When expected monthly volumes of water have been estimated in this way, the figures are plotted on a diagram such as Figure 3.2. In this diagram, each calculated monthly total is added to the total for previous months so as to represent, by an approximate, stepped form of graph, the way in which water levels in a cistern would rise through the year if none were drawn off and used. In Figure 3.2, the dry season is from May to September. Very little water enters the tank then, so the line on the diagram remains almost horizontal.

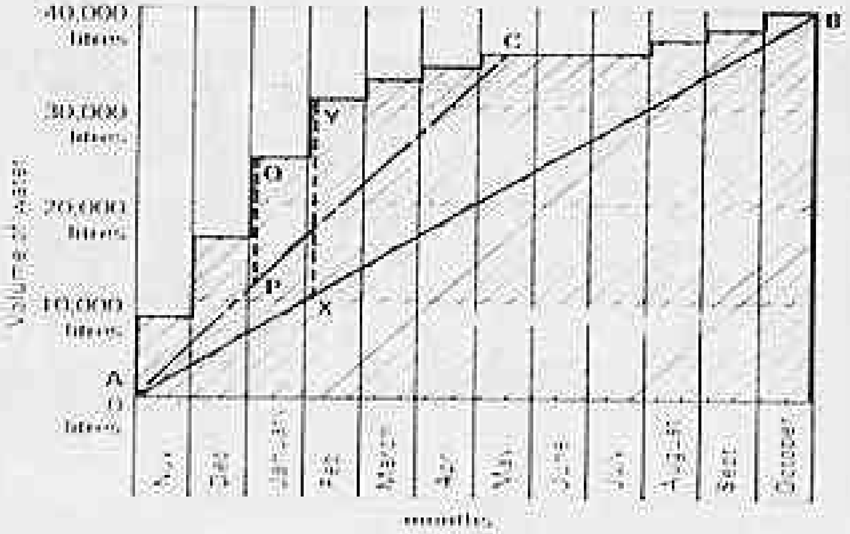

Fig. 3.2 Diagram representing volumes of water collected from a roof (stepped line), and the consumption of water by users of a rainwater tank filled from that roof (sloping lines **AB** *or* **AC***). Each step in the line represents the volume collected and indicates the contribution made by one month's rainfall. The diagram is drawn so that the left hand side corresponds to the month in which the tank is most likely to be empty. The steps thus represent the gradual filling of the tank during the rainy season.*

When plotting graphs of this kind, it is important to start at the left hand side with the beginning of the rainy season, when the tank is assumed to be empty, so that the way in which the water level rises during the rains is clearly illustrated. In Figure 3.2 the graph begins in November, which is the first month of really heavy rainfall.

Usually it is assumed that people will take the same amount of water from the tank each day throughout the year. This is unrealistic, because consumption varies greatly with the seasons, and according to whether water from other sources is being used. However, by assuming a constant rate of consumption, we get a simple indication of the system's capability

Again referring to Figure 3.2, the total amount of water running off the roof in a year of average rainfall is recorded as about 40,000 litres. So theoretically, if their cistern is of adequate size, the owners of the roof could ration themselves so as to use all this water in 365 daily withdrawals of 112 litres each. This steady rate of use is represented by the straight upward sloping line AB. At point B, where this line meets the stepped line representing rain water entering the system, the tank has been emptied, though it should be filled again almost immediately with the onset of the new rainy season. However, at point X, where the two lines are furthest apart, the tank is fuller than at any other time. The distance separating the two lines, XY, then represents a volume of 20,000 litres, which is thus an estimate of the capacity the tank should have — 20 m³ — if it is to provide the 112 litre daily ration.

Although it is unlikely that any household would draw exactly the same ration from the tank on every day of the year, it is possible to think of this as one method of using a rainwater tank. It might be called the 'rationing method'. By contrast, Parker (1973), working in Ghana, regarded it as more realistic to think of people using their tanks according to a 'rapid depletion method'. This envisaged that members of the household take all the water they require from the rainwater tank for as long as it contains any, and then turn to an alternative source. They will especially tend to do this if the alternative source is a long way from the house, or if they are working hard in the fields during the season when the tank is full, because the tank is so much more convenient.

In Figure 3.2, the steep line AC represents use of the tank by the 'rapid depletion' method, with point C indicating the date when the tank is empty. This is in May, and the maximum amount of water stored, represented by line PQ, is about 15,000 litres. So a tank of this latter size — 15 m³ — would meet the rate of consumption shown as AC for about six months of the year: November to May.

This illustrates the paradoxical choice which often has to be made between a *large* tank capable of meeting a rationed rate of consumption over a whole year, or a *small* tank capable of providing for greater consumption on a rapid depletion basis. For most households, the latter will be the more realistic option.

Hafirs and excavated cisterns on arid grazing lands will have to meet a very different pattern of demand. During the brief rainy season, when animals can drink at natural water holes, there may be no withdrawals of water from a cistern or small hafir, only losses due to evaporation and perhaps leakage (Fig. 3.1, line AB). Then, when the water holes have dried up, herds will be moved so that they can graze within each reach of the hafir, and will be watered there regularly — perhaps daily, or perhaps on alternate days. Withdrawals will be very heavy — cattle drink between 20 and 30 litres per day depending on their breed and size, and varying with

The amount of runoff actually obtained from the catchment was estimated by the method described in Box 3.2, and was found to be 30 per cent of the rainfall, that is:

$$\frac{30}{100} \times 218\text{mm in an average year.}$$

If the area of the catchment is A, the actual volume of water running off it is then:

$$\frac{30}{100} \times 218 \times A \text{ litres,}$$

which must provide the requirement of 400 × H litres previously specified. Equating these two quantities, we can then calculate the necessary ratio of catchment area to cultivated area, A:H.

$$\text{Thus } A:H = \frac{400}{218} \times \frac{100}{30} = 6.1:1$$

Despite the allowances made in this calculation for drier seasons than average, a greater margin of safety is actually sought in this part of Kenya, and the ratio of catchment to cultivated area normally used is about 10:1.

By contrast, when rainwater is to be collected from house roofs, much more approximate data is usually sufficient. The main question hydrologists need to ask is 'how big should the sto[illegible] be?' This breaks down into three subsidiary problems:

1. matching the capacity of the tank to the area of the roof;
2. matching the capacity of the tank to the quantities of water required by its users;
3. choosing a tank size that is appropriate in terms of costs, resources and construction methods.

Some researchers have devoted considerable attention to calculating answers for the first two questions, using computers to process long runs of rainfall records where these are available (see Fujimura 1982), or even to simulate data where records are missing. This may be appropriate in some richer countries where the usual approach is to start with the second question above, specifying a desirable level of consumption and then designing catchment areas and storage tanks so that this can be provided. By contrast, in poorer countries much greater weight has to be placed on cost, and hence on the third question. It also makes sense to take account of what resources are available — roofs as they already exist, local materials, and labour. One can then work out a plan for expending these resources in a way that comes as close as possible to a target for water

consumption (Keller 1982). In practice, costs and construction methods tend to limit tanks to smaller capacities than would otherwise be justified by roof areas or likely needs of consumers.

For this reason, elaborate calculations aimed at matching tank capacity to roof area and consumption are usually unnecessary. However, a simplified calculation of this form can give a rough idea of the potential for rainwater collection in a particular region. The starting point is data for average monthly rainfall, expressed in millimetres, and measurements of the roof from which rain is to be collected — its length and *horizontal* width. The volume of water (in litres) likely to be collected each month is then found by multiplying the average monthly rainfall by the horizontal area covered by the roof (in square metres), and then multiplying by 0.8.

The latter figure is the runoff coefficient, and allows for the fact that some rainfall will be lost from the roof by evaporation and in other ways. While 0.8 is typical for a hard roof, the number to adopt here would be better chosen in the light of the roofing material actually used, for which some rough figures are given in Table 3.1.

Table 3.1 Runoff coefficients. (Hofkes, 1981; UNEP, 1983; Fraser, 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 per cent	0.0	0.3*
rocky natural catchments	0.2	0.5

*Figures for specific sites should be determined by measuring runoff [illegible] ambient temperatures, but camels, goats and sheep require much less (usually less than litres). As water levels in the cistern or hafir get low, the herdsmen will find out which other water points in the region can still provide for their livestock, and will then move on. Figure 3.3 illustrates a location with a short July–August rainy season, and indicates schematically the likely consumption of 200 cattle for a 6 week period in the dry season. Once again, the stepped line shows inflows to the cistern, and the straight lines ABC show consumption. The cistern is empty at point C, and the maximum storage required is indicated by PX.

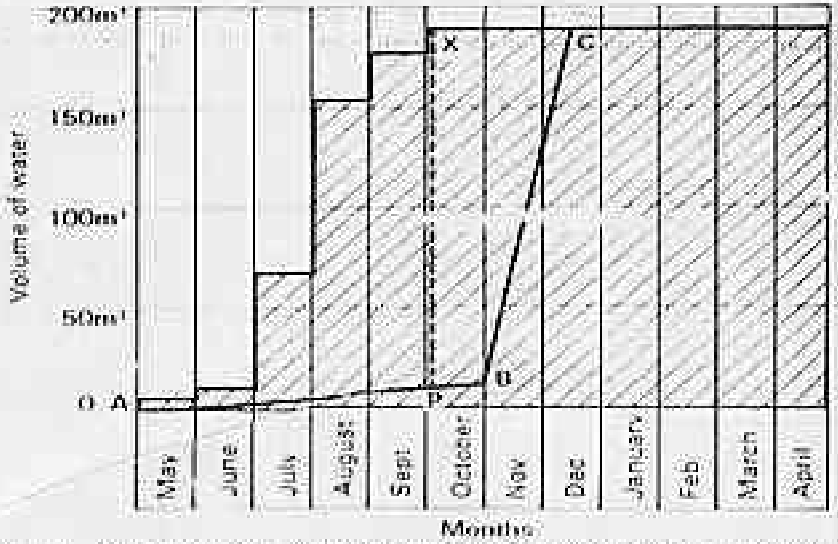

Fig. 3.3 Volumes of water flowing into, and being consumed from an unroofed or very small hafir in an arid pastoral region. The rains come mainly in July and August. The cistern is used to provide drinking water for livestock which graze in the area during November and early December. The cistern is empty during mid December until early May.

AB represents loss of water by evaporation while the cistern is not being used.
BC is the consumption of 200 cattle during 6 weeks (at the rate of 30 litres/head/day approximately).
PX is the storage capacity required to meet this demand, which in this case is very slightly more than the volume of water consumed by the animals.

In designing a cistern or hafir for use in these circumstances, the starting point should probably be an examination of how much grazing local grasslands and forage shrubs can withstand. Cattle will graze within a day's walk of the water point. If it is thought that the area defined by this can only safely feed 200 cattle for six weeks, care should be taken to limit the capacity PX to their likely requirements, so that lack of water forces the herd to move on in due time, and allows the vegetation to recover.

TANK CAPACITIES IN PRACTICE

Reverting to the question of how large *household* water tanks should be, we have seen that it is unrealistic to assume that people will ration themselves precisely when using rainwater. However, lessons can still be learned by gathering together some of the varied recommendations for tank sizes which have been based on the idea of rationing. Thus in Table 3.2, the data given by a number of authors have been recalculated to provide information in a standard format relevant to roofs of relatively small houses, 30m² in extent. Where the original authors emphasize figures for much larger roofs, these are also included.

Not all the figures in this table are comparable. Differing methods of calculation (or estimation) have been used, and differing assumptions about runoff coefficients. More fundamentally, divergent views about how reliable rainwater systems should be are incorporated in the figures. Several authors specify conditions under which the system will operate with 95 per cent reliability — that is, with the tank containing water and sustaining the daily ration for 95 per cent of the time, but with supply failures during drought leaving the tank empty for 5 per cent of the time. As the figures for Botswana and Java show, recommendations may be greatly modified if altered requirements regarding reliability are fed into the calculation.

A surprising feature of Table 3.2 is that despite the large variations which might be expected to arise from different assumptions of this sort, recommendations for tank capacities mostly lie in a rather small range between 3m³ and 8m³. This is particularly remarkable in view of the wide range of climatic conditions represented. However, information from Java indicates that, in high-rainfall regions, authors may be suggesting smaller tanks than are feasible because they assume that households will restrict themselves to a rather limited daily ration. So even if local rainfall could provide a larger ration — say 60 litres per day in Java — tank capacities are specified for half this, presumably because that is consistent with a tank capacity which people can afford. Only for the two most prosperous countries represented, Australia and Bermuda, are significantly larger tanks recommended with a view to maximizing the daily ration.

This may seem to confirm the unreality of sophisticated hydrological calculations. Not only is the idea of a strict daily ration at variance with normal human behaviour, but many calculations are not entirely objective — they incorporate assumptions about how big the daily ration should be based on economic criteria. Observations of how much water people use for drinking and cooking can, of course, provide a rough guide, and a ration of 5 litres per person daily seems to accord with conditions in Indonesia (Geerkoorden 1982). With typical families of between four and six individuals, it is thus tempting to design for 30 litres per household