annual rainfall from a year with poor rainy seasons. By using such a low figure the roof catchment system will supply sufficient water during years with poor rainfalls. The best way of calculating this figure is to deduct the average annual figure with 50%.

The annual volume of run - off during a year with poor rainy seasons is found by multiplying the roof area (m2) with the annual rainfall (mm).

Step Three - **Calculating Volume Of Water Tanks**

There are a number of formulas that can be used to calculate the volumes of water tanks . Depending on the shape of water tanks the following formulas can be used.

a) **For a cylinderical tank**

V = II X square of the radius X height where

II = 22/7

r = radius (m)

h = height (m)

b) **For a hemi-spherical Tank**

The volume is calculated by :

V = II X the cube of diamtere divided by six where :

V = volume

II = 22/7

d = diameter (m)

Step four - Bills of Quantities

This involves the identification of types of materials and estimate the quantity needed.

Example of Roof Catchment is demonstrated by the sketch shown in the next page.

CCRDA

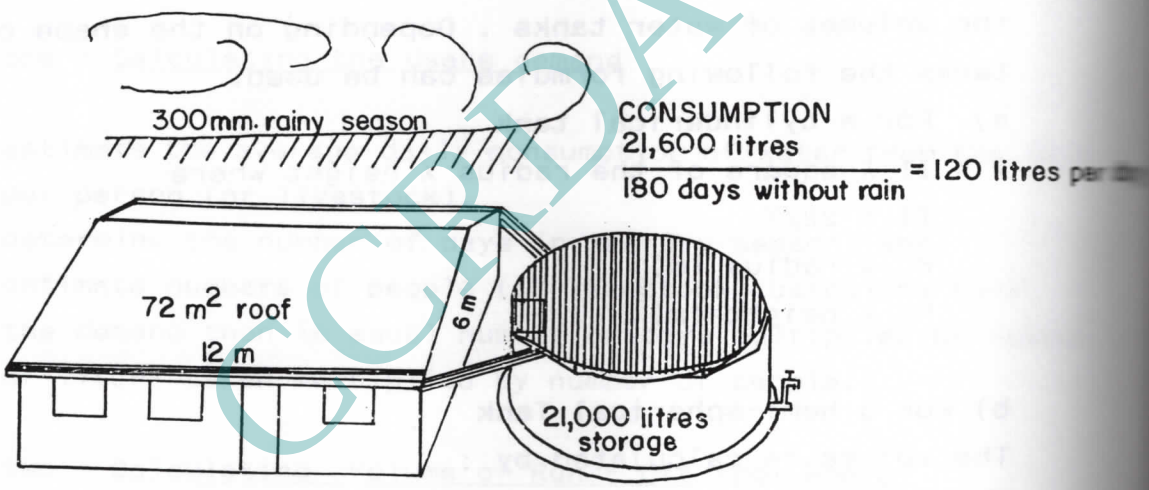


Figure 7·1 Roof Catchment

CCRDA

B). Rock Catchment Dam

Rock catchment dam is a vertically wall constructed around the outer edge of a depression or hollow in a rock-surface to capture and retain water running off the rocky surface. The gravity walls can be built in all lengths and sizes depending on the shape of the site where they are built and the size of the reservoir they will hold. The maximum size of the reservoir is ultimately determined by the size of the catchment and the expected rainfall depth in a season or year.

Siting and selection considerations

In the selection process it is useful to look for features that are hollows, depressions or gullies where the rock dips either looking down the slope, across the slope or both.

These dips can be converted in to a water
- holding reservoir by constructing a single gravity wall dam, or several sections of wall in a v - shaped or u - shaped dam.

Deciding on the size of Dam to build

Points to consider:
- the water demand of the users
- the amount of labour that can be available
- the size of the catchment area and the rainfall.
- the volume of the reservoir created by the dam.
- the dam height can range from 2.50 m to 4.50 meters.

The width of .30 meter can be considered. The size of the basement can have a value of 1.40m - 2.80 meters.

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The dams can be built at phases as shown on the sketch of the previous page . Building the dam at different phases will help to resolve problems that could be encountered particularly as related to over design.

Water Demand

The following formula can be used to calculate the water demand for a group of people.

No. of families X liters per family perday in dry season = demand.

The amount of water that needs to be stored at the end of the rainy season is the product of the above factors. To satisfy the demand it is wise to include losses to evaporation of about 33%.

The minimum size of the dam reservoir can then be determined as:

demand = dam + 33% in evaporation losses.

Calculating the required catchment area

Use the following formula for calculating run - off.

Rain fall (mm) x rum - off coefficient x catchment area (sq.m)= run - off volume.

The run - off coefficient is the proportion of rainfall that will become run - off and for all rock surfaces use 0.9.

The standard design of Rock Catchment Dam is shown in the figure on the next page.

CCRDA

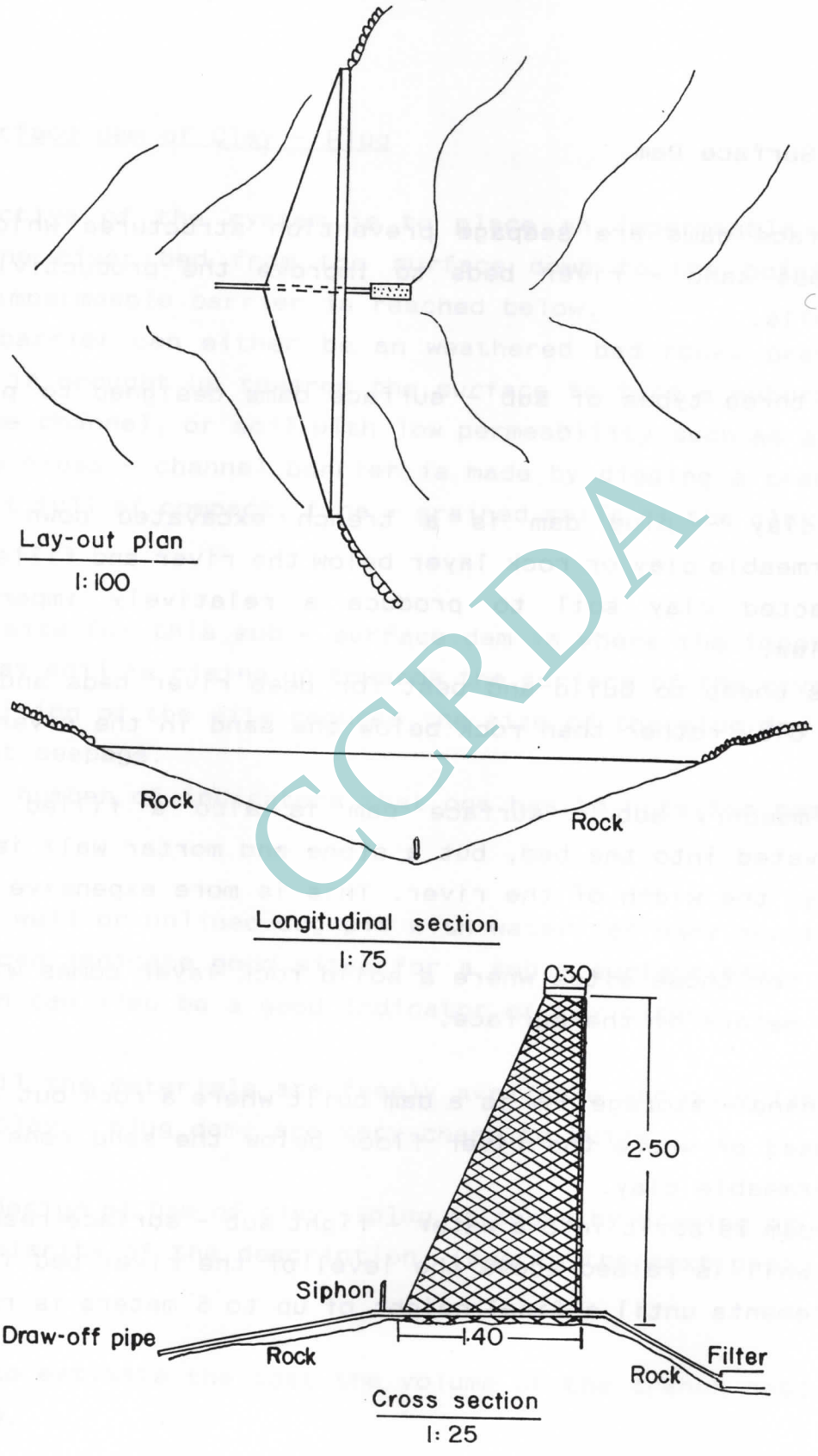


Figure 8·1 Standard Designs of Rock Catchment Dam

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9). Sub - Surface Dam

Sub - Surface dams are seepage prevention structures which are built across sand - river beds to improve the productivity of shallow wells.

There are three types of sub - surface dams designed to prevent seepage.

a) The clay - plug dam is a trench excavated down to an impermeable clay or rock layer below the river and filled with compacted clay soil to produce a relatively impermeable barrier.
It is cheap to build and best for deep river beds and those with clay rather than rock below the sand in the river bed.

b) The masonry sub - surface dam is also a filled trench excavated into the bed, but a stone and mortar wall is built across the width of the river. This is more expensive and is best for those sites where a solid rock layer comes within 2 to 4 meters of the surface.

c) The sand - storage dam is a dam built where a rock out crop is exposed or where the river floor below the sand consists of impermeable clay.
The dam is built into a water - fight sub - surface reservoir. The wall is raised above the level of the river bed in 50 cm increments until a final height of up to 5 meters is reached.

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Sub - Surface Dam of Clay - Plug

The objective of the system is to place an impermeable barrier across the river bed from the surface down to the point where another impermeable barrier is reached below.
The low barrier can either be an weathered bed rock, preferably where it is brought up towards the surface to form a natural dyke across the channel, or soil with low permeability such as a lay of clay. The cross - channel barrier is made by digging a trench and filling it full of compact, fine - grained soils of the clay - rich types.

The best site for this sub - surface dam is where the impermeable bed to clay soil is rising up towards the surface of the river bed. This condition of the site reduces the size of the plug dam needed to prevent seepage.
There are number of indicators that one has to note for best site selection.

A shallow well or unlined dug pit with water for many months in a riverbed can indicate good sites for a sub - surface dam.
Vegetation can also be a good indicator of key sites.

Because all the materials are freely available and only labour is required clay - plug dams are very cheap to build.

Standard design of Dam of clay - plug is shown by drawing or sketch for more clarity of the description (see in the next page).

Costing

In order to estimate the cost the volume of the trench need to be calculated.

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The volume of trench = length of the channel x width of the trench normally 12 meters, x average depth of the channel.

Labour requirement

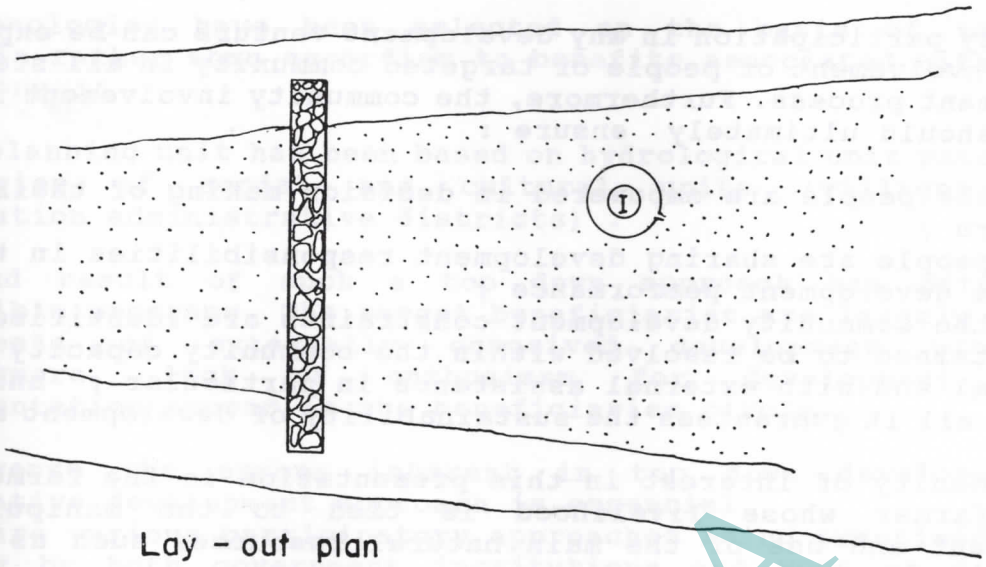
To budget labour needs use the following formula.

Volume of 1 cu.m x 4 days = number of unskilled days.

Total unskilled days = calculated

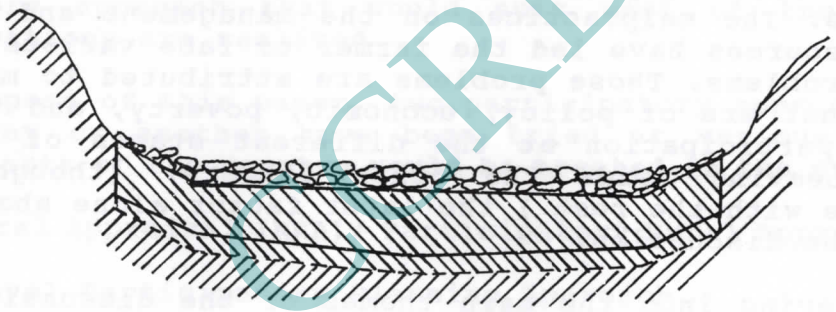
Volume of the trench x 4 days.

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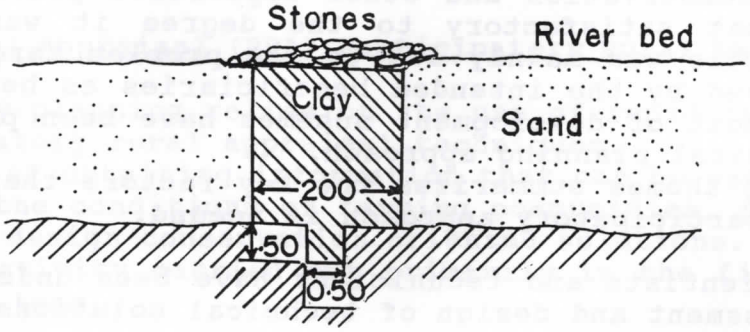
Lay - out plan

1: 200



Longitudinal section

1: 125



Cross section

1: 50

Figure 9.1 Standard Design of Sub - Surface Dam

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Background

Community Participation Strategy and Approach

Community participation in any development venture can be explained as the involvement of people or targeted community in all stages of development process. Furthermore, the community involvement in such affair should ultimately ensure :

- that the people are empowered in decision making of their own affairs ;
- that people are sharing development responsibilities in the future development performance ;
- that the community development constraints are identified and entertained to be resolved within the community capacity in general and with external assistance in particular ; and above all it guarantees the sustainability of development assets.

The community of interest in this presentation is the farmer. The small farmer whose livelihood is tied to the manipulation, management and use of the main natural resources such as water, soil and forest.

Farmers in the past as well as now even, have not been using the natural resources they have access to utilize properly, in a manner sustainable. The malpractices on the management and use of the natural resources have led the farmer to face various social and economic problems. Those problems are attributed to multitude of factors, that are of policy, economic, poverty, and the lack of community participation at the different stages of development process. Leaving aside the other factors, (though they are inseparable with the rest) the later factor alone shall be the focus of the discussion.

Before entering into the main themes of the discussion it seems appropriate to examine why participatory approach is needed. Successful agricultural development must entail sustainable land management and land use taking into consideration the goals and circumstances of the farmers.

In the past conservation and other supportive practices had not been some what satisfactory to the degree it was desired to accomplish. This was mainly due to the problem targeted are not those perceived by the intended beneficiaries as being immediate priorities. Most of development schemes have been prepared using top down physical planning approach.
The following themes summarizes the key factors that may lead us respond why participatory approach is needed.

- Natural scientists and technicians have been undertaking almost problem assessment and design of technical solutions;

- Farmers have often been seen as part of problems i.e conservative and reluctant to change of innovations they are provided with ;

- Technologies have been selected on the basis of technical criteria rather than according to benefits associated with their adoptions ;

- The planning unit has been based on hydrological unit rather than boundaries of social and cultural units (villages,peasant association administrative districts) .

The end result of such a top down approach has often been inflexible programs. The target beneficiaries are largely passive recipients of externally conceived development proposals. Furthermore, lack of enthusiasm for development scheme implementation appear in the beneficiaries circle.

To reverse the errors inherent in top down development an alternative development approach is essential.
There are various participatory approaches being practiced in the country by both government institutions and NGOS at different scales of operations. To date no definite participatory approaches that could serve the national conditions have been determined.
In actuality it would take a longer period before a comprehensive participatory approach that would suit most of the country's varied situations are realized.

For the purpose of this paper, two participatory approaches which were one way or another have been tried at various scales in different parts of the country would be treated in the explanation.

I) Rapid Rural Appraisal (RRA)/ Participatory Rural Appraisal (PRA) and
II) Local Level Participatory Planning Approach.

Both approaches will be described in terms of their use in conservation planning. However,the description concerning the first approach will be limited to the explanation of its Concepts and Principles since there is no much experience in its application at a field level.

I) Rapid Rural Appraisal (RRA) Participatory Rural Appraisal (PRA)

Participatory planning relies on the use of rapid rural appraisal and participatory rural appraisal techniques.
RRA is a way of obtaining information that can be used to identify and analyze the conditions of farming communities, diagnose their problems and design conservation oriented solutions. RRA is a semi structured activity carried out primarily in the field by inter-disciplinary team.

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Key features of RRA are:

- Iterative : data collection, analysis and review are on-going activities throughout the study.

- Flexible : the sequence of activities and goals of the study are not fixed before hand, but they can be constantly reviewed and modified as the team realizes for a change.

- Innovative : there is no simple, standardized methodology . Technologies are developed and modified for particular situations depending on the local circumstances and the skills and knowledge of the team members.

- Interactive : all team members and disciplines combine together in a way that encourages lateral thinking and inter-disciplinary feeling.

- Informal : the emphasis is on partly structured and informal interviews and discussions.

- In the Community : learning takes place largely in the field and in particular farmers' viewpoints are used to help define differences in field conditions.

RRA has evolved into the approach termed participatory rural appraisal (PRA) . With RRA outside professionals go to rural areas obtain information and then bring it away to process and analyse. With PRA outside professionals still go to rural areas, but their role is more to facilitate the collection. presentation and analysis of information by rural people themselves.

There are a number of features that are common to both RRA and PRA which shall not be dealt in this paper, however attempt is made to briefly describe for those features that are basically restricted to PRA.

PRA features :

- They do it - facilitating investigation, analysis, presentation and learning by rural people themselves, so that they own the outcomes.

- Self critical awareness - meaning that practitioners are continuously examining their behavior.

- Relaxing and not rushing - exploiting the dilemma that taking plenty of time in PRA is often faster and better than trying to be quick.

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- Embracing error - meaning welcoming error as an opportunity to learn to do better.

- Sharing of information and ideas - between rural people, between them and practitioners, and between different practitioners, and sharing training and experiences between different organizations.

In the participatory planning approach the "external" planning team's role is to act as facilitator enabling farmers themselves to : a) determine the problems associated with productive and sustainable land management; b) identify the constraints; c) develop locally adoptable solutions.
Instead of 'making recommendations' the role of external team is to 'offer advice and information'.

There are a range of PRA methods exist, few of them are listed below as an example:

- collection /review secondary sources (background information)
- direct field observation
- informal interviews with key informants
- informal group interviews
- informal individual interviews
- participatory transects
- participatory mapping
- participatory seasonal profiles
- participatory diagramming
- ranking
- community level presentation and analysis
- community problem brainstorming

There is no one definitive RRA/PRA method. It varies depending on the social and cultural circumstances of the communities involved, the nature of the local problems and the skill and experience of the members of the external planning team.

PRA considers the interaction of farm household enterprises, such as crop production, livestock production, tree production and other off-farm and on farm activities of the farmers.
The method considers different aspects and circumstances which includes biophysical situation, socio-economic situation, policy, and institutional situations.

Identification of Potentials
Based on the prioritized list of problems development options and potentials are selected. Traditional knowledges and practices are investigated to solve problems. Beneficiaries thought and experiences are entertained in managing the problems.

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Development Options and Interventions

Development options are determined to address the problems identified at the earlier stages of the method. Discussions are held with the farmers to determine areas of community interventions at the implementation stages of the development schemes. PRA methodology assumes that development options are to be undertaken by farmers with out heavily depending on the external assistance for inputs

Like most of similar methodologies PRA has also its own merits and short comings and are briefly as in the following ;

Merits of PRA

- PRA helps both farmers and experts to learn from each other.
- PRA helps the experts to appreciate that farmers know their environment very well.
- PRA considers the coordination of different development agencies.
- PRA is claimed to assist in the promotion of community participation in development activities.

Short comings of PRA

- Participatory approach may often raise the local expectation of participants.
- PRA techniques may not be cross culturally transferable, they need to be adapted to local conditions.
- Appropriate use of PRA techniques require the training of facilitator and participants.
- PRA involves multidisciplinary team which is not readily available at one institution
- PRA may involve much amount of budget and time during execution

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B) **Local Level Participatory Planning Approach**

Background

The approach is basically developed from a series of similar methodologies undertaken by the then Department of Community Forestry and Soil Conservation. The root causes for the introduction of the previous methodologies to the regular Department's work was :

- to encourage the participation of farmers in any stages of soil conservation work,
- to draw more effectively the technical manpower resources of the Ministry for the purpose of providing appropriate technical assistance directly to peasant organizations.

To concretize the theme of peoples participation it was found necessary to initiate, and promote Watershed management planning methodology in selected pilot areas in the field offices as of June 1988/89 ,

The scheme was launched on about nine pilot areas encompassing a wide range of agroclimatic conditions, physical conditions and socio-economic settings. According to the methodology a sub-watershed is assumed to be a unit of operations .

The following items are contained in the guide line for the preparation of a sub-watershed management plan.

- definitions and concepts of watersheds;
- photo interpretation technique;
- watershed management planning;
- identification of agroclimatic conditions;
- survey of soils and land-classification systems ;
- socio-economic surveys;
- present land use/cover survey and
- options for sub-watershed development and management plans.

The guideline in principle is technically proper and suitable to amass infromations for the intended purpose.

The sub-watershed plans formulated for the pilot areas could not be fully implemented due to a number of reasons. Lack of adequate budget to carry out the plans as stipulated in the respective plans was the major impediment in the total effort. On the other hand the guide line appeared to have its own technical problems for a promotion purpose.

Hence an informal type of assessment and observation on the validity of the guideline as related to promotion purpose had indicated the following notions.

- The guideline required quite a lengthy period to have it gone into action,

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- The technical contents of the guidelines though they were found to be relevant, they were presumed to contain high level of technique and skills that cover a range of subjects such as :

  land classification system, aerial photo interpretation system, elements of cartography and data analysis. Junior field staff often found it difficult to cope up with such levels of techniques and skills.

- Resource wise it demanded a substantial amount of money which was not easily attainable by the department at that time.

- The technical backstopping requirement from the Head Quarter demanded high level expertise which was unaffordable to the then department.

How to make a Work Plan For Community Forestry and Soil Conservation Activities.

After having realized the above constraints it was deemed necessary to alter or replace the guideline by a new version which had to be simple for a user.

As a result a new version of the guideline bearing the name of " Minimum Planning " (a name used with in the Department) was introduced. **The Minimum Planning Methodology** was nothing but very much simplified version of the sub-watershed guideline with some alterations. The minimum planning methodology assumes the unit of operation to be a peasant association rather than a sub-watershed. The PA executive committee were the contact groups to the people residing in a given PA area. Further more, the methodology suggests the formation of a **"Community Forestry and Soil Conservation Committee"** with five people in it. The committee's task basically was to represent the general public of the planning area and work continuously with the field experts on an area until the preparation of a plan is completed.

Most of the technical descriptions and recommendations contained in the former guideline were scraped off from the later one.
A considerable effort has been made to disseminate the methodology through out the administrative regions of the country. As part of the promotion exercise several field staff perhaps reaching about thousands of them have been trained on the approach .
The preparation of plans and implementation as per the training rendered could not be achieved at that time largely due to inadequate follow up from the **Head Quarter** as well as due to insecurity circumstances that prevailed in a large areas of the country. The prevailing top down approach within the structure of the institutions of MOA had also contributed to the slow process of

virtually no achievement in planning and implementation inspite of fast acceptance of the methodology by trainees.
Since the major political turnover of 1991 several donors and external institutions expressed interest and concern about the adoption of bottom- up approach in relation to the continuation of their assisted programme and project activities.

It was then decided to launch a bottom up approach programme on a pilot basis taking into account the Department's previous experience in a similar task.

The "Local Level Participatory Planning Approach " (LLPPA) had been designated as a name for the revised version of the Minimum Planning Methodology.

Orientation regarding the LLPPA had been given to the field staff pooled from eight representative pilot areas. The trained staff had finally were requested to submit their respective plans to defend and share their own experiences among their own colleagues gathered from different corners of the country.

While such kind of exercises were undertaken the LLPPA document have been revised regularly (three times in two years period) based on the feed back from the field test. An external evaluation had made an assement on how the methodology worked out on the pilot areas before a go head actions were taken to expand the programme outside the pilot areas,

Since the outcome of the evaluation was positive it was then decided for its expansion to be carried out covering large areas of the country. No sooner than the decision had been under-taken series of conservation plans had been prepared by the field staff who had access to the orientation and exposure of LLPPA methodology. Currently there are over 500 conservation plans prepared and distributed in four regions and sixty woredas covering over two hundred thousands of hectares of land.

LLPPA is destined to serve as a tool for conservation planning largely to the grassroot and woreda level field experts .
The ongoing effort in this respect have contributed considerably to involve a significant number of development agents and conservation technicians with a favorable response from the participants.
Most of the plans prepared under the LLPPA methodology have not been implemented. Large number of these plans were only ready in April 1994, and coincidentally that period was a slack season of the year where much soil conservation activities could not be launched. Limitation in the availability of resources was another factor.

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It is expected as of this fiscal year provided there are adequate budget supports ,technical backstoppings and follow up the implementation shall be commenced .

The main contents including objectives, procedures and other salient features of the methodology shall be discussed from here on in the succeeding sections of this paper.

General Objectives Of LLPPA

The eminent objectives are jotted below;

° To entertain farmers land management problems in general and degradation problems in particular according to their perspectives in the planning process.

° To facilitate in the identification of priorities and define targets that can enable to reach at the objectives of soil conservation development .

- To help in sustaining the introduced soil conservation based development measures via awareness developed by the adoption of the methodology.

- To sustain strong working relationship between the soil conservation expert and rural community.

- To provide a means for evaluating the effects and impact of activities

Specific Objective of LLPPA

- To equip the technical staff with a tool of planning methodology which ultimately assist him/her to organize his or her work in a planned manner.

- To encourage and inculcate a bottom up approach of activities in the everyday works of the grass root field personnel.

- To urge the grass root field personnel to maintain close contact with farmers in carrying out their routine duties.

- To create a learning process between the two partners in rural areas

3. Main Procedures

Features of the main procedures included in the LLPPA planning methodology are eleven in steps and are briefly described below.

CCRDA

a) **Identify the planning unit**

It assumes that there is no as such definite planning unit that is associated firmly with a given physical parameters or conditions. It rather gives preference to that part of a community who will be willing or convinced to adopt the methodology. Accordingly the planning unit could be those areas occupied by whole members of a peasant association community , or a community area located in a given village,or group of farmers residing in the part of either of the former two units. Besides, the planning unit will have to accommodate sub-watershed concepts and requirements.

Any finally selected planning unit is assumed to be homogeneous in respect to agroclimate , socio-economic setting,and general nature of topography.

b) **Carrying out of initial meeting with the volunteering community Target Group**

c) **Establish planning Team**

It is designed that members of the planning team be nominated by the general assembly of the target area. Members of the planning team are assumed to be selected from different levels of the socio-economic strata in a given planning area.

The size of the planning team is assumed to be five one of them being a female who can speak of a woman issues.

d) **Carry out problem identification**

The methodology recommends that problem identification and its priority arrangement of a target area be conducted by a planning team in collaboration with the concerned field technician.

e) **Description of a target area**

The description of a target area require the collection of information about the area which includes the following items.

- determination of agroclimate of the survey area.

- gathering informations on the topographic details of the survey area.

- general assessment of the vegetation type of the survey area.

- assessment of the degradation status of the survey area.

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- survey of the present landuse of the target area.

- determination of the actual size of target area by a suggested set of means contained in the methodology.

- examining the major soil types of the planning area

f) Selection of Soil conservation development measures and or options.

This section of the methodology suggests the strong consultation to farmers in the identification of optional measures to be implemented.

The technicians being a member of planning team they are advised to a large extent to depend on previous technical documents and own experience in the selection of appropriate measures that could be suited to a planning area. The other emphasis that is included in the section is the inclusion of other supportive disciplines such as crop husbandry, animal husbandry, small scale surface water development schemes.

The technicians who are in charge of initiating, organizing, and implementing the conservation plans prepared using the methodology are firmly recommended to play a catalyst role in the overall execution of the programme at all stages.

g) Verification of the proposed conservation measures in a general assembly of a target area

This part of the procedure requires a general meeting of the people in the target area to discuss ,scrutinize and ratify the measures selected in the earlier stages of the procedure. The planning team will have to present the tentative actions of planning work for comments, change,improvement and final agreement.

h) Generate a work plan table

This is a stage where a work plan has to be prepared utilizing the form designed for this purpose. The work plan is suggested to contain activities that could last for three to five years.

i) Preparations of annual work plan table

There is not much difference from the section (h) of the procedures. As the name implies the annual programme is supposed to display activities that shall be executed monthly, quarterly, and annually.

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j) Estimation of inputs required for the planned activities.

The procedure requires to fill in and complete three tables with informations on labour, tools and food requirements (when necessary).

k) Record of activities.

Instructs to record accomplished activities during implementation.

l) Devise a filing system.

To facilitate monitoring and evaluation tasks an arrangement of filing system is recommended to be pursued.

4. Identification of Potentials

The methodology recognizes the proper description of various potentials that could be noted in a given planning area.
LLPPA prime target is to foster proper land management by application of sustainable soil conservation measures and lay a proper foundation on which an improvement of agricultural production could be attained.
In the identification of potentials the methodology is has an inclination towards the detail assessment of major natural resources such as forest, soil and water.
In respect to crop production, it addresses those parameters of production that has strong ties with the natural resource

management in general and land management in particular. Further are the status of yield per unit of an area in respect to the situation of production year ,types and numbers of cash crops, marketing conditions, labour supply, the land tenure arrangement, the availability of agricultural inputs, and the prevailing extension system are all an integral part of the crop production potential identification.
In general the content of this potential description is adequate for the intended purpose of the methodology .

- In terms of livestock production the parameters considered are those aspects which deals with crop residue grazing and the availability of feed. Most of the remaining production parameters are similar to those of items considered in crop production potential.
The interest in the section of the methodology is to examine the grazing system or habits of livestock on a cultivated field.
This information would assist to determine compatible recommended conservation measures . The points addressed in this investigation would suffice to handle the desired informations.

CCRDA

Examining of potentials in terms of irrigated agriculture, the methodology does not have provision for this affair, with understanding that irrigation activities are out of the mandates of the department. Instead the methodology emphasizes to survey the situation of water supply in a given locality for planning.
The supply and the availability of fuel wood and construction wood in the present rural Ethiopia is a big concern. Realizing this fact there is a provision in the methodology to conduct a survey on the situation of the item.

5) Development options and interventions.

Concerning this subject it has been treated earlier in one of the procedures step. As it was explained the document assumes that the development options and interventions should be based on objective realities of local conditions as well as on the real possibilities that local organizations be it governmental or NGOs could contribute to implement suggested opportunities.
Traditional practices is a matter of concern treated in the methodology . It is stressed that traditional practices be given due attention prior to the selection of new development options or interventions.

6) Suggestion and Recommendations .

Like any technical methodology LLPPA cannot be exceptional to do away with possible short comings and merits.

Short comings of LLPPA.

- it might be considered as time consuming venture as opposed to chaotic way of carrying out activities.
- it might some times be considered as slow process for people who want to execute activities in a massive manner by mobilizing people.
- it might require a considerable high budget as well as more human resource allocations as opposed to traditional way of doing things.

Possible Merits of the Methodology.

- It encourages bottom up approach planning process .
- It helps to maintain firm harmony between the farmer and technicians .
- It helps the user to have confidence developed on him \her to pursue his or her day to day work.
- It helps for a user to practice self monitoring exercise of own duty .

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- It facilitates to make monitoring and impact evaluations of activities undertaken on a given area.
- It facilitates to prepare sets of ready made projects that could be made available to a donor assistance when the need arises.
- It increases a sense of owner ship for the assets established through the development interventions .

CCRDA

CCRDA

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CCRDA

Water Harvesting Techniques for plant production

Water Harvesting is defined as "Collection of runoff for productive purposes, using the soil as a storage body".

Rainfall over large area is concentrated on smaller area to increase the moisture content of the soil profile and store it for consumption by plants. Thus the area where water is stored in the soil is cultivated.

Water Harvesting Techniques:

In arid and semi arid areas of the world where agriculture is practiced at subsistance level, different techniques have been developed over the centuries to collect rain for plant production purposes.

Experts catagorize these techniques in different classifications. For the purpose of this discussion, it could be adequate if they are divided into 6 classes based on layouts, construction materials and objective of the scheme.

1.0 Harvesting From Short slopes.

This is water Harvesting from "small catchments" or within field catchments. Different authors designate different maximum lengths to the short slope which varies from less than 25M to less than 150 M. The shortest slope has a catchment length of 1-2 M. In less area, water harvesting, if practiced, changes into insitu moisture conservation. The Water Harvesting methods included in this category are:

1.1. Negarim Microcatchment System.

These are small diamond shaped basins surrounded by small earth bunds with an artificial pit in the lowest corner of each. Runoff is collected within each basin and stored in the infiltration pint. The technique is appropriate for small scale tree planting in moisture deficit areas. Negarim Cathments are neat, precise and relatively easily constructed by hand.

- The technique originated in Southern Tunisia and was developed in the Negive Desert of Israel - where the name was adopted from Hebrew Word "Negew" meaning runoff.
- Now, it is the most proven technique widely known system in arid and semiarid areas in North and Sub-Saharan Africa.

Technical feastures:

a) Suitability:

- Suitable for growing trees in arid and semi-arid areas
- Rainfall : can be as low as 150 mm per annum
- Soils : should be at least 1.5m. deep but 2m. preferable to ensure adequate water storage and root developement.

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- Slope ; • Slope of the land could range from flat to 5.0%.
- Topography: need not be even; the microcatchment can be subdivided if land is not even.

b) Overall configuration

The system consists of square shaped microcatchments. Layout is made in such a way that one of the corners is located in the lowest spot where the infiltration pit (cultivate area) is located

c) Limitations

- The technique is only suitable for hand construction operation and maintenance as well as cultvation.
- Labour intensive.

d) Microcatchment size

- Depends on the water requirement of the plant
- Ranges from 10 m^2 to 100 m^2 depending on tree species and number of trees.

1.2. Semicircular Bunds

Semicircular Bunds are earth embankments with a shape of semicircle with the tips of the bunds on the contour. The system is mainly used for range land rehabilitation or fodder production. It is also useful for growing trees and sometimes for growing crops. It is a newly developed technique not developed earlier traditionally.

a) Technical Features

Suitability

The system is used for collection of runoff under the following conditions.

Rainfall - 200 - 750 mm.
Soils - Not too shallow or saline

Slope - Flat slopes less than 2 percent. With modified design it could be used on slopes up to 5 percent.
Topography - Even topography is required.

b) Types: Two types are used based on dimensions.

Type "a"

small structures closely spaced
adopted for relatively wetter areas:
require low slopes and even terrain.

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Type "b"

larger and widely spaced bunds
more suitable for drier areas.
does not require such an even topography:

c) **Overall configuration**

The two types differ in layout and size.
Type 'a' or design 'a' has a radius of about 6m. used for short slopes. Does not accomodate overflow.

Type 'b' used for short slopes, radius about 20m, can accomodate limited runoff from an external source, overflow occurs around the tip of the bund, which are set on the contour.

In both types, the bunds are constructed in staggered lines with runoff producing catchments between the structures.

Advantages of the system

- Recommended as a quick and easy method of improving range lands in semiarid areas.
- The system is more efficient in terms of impounded area to bund volume than other equivalent structures

Limitations

- Construction can not easily be mechnaized.

1.3. Contour Ridges for crops:

Contour ridges sometimes called contour furrows or microcathment shedes are low ridges constructed along the
contour at spacing of usually 1-2m. Runoff is collected from the uncultivated strip and stored in a furrow just above the ridges. The system is not widely spread but being tested.

Technical features:

a) **Suitability**

Contour ridges can be used for crop production under the following conditions.

Rainfall - 350 - 750 mm/yr.
Soils - all soils suitable for Agriculture
Slopes - from flat to 5 percent
Topography - must be even

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b) **Limitations**

- Limited to areas of relatively high rainfall
- amount of harvested runoff is comparatievely small due to small catchment area.

c) **Overall configuration**

- Layout consists of parallel or almost parallel earth ridges approximately on the contour at spacings between 1-2m.
- To form a ridge soil is excavated and placed on the lower side.
- Furrow above the ridge collects runoff
- Small earth ties provided in the furrows every few meters to ensure an even storage of runoff
- A diversion boundary may be required at the upper side

d) **Advantages of the system**

- Simple to construct by hand or machine
- Less labour intensive than conventional tillage of a plot.
- Yield from very short catchment length is extremely efficient
- growth of crop is even

1.4. Contour Bunds for Trees

Countour bunds are low earth bunds constructed along the contour, at close spacings, the system being divided into individual microcathments by small earth ties provided at certain spacings along each bund.

Technical features:

a) **Suitability**

Suitable under the following conditions
Rainfall - 200-750mm/yr.
Soils - must be at least 1.5 m. deep preferably 2.0m.
Slopes - from flat to 5.0 percent.

b) **Limitations**

Not suitable for uneven or eroded land.

c) Overall configuration

The system consists of parallel or nearly parallel earth bunds constructed approximately along the contour at spacings of 5 to 10m.

- Small earth ties perpendicular to the bunds sub-divide the system into microcathments for tree growing
- Infiltration pits are excavated at junctions between each tie and bund.
- A diversion ditch at the top of the site protects it from external run off.

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d) **Unit Microcathment size**

Size per tree is determined in a manner similar to that of the Negarim Microcatchment. Common sizes are 10-50 m^2 for each tree.

2.0 Water Harvesting Techniques from Long Slopes

Water harvesting from slopes greater than 50 to 150 m. are referred to as macrocatchment water harvesting or water harvesting from external catchment systems.

2.1 Trapezoidel Bunds:

These stractures are series of bunds each having a layout of trapezoidal configuration arranged in such a way that the overflow from one structure is trapped by the lower one.

These bunds enclose large areas (up to one ha.) and impound large quantities of runoff harvested from an external or long slope cathment. Overflow discharges around the tip of the wing walls.

Technical features:

a) **Suitability**

Rainfall - 250 - 500 mm
Soils - agricultural soils with good constructional properties
Slopes - from 0.25 - 1.5% but most suitable below 0.5%.
Topography- area within bunds should be even

b) **Overall configuration**

- Each bund consists of a base bund connected to two wing walls which extend up slope at an angle of 35°.
- Size of enclosed area varies according to slope (0.1 to 1.0 ha.)
- Can be constructed in single units or sets.
- When laid in sets, arranged in a staggered configuration only two rows recommended as lower ones receive less water.

c) **Advantages of the system.**

- Simple to design and construct
- Minimum maintenance required.

eg. Turkana District, Kenya, Traditionally used in the Sudan, Tunisia

d) **Limitations**

Limited to low ground slopes
Labour intensive, difficult to construct by individuals.

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2.2. Contour Stone Bunds (Stone bines)

Contour stone bunds are constructed along the contour. They slow down and filter runoff thus encouraging infiltration. The sediment harvested improves performance of crops.

Technical Features:

a) **Suitability**

Stone bunds for crop production can be used under the following condtions.
Rainfall - 200 -750 mm.
Soils - agricultural soils
Slopes - preferably below 2%
Topography - need not be completely even
Stone availability - there must be good local supply.

b) **Overall configuration**

The bunds follow the contour across the field or grazing land. Spacing normally range between 10 and 25m. depending on the amount of labour and stone availabile. Mimimum height is 25cm. The layout is shown in figure 6

Advantages of the system

- Well suited to small scale application on the farmers field
- Can be implemented quickly and cheaply where adequate supply of stone is available by the farmers themselves.
- The system does not require spillways.
- Filtering effect of the semi-perimeable barrier along the full length of the bund gives better spreed of runoff than earth bunds
- Stone bunds require much less maintenance.

The system is well popular in Burkina Faso - introduced by OXFAM.

2.3. Hill side conduit system.

Graded channels are cut on the long slopes to tap, concentrate and convey runoff to a valley below.

The technique is used in situations where good agricultural soils are surrounded by hills having long slopes and runoff from the slopes owing to low intensity of the rainfall does not reach the valley.

The valley soils must be terraced, using check dams, and spillways, to regulate, retain and store the harvested water.

The technique is used in experimental farms in Israel.

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2.4 Flood water Harvesting within the stream bed.

Includes those techniques which concentrate runoff in the stream bed by blocking the water flow. The valley floor is cultivated and water is utilized on the spot.

Suitable conditions

Valley floor should be relatively flat and the stream bed should not be too incized. The site should be surrounded by runoff producing slopes, flood events should not be inconflict with growing periods. The technique is widely used in North Africa and the Middle East - Jordan, libya, Burkina Faso, India, Tunisia.

Permeable Rock Dams.

These are long, low permeable rock dam walls constructed across valleys to spread flood water for farming.

a) Suitability

Permeable rock dams for crop production can be used under the following conditions.

Rainfall - 200 -750 mm/yr
Soils - all agricultural soils
Slopes - best below 2.0% for most effective water treatment
Topography - wide, shallow valley beds.

b) Limitations

- They are site specific. The technique is labour intensive - group approach required.
- Some assistance with transport of the stones is required
- Number of direct beneficiaries is limited
- Site mostly determined by the people

Overall Configuration

The dam is a long, low structure made from loose stones across the valley floor. The central part of the dam is perpendicular to the water course while extensions of the walls to either side follow the contour. The structure spreads the concentrated flow across the valley floor. Excess water filters through the dam or overtops during peak flow. If series of dams are built along the same valley, the dams silt up giving stability to the whole valley.

2.5. Water spreading bunds

These are bunds, usually made of earth which spread diverted flood water over land to be cultivated, thus allowing it to infiltrate. They are usually adapted in situations where trapezoidal bunds cannot withstand the high runoff or where crops to be grown are suseptible to temporary waterlogging. The structures are used to spread diverted flood water or that naturally spreads into the flood plain.

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Technical details

a) Suitability

The technique is used under the following conditions:

Rainfall - 100 -350 mm
Soils - alluivial fans or flood plains with deep fetile soils
Slopes - most suitable for slopes of 1% or less
Topography - even

b) Limitations

The technique is site specific and must be sited close to a Wadi, or another water course - usually on flood plains.

c) Overall configurations:

Two design types are available

1. Straight open ended structures sited across the slope which baffle the flow. Suitable for slopes less than 0.5 percent.
2. Series of graded bunds each with a single up slope wing, which spread the flow gradually down slope. Suitable for slopes greater than 0.5 percent.

Spacing between bunds upto 200m.
Length - max. 150m
Height - min 0.75 cm
Countries practicing this technique : Yemen, Pakistan, Kenya, China.

2.6 Cultivated Reservoirs

Water is stored above the ground level for long period, as long as several months, mostly behind large bunds. The source of water could be streams or long slopes. following emergence of the land or evacuation of the remaining water, the bottom of the reservoir is cultivated. eg. sudan, India, Israel.

Suitable sites

Rocky catchment with sandy soils and level valley plains with heavy and very fertile soils, on which runoff is stored behind an eartheren bund. Height of bund can be as high as topography permits and length is not limited as long as topography permits and runoff is available. Structure could be equipped with slvices and spillways.

3.0 Auxiliary Techniques

A number of techniques are available, which are aimed at improvement of environmental conditions related to water harvesting. They either induce runoff in the catchment or infiltration in the cultivated area. The limitation of these techniques are:

- They are costy
- Make use of non readily available material
- Require high skill to implement
- Not applicable on large scale

Examples of these are:

a) Surface improvements to induce runoff soil conditioners and water repellants artificial surfaces - plastics, asphalt, concrete

b) Surface improvements for increasing infiltration vertical mulching - placing straw or stubble in the top soil.

c) Vetetation management for runoff production.

- Removal of phreatophyetes/riparian vigitation from banks of open water bodies to reduce transpiration
- land clearing to increase runoff
- replacing trees with grass and schrubs

Selection of Water Harvesting Techniques

For any water harvesting scheme to succeed, the following have to be considered

Social Aspects

a) Social and cultural aspects prevailing in the area
b) Peoples set of priorities
c) Availability of alternative sources of water compared with water harvesting in
   - risk involved
   - water quality required
   - implementation, operation and maintenance cost. eg. development of springs or shallow wells vs microscale water harvesting.

3.2 Technical aspects

The basic technical criteria to be considered for selecting a water harvesting technique for a site are:

1. Slope of the land: land with slope exceeding 5 percent should be excluded
   - runoff is unevenly distributed
   - large quantities of earth work required
2. Soils - should be similar to those of irrigation
3. Costs - the labour and material required for the scheme should be available at the site. If not, outside assistance should be sought.

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Water harvesting pilot scheme at Amibara

A case study

1.0 Background

The Eastern Dyke, was constructed to protect the farms in the Middle Awash Agricultural Development Enterprise, from the floods originating in the eastern catchment of the Alidegi Plain, covering an area of 800km^2. The dyke was designed to withstand one in ten year flood estimated to reach a peak of 90 - 95m^3/sec. Following the completion of the construction works the in early 1980's, the dyke was breached by the recurrent floods annually. To address the problem the Drainage Master Plan for Melka Sadi and Amibara Areas, which was concluded in 1984, recommended implementation of an extensive water harvesting scheme over the catchment to reduce the magnitude of the floods.

However, as the proposed scheme constituted a large project by itself, implementing such a large scheme for the mere purpose of flood protection was not found to be justifiable on financial grounds. On the otherhand, it was considered that significant benefits could be gained from the scheme in reducing soil erosion and vegetation regeneration. Accordingly, it was recommended that a pilot scheme of 200 hectares be developed to demonstrate such benefits and determine the most appropriate techniques for the particular conditions prevailing at the site.

2.0 Site selection

A site typical of the area was selected about 500m north of the road that links the Amibara Irrigation Project farms with the main highway.

2.1 Topography

The topographic map of the site which was prepared at a scale of 1:2,500 with 100cm contour intervals has indicated that the land falls at a slope of about two per cent over the scheme ranging from 2.5 per cent at the foot of the escarpment to 1.5 per cent towards the foot of the slope 2.5km away.

Natural drainage lines have formed shallow gullies, up to two meters deep at some places. These gullies are subject to short lived, but very intensive flood flows during the rainy season. The elevations vary from 755 to 770m over the scheme.

2.2 Soils

The soils of the area are shallow, generally coarse textured and highly susceptible to erosion by rain and flood. Erosion was taking place all over the area. Immediately following the rains, friable thin cap, less than 5mm in thickness, forms over much of the area.

2.3 Rainfall

According to meteorological data available in the area, the annual rainfall is 533mm per annum. This includes long rains occurring from July to September (260mm) and the short rains (273mm) from February to April.

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2.4 Vegetation

The vegetation prevailing at the site consists of mainly scattered acacia trees, together with a fairly extensive woody shrub layer dominated by acacia and mesquite (prosopis) Ground cover has been almost completely removed by grazing leaving only a few small perennial herbs. Only some perennial grasses are surviving in the upper part of the area near the escarpment and occasional unpalatable plants could be observed.

2.5 Social Environment

The Afars, who are pastoralists, live in temporary camps near the area and cut the woody vegetation for fuel. Further, the area was heavily grazed by their animals.

3.0 Selection and design of the water harvesting technique

3.1 Original Proposal

The water harvesting technique proposed originally in the drainage master plan was the construction of one meter high contour earth bunds at vertical interval of two meters each having a length of about one kilometer. The topmost bund nearest the escarpment was to be made into a diversion drain with grade to remove external runoff from the pilot area. The total length of the bunds was 7.0 km being 7.0 in number. sheet runoff originating in the strip of land between each bund was envisaged to pond-up against each bund and infiltrate depositing any sediment. The infiltrated runoff was expected to assist in establishing and sustaining vegetation.

To minimize erosion of the down slope of the bunds, they were to be faced with stones. The shallow natural drainage lines were to be plugged by checkdams, but where they developed into deep gullies, the contour bunds were to be interrupted. To strengthen the bunds, it was planned to plant mesquite (prosopis Julifora) on their upper side.

For keeping out the animals and people thus avoiding grazing and collection of fuel wood, a perimeter fence was recommended.

3.2 Revised Design

As part of the original site was required for construction of a school, the site was shifted closer to the link road. Based on the new topographic map, a new layout was prepared using a design criteria of contour bund of one meter high and two meter vertical interval. Based on this design a total of nine bunds with a total length of fifteen kilometers were required.

To cut down cost, further design changes were made. As the inclusion of stone facing in the construction of bunds required about 150-200 working days per kilometer, this proposal was later dropped. Plugging of the gullies with checkdams was also canceled and the gullies were simply filled in with earth.

The proposal to construct stone fencing to provide protection of the scheme from animals and people was also excluded. Further to being expensive, under the circumstances, it was felt that even if it were constructed because of possible theft,

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it would not provide the required protection. Instead live fencing was suggested, but this too was dropped as it was too slow to establish under the low rainfall.

Further recommendations were made to include rotational grazing in the pilot scheme. It was thus proposed to plant three grass species, baffle grass, Bhodes grass and gamba, that could establish under the prevailing climatic conditions. If found successful, they were to accelerate the revegetation process. The area to be planted was a 25 ha block between bunds number eight and nine.

It was also planned to plant mesquite (prosopis) on the upper side of the bunds.

3.3 Cost estimate

The cost of construction of the scheme as designed originally, including six kilometer fencing in accordance with 1984 prices was Birr 435,000. Based on the revised design including fencing (1.0 m) was Birr 50,000. Excluding fencing, the cost was Birr 32,377.60.

3.4 Monitoring Design

As the original objective of the scheme was to reduce flood from the escarpment through encouraging infiltration of the runoff and vegetation regeneration which further reduces the occurrence of the flood, it was intended to monitor the rate of regeneration to evaluate the performance of the scheme. For this purpose, line intercepts were selected and were to be aligned at an angle to the slope. For the 200 ha, a total number of five intercepts each having a length of fifty meters were required. The data to be collected included;

- records of all species present
- basal diameter of ground cover plants
- crown diameter an height of trees and shrubs.

The data were to be collected once in a year, at the end of the short rainy season, in August or mid september.

4.0 Construction of the pilot scheme

The construction of the contour bunds was carried out in September 1991 by using Bulldozers, by pushing materials from the side to form a bund of one meter height. However, as the bunds were too narrow to compact, the effective height after consolidation was only o 60 M. At the end of the bunds, lateral bunds were constructed, thus containing the runoff within the bund boundary.

As planned, about 10,000 prosopis seedlings were stablished on the upper slopes of the bunds in 1992 main rainy season.

Owing to lack of fencing protection, the grass seeds were not planted until July 1992. A total of 65 kg of seeds of baffle grass, rhodes grass and gamba grass were planted over a total of five hectares. Two additional types, vetiver grass and napier grass were planted on 100 M of bund.

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5.0 Flood Damage

A few months after completion of the construction of the bunds, on 4th February 1992, between 85 and 100 mm of rain fell in about two hours. As a result, the diversion channel and all contour bunds breached in a number of places, particularly where they crossed the natural drainage channels. The lateral bunds, which were constructed to hold the runoff did not allow the flood to escape. The damage was not limited to the bunds, the eastern dyke which was constructed more than ten years earlier also breached at several places.

The total length of the damaged sections of the bunds was 2.6 kms. Repair required 7940 m^3 of earth works at a cost of Birr 10,800.

As a consequence of the flood damage and potential similar occurrences as well as absence of fencing protection, it was decided to concentrate monitoring works on a smaller less vulnerable area. The area traversed by a number of gullies which is located adjacent to the link road was excluded thus reducing the area to 80 ha, one third of the original area. In the reduced area, plugging of the major gullies by checkdam was carried-out.

6.0 Monitoring

Owing to the absence of protection fence, animals continued to cross the bunds, and cause wearing and lowering of the tops at crossing points.

Following the reduction of the area to be monitored, the number of line intercepts were reduced to three and were aligned as follows.

a) at an angle of about 90° to the prevailing slope.

b) along and just above contour bund line.

c) just below the same contour line.

The location of the line intercepts are shown on topographic map attached herewith. Using the above intercepts, monitoring of the regrowth of vegetation was carried out in November, 1993 and the results are shown in Table, attached herewith. Based on the records, the following observations were made for the two years that elapsed since construction of the bunds.

- the rate of regeneration of the plants without adequate protection was encouraging.
- regeneration of prosopis and thorn brush was rapid.
- Regeneration of grass was slow.

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Owing to shortage of staff the monitoring works planned for 1994 were not carried out. It is planned to reinforce the monitoring by collecting additional data.

- Variation in number and sizes of plant growth with regard to position to study topographic effects.

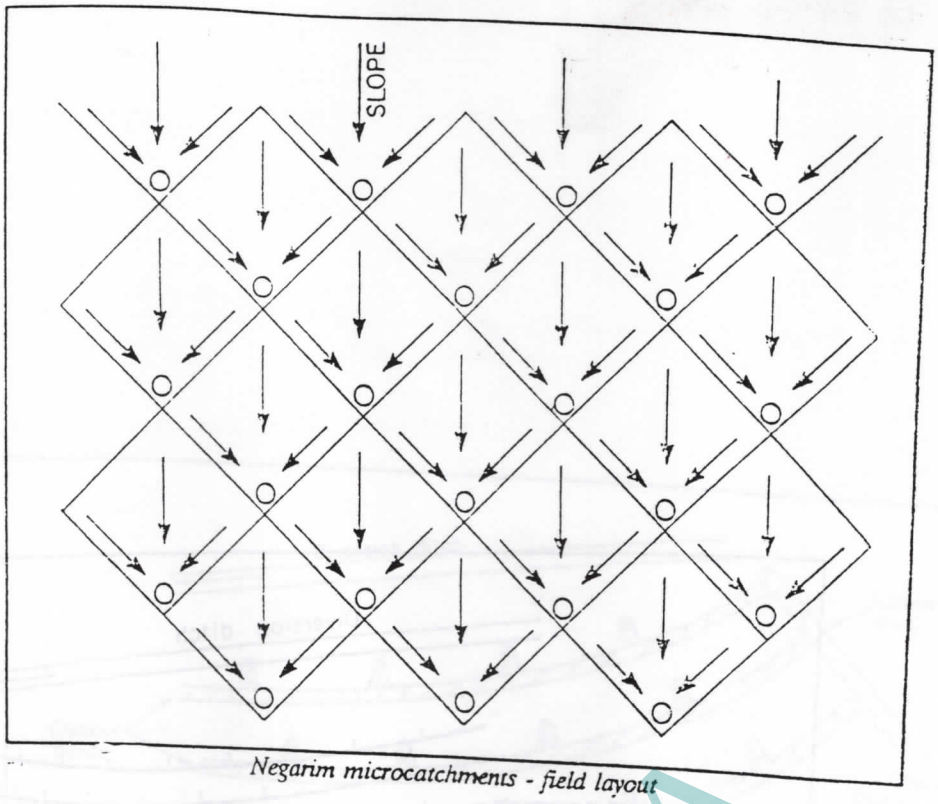
- Conditions immediately up and down slope of the contour bunds.

- Differences along and between bunds.

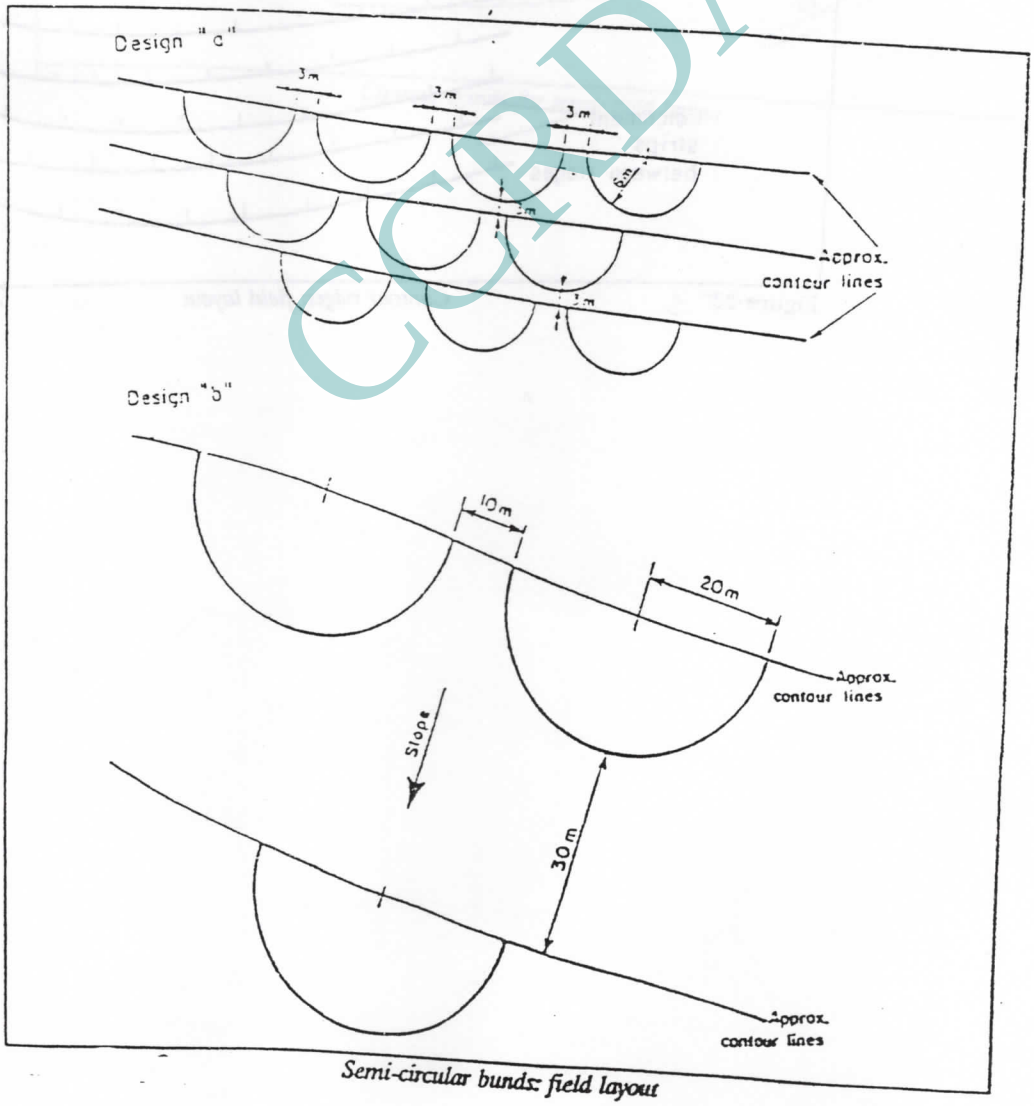
- Differences at the top, middle and bottom of the scheme.

- Prosopic establishment should be observed further.

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Negarim microcatchments - field layout



Semi-circular bunds: field layout

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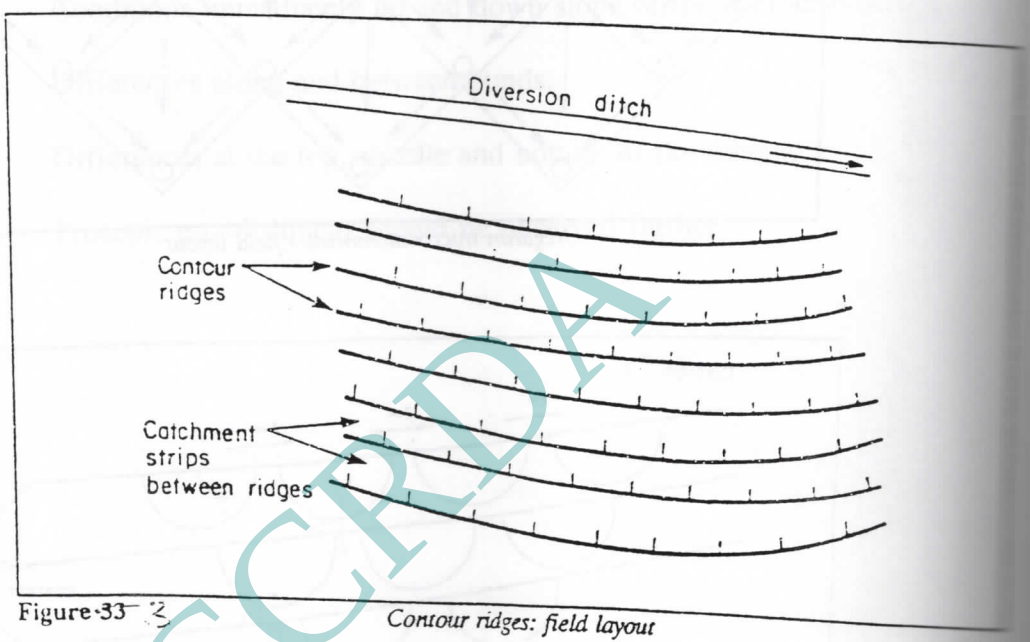
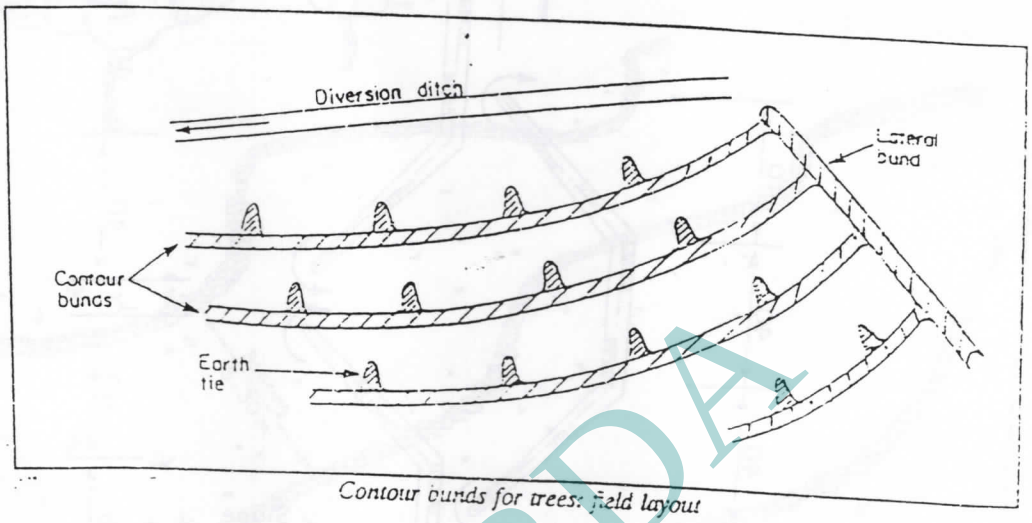


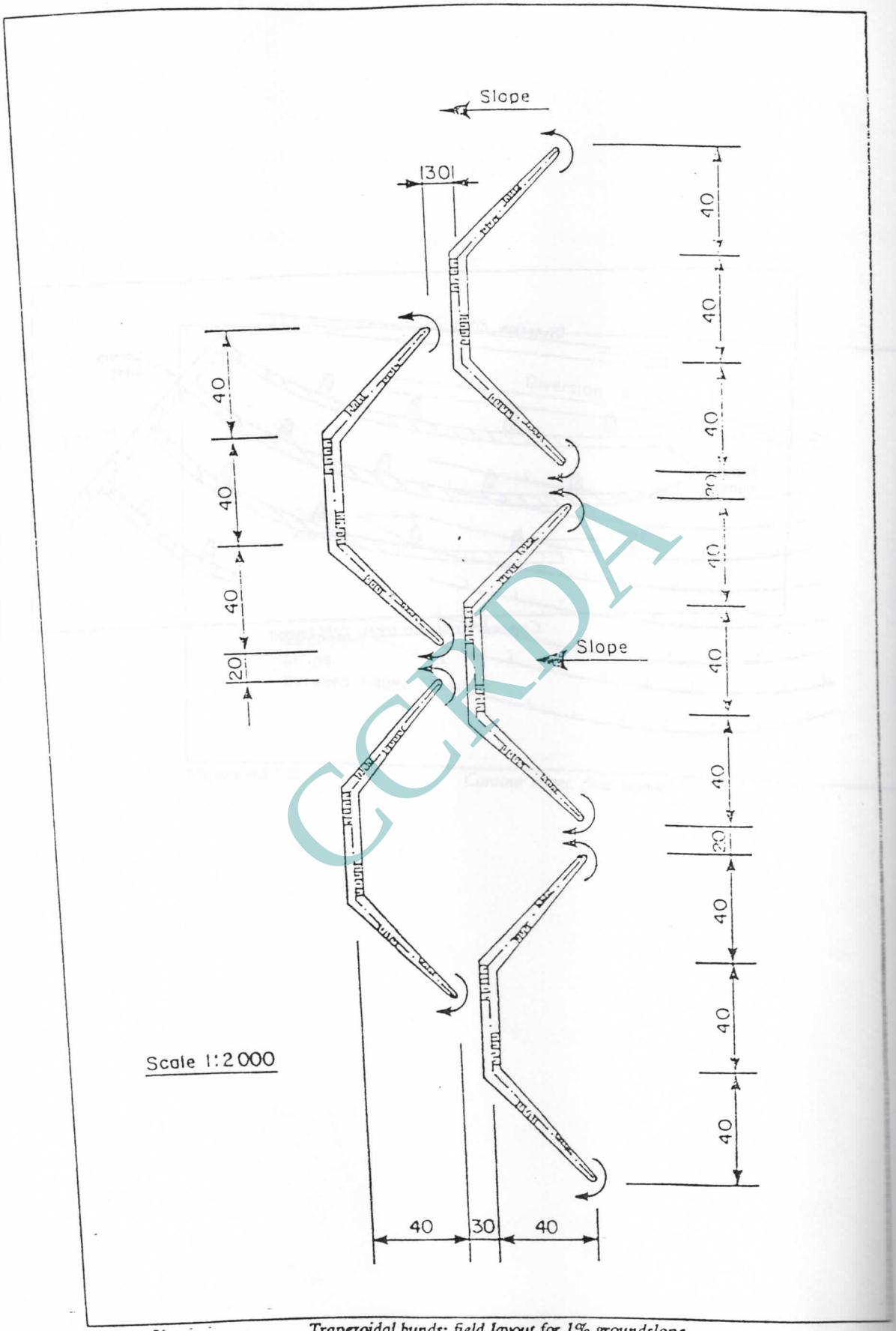
Figure 33 Contour ridges: field layout

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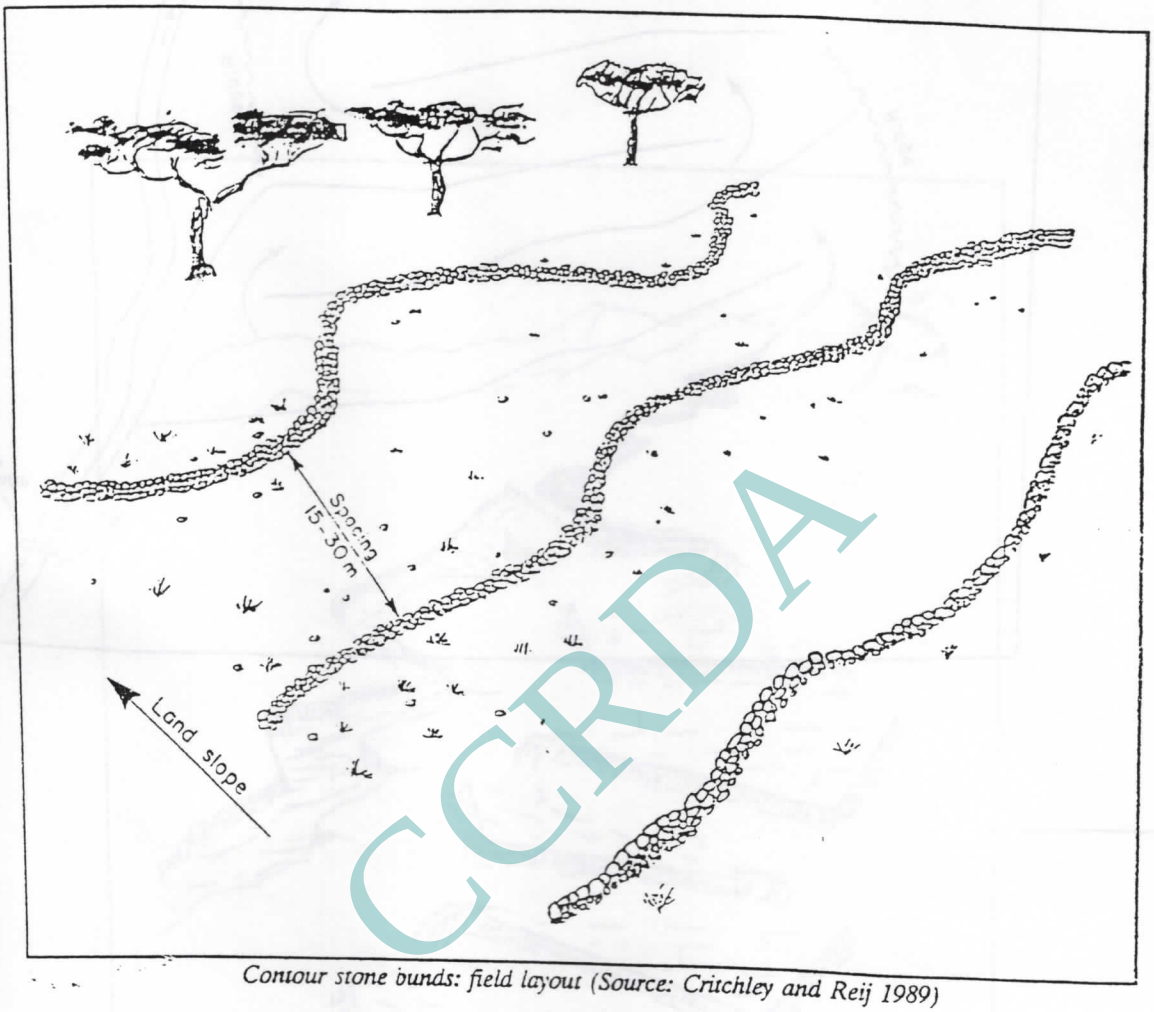
Contour bunds for trees: field layout

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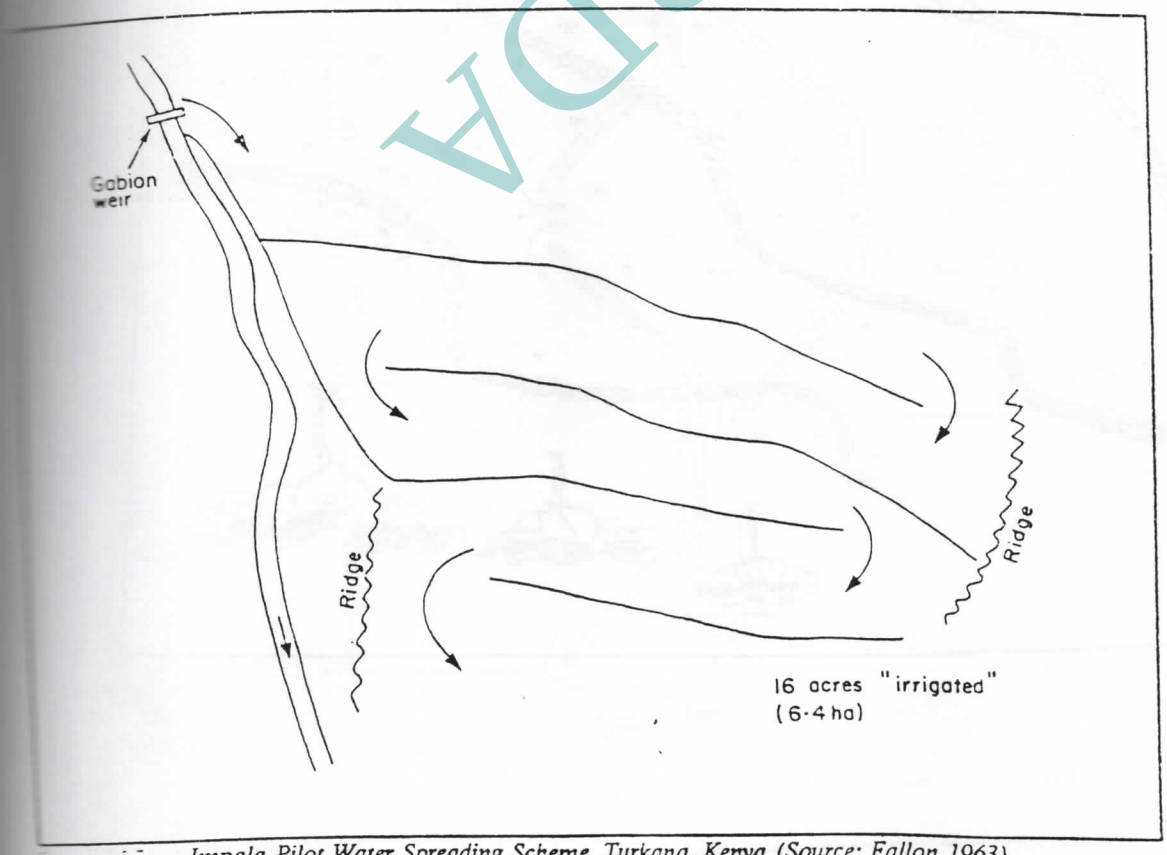
Trapezoidal bunds: field layout for 1% groundslope

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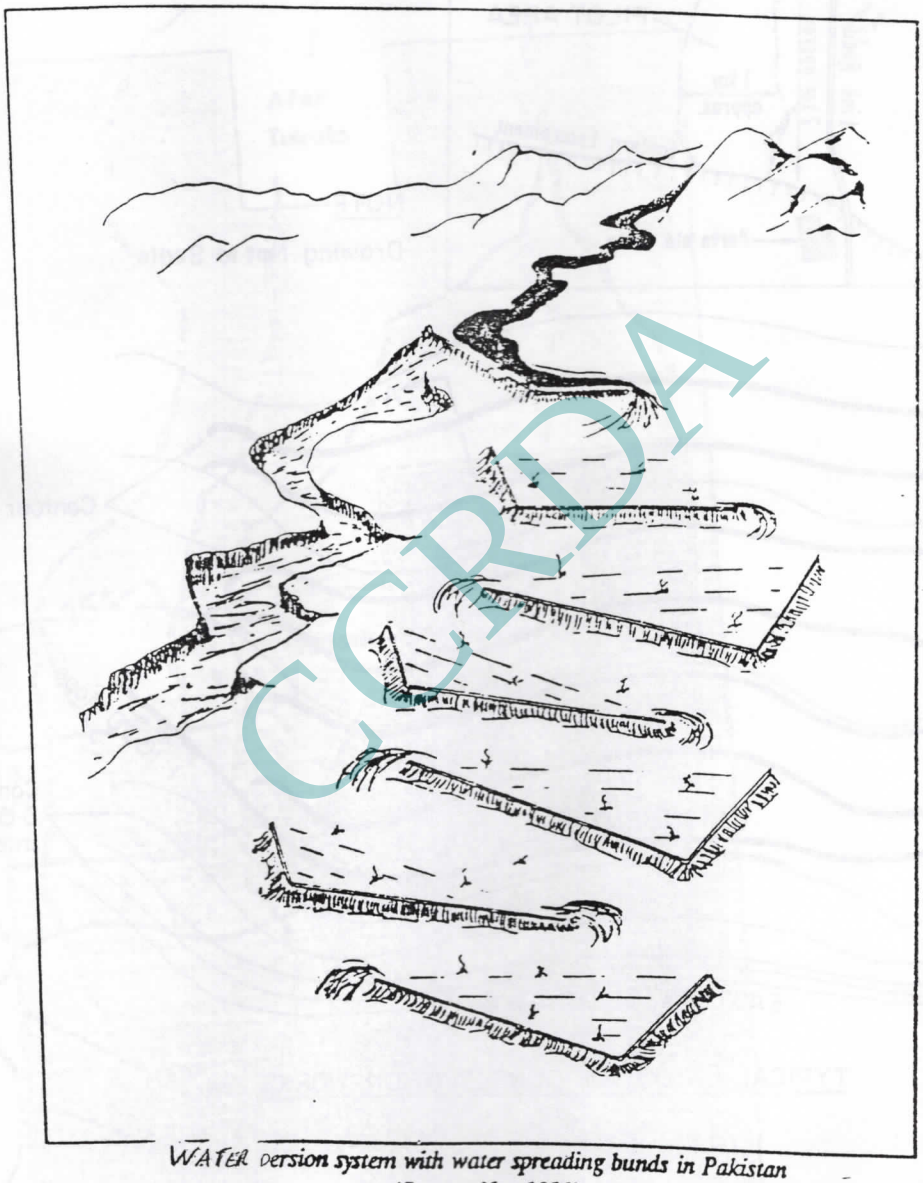
Contour stone bunds: field layout (Source: Critchley and Reij 1989)

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Impala Pilot Water Spreading Scheme, Turkana, Kenya (Source: Fallon 1963)

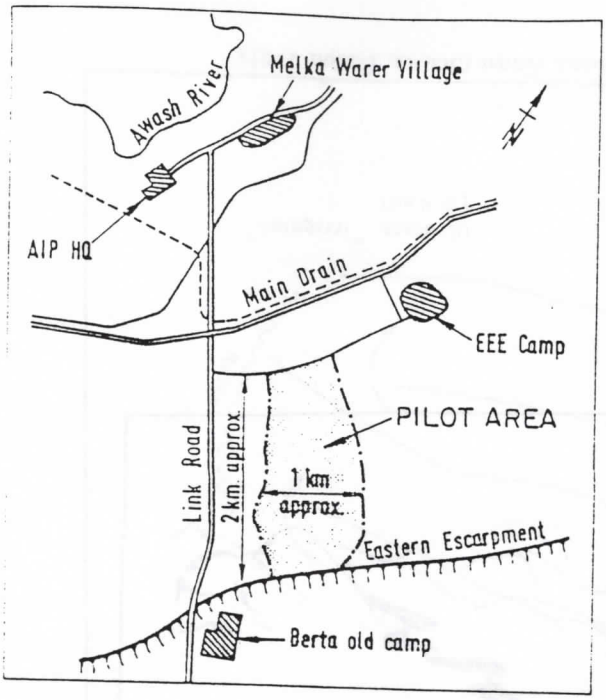
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WATER version system with water spreading bunds in Pakistan
(Source: Nas 1980)

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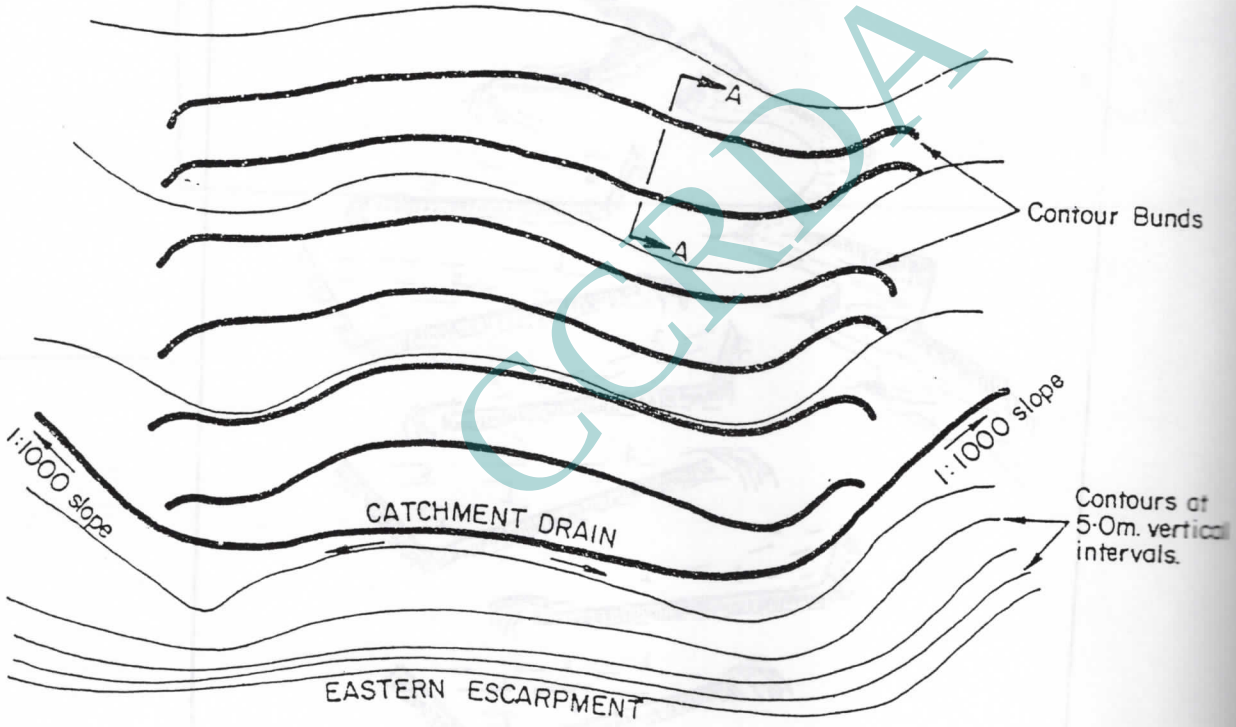
PROPOSED CONSERVATION WORKS FOR WATER HARVESTING PILOT AREA



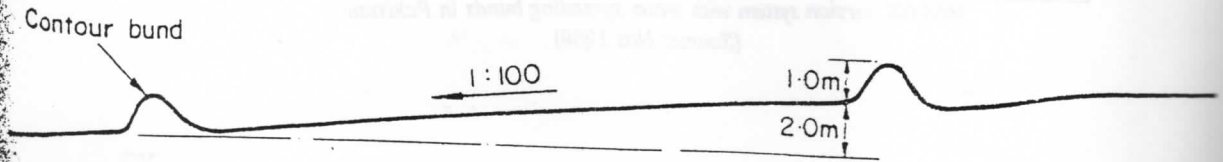
LOCATION MAP

NOTE

Drawing Not to Scale.



TYPICAL LAYOUT OF CONSERVATION WORKS



SECTION A - A

SIR WILLIAM HALCROW & PARTNERS

JULY

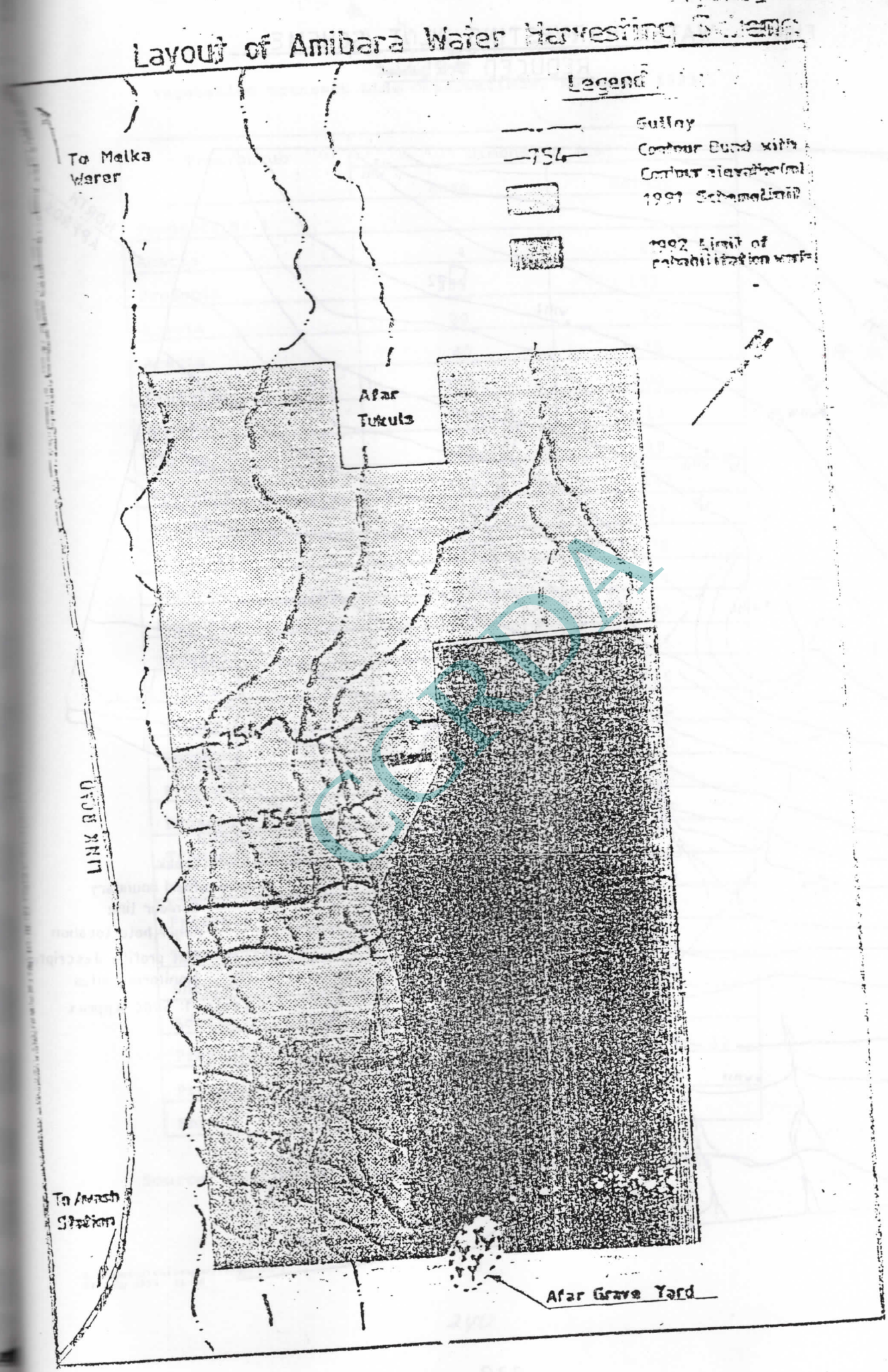
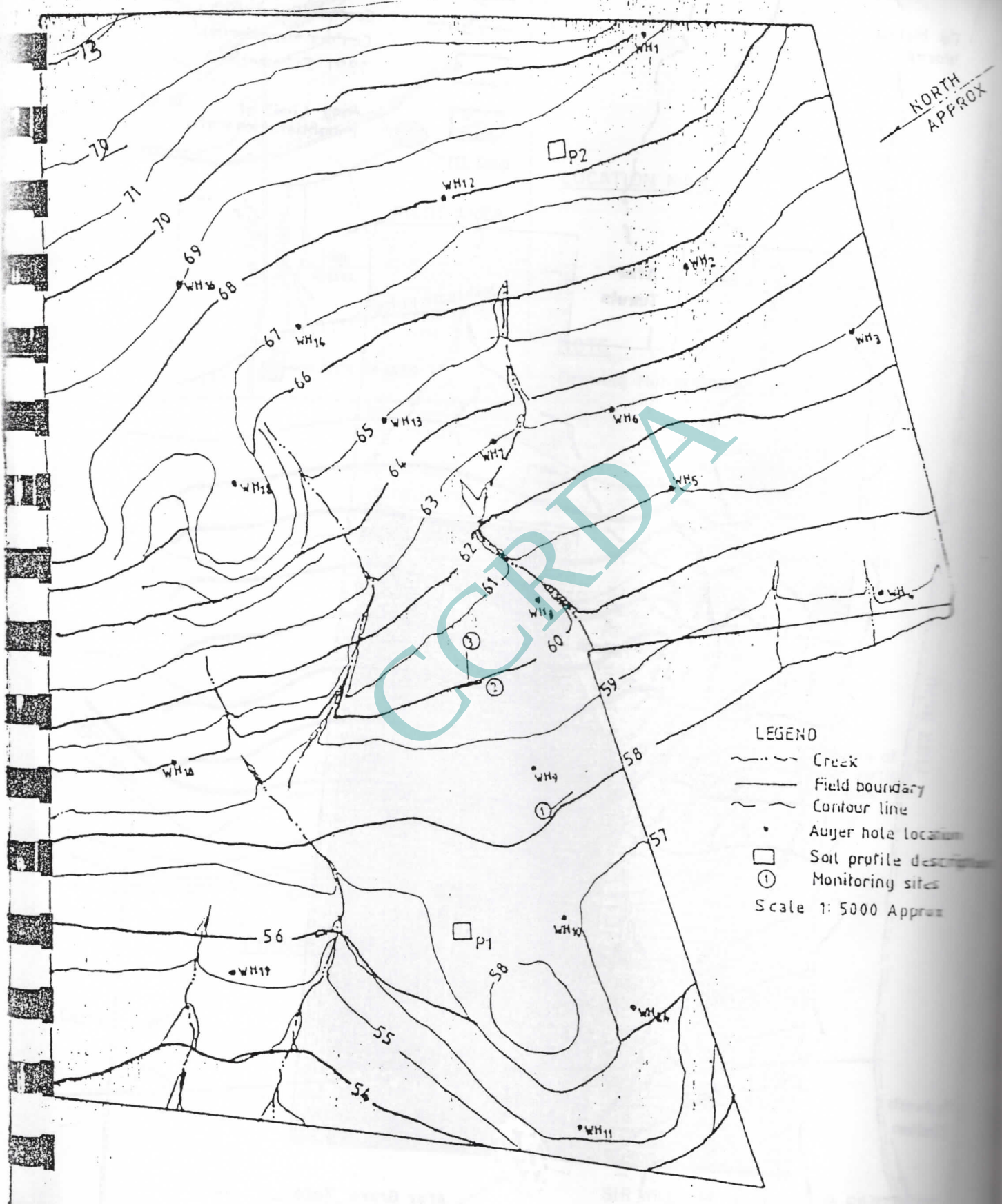

Layout of Amibara Water Harvesting Scheme
Legend
Gulley
Contour Bund with
Contour elevation(m)
1991 Scheme Limit
1992 Limit of
To Melka
Werer
Afar
Tukuls
754
754
754
LINK ROAD
To Awash
Station
Afar Grave Yard

Figure _ WATER HARVESTING PILOT SCHEME
REDUCED AREA



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~~Table 3.2~~ 4.

Vegetation Transect Line Observations, November 1993

Tree/shrub	Dimension (cm)	
	Base	Height
Transect Nr 1		
Acacia	4	61
Prosopis	265	102
Acacia	20	30
Acacia	40	15
Prosopis	200	100
Shrubs	19	13
Shrubs	29	10
Prosopis	352	100
Shrubs	45	27
Prosopis	91	70
Shrubs	16	20
Prosopis	234	70
Prosopis	229	75
Shrubs	22	15
Shrubs	30	30
Prosopis	109	40
Prosopis	241	150
Prosopis	160	65
Transect Nr 2		
Prosopis	147	75
Prosopis	360	125
Transect Nr 3		
Shrubs	320	2
Acacia	25	5
Prosopis	360	2
Prosopis	180	50
Shrubs	34	50

Source: ADPI Water Harvesting Scheme Status Report, 1994

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1. Background

According to many literatures, some of the failure stories of technological diffusion are mainly attributed due to the emphasise on 'technocratic fix', Community were consider as homogenous with similar problems, needs and interst.Consquently introduced similar and standardised technologies across the community. The approach was top down which margenalized land users participation and recognition of indigenous knowledge and practices. The socio-cultural parameters are often less considered or completely ignored.

Today the Arid and semi-arid regions of Ethiopia are facing more difficult problems than ever before, population and livestock pressure, famine and drought, land degradation and soil erosion due to water and wind are some to be mentioned. Nevertheless such areas have also a potential to be exploited with appropriate technology and popular participation of the land users. Where the consideration of the prevailing soco- cultural environment has a great bearing for sustainable land use management.

2. An over view of socio-cultural information

Generally to develop an efficient, effective and sustainable water harvesting technology a wide range of socio-cultural information is needed. Some of the socio-cultural questions in evaluating a water harvesting technology could be its fitness to existing practice, farmers understanding, local land tenure system, local institutional frame work and costs with regarded to the importance of the problem, land users capability and benefits (short and long term).

Therefore some of the information needed are mentioned as follow and the methodology for obtaining the required information could be Participatory Rural Appraisal (PRA)

- access to resource (land holding size, fragmentation, livestock holding etc.)
- community classification (economic or other criteria)
- demographic situation (large family size as a status and gift of God, migration)
- labour requirement and availability
- local institutions (mutual cooperation)
- survival strategy and decision making process (distinction between people within the house hold)

CCRDA

- problems , needs, interest and priorities (seasonal calendar see also fig)
- indigenous technologies practiced

Local level Strategy: resource --- ownership --- problem solutions (local/external)

Generally some of the major silent features the small land holders are :

- subsistence farming
- risk avoidence than profit maximization
- large family size
- small land holding and fragment
- shortage of cash for investment in agriculture
- use indigenous techniques for multi purpose

3. Facts on Socio-cultural conditions

3.1 Northern Shoa (around Gude-Beret)

A. Major features of the community

- the family size per h.hold varies from 3 to 14
- the land holding size ranges between 0.25 to 6 ha.
- the fragmented plots range from 2 to 11 plots
- Barley is a stable food and cash crop. The community grow different species of barley as locally known as Enat Mawege, Gedeme Mawge, Nech Ferke, Tikure Ferke Keye Ferke etc Each species are grown for different purpose. Some are long growing period others are short growing, some are soil specific others are not, some are for better yield others are for drought resistance, some are for food some are for cash.

B. *local institutions and linkages*

- economic ranking (A:rich, B:medium and C:poor)
- local institutions and linkages (see fig. below)

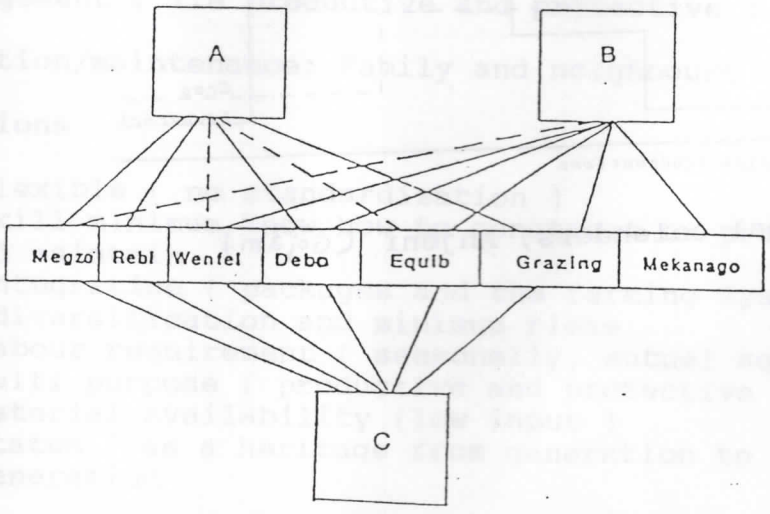


Fig. . Relationship among the farmers.