1 NEED FOR HYDROLOGICAL INFORMATION

Although hydrology as a science includes all aspects of the water cycle, it is generally applied in the development of water resources or flood control. The design of a water resources project, or the assessment of the water resources of an extended area, requires a network of hydrological records that is both reliable in quality and reasonably long in duration. In this chapter the types of hydrological data needed for different types of surface water resources project are discussed. In general terms measurements should be adequate to estimate the different components of the water balance in the project area, including both long-term averages and variations over time.

THE WATER BALANCE

One of the main scientific bases of hydrology is the knowledge that the inflows to any area over any period of time must equal the outflows plus the change in water storage. In general terms the precipitation, in the form of rainfall or snowfall, must equal evaporation and river or groundwater outflow, plus changes in soil moisture, groundwater and channel storage. Thus measurements of all the components of the balance can provide a check on the accuracy of the estimates, or alternatively one of the components of the balance can be deduced by comparison of measurements of the other components.

Thus the volume of river flow available for water resource development may be estimated from the other components of the water balance, or may be measured directly and the precision of the estimate confirmed by comparison. The use of the water balance is perhaps the most powerful tool available to the hydrologist. It may be expressed by the equation:

$$R + I = E + Q + \delta S + \delta G$$

where R is rainfall, I inflow, E evaporation, Q outflow, and δS and δG changes in soil moisture and groundwater storage, respectively. It may be applied to a whole basin, or part of a basin, and may be adapted to describe the water balance of a subcomponent of the system, for instance a groundwater system.

TYPE OF WATER RESOURCES PROJECT

The need for hydrological records to assess the potential of a project or of an area depends partly on the type and scale of the likely exploitation of the water resource. A water resources project may include water supply for domestic, industrial or environmental use, for irrigation, hydroelectric power production, or flood control; each will require long-term river flow records to estimate water availability and for the hydraulic design of works.

Some types of project can be predicted further in advance and therefore have flow stations installed in good time to provide adequate data for analysis. For example, domestic water supply demands can be forecast reasonably accurately from population statistics and historic or theoretical estimates of water use; the sources which are likely to provide the required supply can therefore be monitored for a reasonable period in advance of the need for detailed design.

Water supply and river flows

In terms of the three main variables in surface water studies, which are rainfall, evaporation and river flow, river flows are the most directly applicable to project evaluation. Flow records are important for almost all forms of water supply; however, different types of water resources project have varying scales of consumption, and therefore different priorities in terms of flow series. Domestic water requirements are likely to be relatively small, and may in some cases be met by direct abstraction from a river source without the need for reservoir storage. In this case the hydrological requirement in terms of quantity may be simply an estimate of the magnitude of low flows of a given frequency at the abstraction site. The demand is likely to have been foreseen, so that analysis may be limited to an examination of a series of low flow records. The abstraction, which can be withdrawn from the river with a given reliability, can then be compared directly with the water demand characteristics required. The location and scale of water supply demand may be more difficult to predict well in advance in developing countries. This is especially true when industrial demand is a major component. The development of a new industry is likely to result in a larger change in water demand than the growth of domestic supply and may require reservoir storage near the demand site. The locations of potential industrial demand are less easy to predict, especially in the case of mining developments which depend on the results of geological exploration; thus the availability of nearby river flow records cannot be assumed. In the case of northeast Botswana in 1968, the development of important mining potential in the newly independent country depended on the potential infrastructure and particularly on the availability of a significant volume of water supply. The only information on which the urgent choice of location of a major reservoir scheme could be based was the short record of three gauging weirs on ephemeral rivers, supported by rainfall records from which an isohyetal map could be derived. Although the site chosen for the reservoir turned out later to provide a key element in the water resources development of the country, and thus demonstrated that the sites for the gauging weirs had been well chosen, the lack of a more comprehensive network could have proved an obstacle to the economic development of the country.

Irrigation demand

The demands of water for crop irrigation, especially in arid or semiarid countries where irrigation is essential for agriculture, are likely to be of a magnitude to require reservoir storage, especially as demands are liable to increase during the dry season when river flows are low. The estimation of reservoir yields through operational modelling requires relatively long-term flow records and the estimation of annual flow volumes and their variability becomes important. This requires the maintenance of a river gauge network measuring the full range of flows over a period sufficient to sample possible variations. The volumes of water consumed in irrigation are relatively large and therefore the relations between reservoir volume and yield are crucial, though it may be reasonable to accept a higher risk of shortage than for domestic or industrial supply as planting programmes tend to be more flexible and may be adjusted in periods of drought.

Hydroelectric power

An important use of river flows in many areas is the production of hydroelectric power. The need to maintain power supplies and operating head during periods of drought usually requires the use of reservoir storage. Even in the exceptionally favourable case of the Owen Falls dam at the Nile outlet of Lake Victoria, the firm power could be increased by an element of upstream storage. One advantage of hydroelectric power is that the consumptive use of water is limited to the evaporation from the storage reservoir, and this may often be offset by rainfall on the reservoir. The study of hydroelectric potential requires an extensive network of river gauges which is adequate to estimate flows at sites which would be difficult to predict without an initial survey of potential dam sites on suitable rivers.

At the time of a countrywide investigation of the hydroelectric potential of Guinea, a network of river flow gauges had been maintained over periods of 30 years or more. A regional analysis of river flows, supported by water balance studies, enabled reasonable estimates of the potential yield of a number of sites to be made. When a similar regional study of Botswana was carried out, it was possible to estimate the storage potential of a number of dam sites selected from air photography, but only preliminary estimates of the flow potential could be made without flow records. It was necessary to recommend that flow measurements should be initiated at likely sites in order that estimates could be based on actual records in the future.

Sudan example

The water demands for these broad categories of use may be illustrated by estimates of the volumes of water required for town supply, hydroelectric power and crop irrigation in the Sudan, where the semiarid climate increases the dominance of irrigation use (Sutcliffe & Lazenby, 1990). The water supply for the major city complex of Khartoum, whose population is about two million, may be estimated on a conservative scale of 100 l day^{-1} per person, as about 70 $m^3 \times 10^6$ $year^{-1}$. Although most of the country's public electricity demand is met by hydroelectric power from three dams—Roseires, Sennar and Khashm el Girba—with a total reservoir area of 700 km^2, the net evaporation loss of some 500 $m^3 \times 10^6$ $year^{-1}$ can be largely attributed to irrigation, which dominates the role of the dams. The water requirement for the principal irrigation schemes of 1.6×10^6 ha is estimated as 14 000 $m^3 \times 10^6$ $year^{-1}$, though the theoretical potential demand, if the water were available for further development, is much higher.

It is evident from this example that irrigation is by far the largest user of water in the Sudan, at 200 times the urban water supply. Indeed the potential irrigation demand exceeds the available water resources in many semiarid countries. Hence the need in many countries is for sufficient river flow records to estimate the available resources of the whole country or a region, without losing the long-term records at key sites to assess the potential of individual projects.

NEED FOR CONSISTENT RECORDS

It is therefore unfortunate that recent studies have confirmed that in a large number of countries, in Africa for instance, the number of maintained river flow gauging stations has been falling in recent years, as the funds required for the fieldwork necessary to maintain the accuracy of records have not been available. This is particularly important in view of the likelihood that climate change will be most evident in its effect on river flows; the effect of changes in rainfall or in temperature and thus evaporation will be magnified in their effect on river flows because of the sensitivity of the runoff process. It is not easy to estimate the precise value of the length of flow records in the optimal design of water resources projects, but an example from Botswana is given in Chapter 8 of the way in which the precision of flow estimates improves as the record length increases.

For the hydraulic design of most water resource projects, and indeed of all engineering projects within the river flood plain, estimates of peak river flows of different frequencies are needed. These may be derived by direct statistical analysis of flow records at the site or over the surrounding region. Other techniques of estimation of flood potential include combined analysis of rainfall and basin rainfall/runoff potential. All these require adequate networks of flow records, calibrated to give reasonable estimates of high flows. Long historical records (e.g. Herschy, 2003) are particularly valuable in studies of flood frequencies, and significant floods have been recorded in a number of countries where high floods have been observed over long periods. In China, for example, reliance is placed on historical records for flood design. Details of floods on the Chiang Jiang (Yangtze) have been preserved over 800 years by flood marks, at sites where it is reasonable to assume that the channel control has been reasonably stable.

RAINFALL

In the assessment of regional water resources, rainfall records, including snow in some areas, are an essential aid in determining the variation of the water balance over the project area. Raingauge measurements can provide comparable point information from a widespread network. This evidence is perhaps easier to interpret than the data from river flow stations with different basin areas, geological conditions and periods of record. The rainfall records can be translated into an isohyetal map which will demonstrate trends in average rainfall across a region, or the effects of topography in increasing the rainfall over high ground. A number of examples in Chapter 9 illustrate the value of rainfall data to extend the information provided by a river flow network.

Because rainfall records are simpler to collect, and cost less than a river flow network, they often cover longer periods than flow records. They are also less complex to operate and thus more likely to be reliable, especially when a group of stations can be compared. Thus flow records can be extended over longer and more critical periods in combination with rainfall records.

Rainfall data are also needed to estimate net irrigation requirements by comparison with potential crop transpiration estimates. In reservoir trials, estimates of rainfall are required to derive net evaporation from measurements or estimates of open water evaporation. Rainfall records may be useful in assessing the flood potential of the basin above the project site. Rainfall data may be used to estimate the basin storm of a given frequency, or even the potential maximum storm. Comparisons of rainfall depths from specific storms with the resulting flow hydrograph enable rainfall statistics to be converted to flow estimates.

EVAPORATION

Evaporation and transpiration measurements or estimates are a vital component of water balance studies, as they can be used to estimate the depth of rainfall which is returned to the atmosphere rather than available for runoff. A water balance analysis including evaporation is normally a vital check on an estimate of measured river flows.

Reservoir evaporation estimates are also important in the design of water resource projects. Crop irrigation requirements are related to climatic evaporation as well as soil moisture storage, and therefore evaporation rates can be used to estimate water requirements for irrigation projects. However, evaporation can often be the most difficult of the water balance components to estimate.

FURTHER DATA REQUIREMENTS

The detailed design of water resources projects requires other, more specialized, data like the suspended sediment load and bed load of rivers, in order to estimate the rate of sediment deposition and hence deduce the useful life of reservoirs. Water quality data are necessary to judge the suitability of water sources for domestic, industrial or irrigation use and environmental data are required to protect downstream habitats from serious degradation.

Groundwater investigations must be based on a wide variety of measurements or estimates, in addition to a basic knowledge of the geological structure of the study area. Requirements include a survey of depths to static water level from well information, which can be used to compile a water table or piezometric map. Fluctuations of water level over a long period can give information about recharge processes and rates. The physical properties of aquifer material (permeability and storage coefficient) can be assessed from laboratory tests or from *in situ* pumping tests, and these can be used to estimate the rate of flow through the aquifer and the water equivalent of seasonal recharge. However, these properties are best described in the context of specific studies, so discussion is deferred to Chapter 6.

CONCLUSION

Water resources projects are very variable in character and scale. They require different types of hydrological investigation and supporting information; examples will be described throughout this book. However, all these studies have in common that they are based on a need to understand the physical processes at work upstream of the project site. Although statistical techniques may be appropriate to estimate the magnitude of, for example, floods or low flows at a site, the technique should never take over from the attempt to follow the physical evidence.