THE SCOPE OF CIVIL ENGINEERING IN A CATCHMENT PLAN

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INTRODUCTION

A catchment is the total area from which a river derives its flow, and civil engineers have from very early times been concerned with river systems. From the beginning of history, man has found it convenient to establish communities on the banks of rivers. They provided him with food, with a means of communication, and the land adjoining them on the flat alluvial plains was easily cultivated. As these communities grew in size, so they found it necessary to control the rivers.

The histories of most early civilizations contain records of early river control works. The Chinese built flood-banks on the Yellow River 2,500 years ago, the Babylonians diverted the floodwaters of the Euphrates into a natural depression to protect the ancient city of Babylon; but the first flood control works were probably those of Amemehat, King of Egypt, who constructed stopbanks on both sides of the river Nile and diverted floodwaters into Lake Moeris.

At the same time time cultivation, deforestation and the destruction of natural vegetation by the agencies of man have left denuded large areas of land that were inhabited by earlier civilizations, so that empires once surrounded by fertile lands now lie buried by desert and barren wastes. The deserts of North Africa, Persia and Mesopotamia remain today as reminders of the earlier misuse of soil. The forester, therefore, has an important function in the future planning of soil and water resources to ensure that a healthy and well managed protective cover is retained in the catchments.

In New Zealand, in the early days of the colony, drainage and river diversion works were carried out in many areas and from these works large areas of fertile lands have been developed. Urban settlement has been encouraged on many of these flood plains and so a need for flood protection works has arisen. There is also evidence of considerable misuse of the soil. Repeated burning and overgrazing of lands, once covered with scrub and forest, have left large areas of high country in a particularly vulnerable condition.

However, with the steady growth of world population and the demand for water, there is a growing consciousness of the value of water and definite indications that the value will go on increasing. This will call for a continually rising standard in the overall planning of water use within each catchment. It is in the field of planning the use of water that there is greatest scope for civil engineering and it is intended to show how this may be accomplished.

At the same time, the accelerated erosion that is occurring in many places has brought about an increasing awareness that soil conservation and the proper use of the soil that covers the earth's surface is a universal problem and that there is a need for a fully integrated plan for land use in each catchment.

The catchment plan is now recommended as providing a sound base for co-ordinating the work of engineers, agriculturalists, hydrologists and foresters to ensure that every catchment is main-
tained in a healthy condition by sound management of the soil, forest, pastoral and water resources.

THE CATCHMENT PLAN

Each catchment and its associated river system comprises a single physical unit. As such, development should be planned to render the greatest possible benefit to the community it serves, whether or not that community is divided by political or racial barriers.

The catchment plan should be prepared in such a way that it will cover as wide a field as possible. It should not therefore be restricted to the main benefits such as production of power or flood protection. These should be treated as a means to an end, rather than as an end in themselves. The plan should also make provision for the position of the river and its catchment in the social, recreational and cultural life of the community. Because these aspects may not always be compatible with maximum efficiency in a strict economic sense, it should be recognized that, when such measures are included, there may be a smaller economic gain than is otherwise possible.

The entire catchment should be investigated and planned as a unit before the design requirements for any single feature can be firmly established, and a fully integrated catchment plan should be submitted for adoption by local authorities and government departments in much the same way as district schemes are prepared at the present in the sphere of town planning.

The catchment plan may be prepared in two sections: a soil plan and a water plan.

Soil Plan

A detailed soil survey is a first requirement, and it must contain sufficient information to enable an adequate assessment of the capability of the lands in the catchment to be made. Topographic information of the area is necessary to determine the steepness, and the geological structure of the underlying rocks would need to be known. The production of maps showing rock and soil types, contours, watercourses, groundwater information, etc., would then provide a base plan for assessing the value of the soil resources.

The actual decisions as to what will be the most desirable use of the soil resources of any catchment will then be undertaken by a technical group comprising foresters, agricultural advisors, soil scientists and wildlife managers. Provision would be made in the plan for areas suitable for development under pastoral or agricultural use, or as commercial forests, national parks and wildlife reserves. The part played by civil engineering in this plan would be only a minor one, restricted to roading, bridging and minor structures to control gully and stream erosion.

Water Plan

A plan defining the uses of the water resources should also be prepared, to ensure that adequate and reliable supplies of pure water are made available for all purposes in the most suitable and economical way. It is in this sphere of the catchment plan that the civil engineer would be largely concerned. Provision should be made for hydro power, water supplies for domestic, industrial, and livestock consumption, and for irrigation, land drainage and flood
Fig. 1: Organization of a typical catchment plan.
control. The preservation of fish and waterfowl should also be included. In some rivers, navigation would be important.

It is now proposed to show how the water plan is best developed and what information is necessary to ensure that the best value is obtained from the water in the catchment. Probably the three main types of basic information required are rainfall, run-off and sediment data.

(1) **Rainfall.** Unless adequate rainfall records are available, it is not possible to predict with any great degree of accuracy the maximum probable flood discharge. The United States Bureau of Reclamation (which is responsible for many major river works) states*:

"Statistical analyses of stream flow records do not provide reliable estimates of maximum probable flood discharges. . . . The determination of the maximum probable flood should be based on a study of storm potential." It is therefore extremely important that reliable and adequate rainfall information is provided for each catchment. Rainfall data and detailed information about the rainfall distribution over much of the country are woefully inadequate, and it is important to emphasize the deficiencies. While adequate records may have been kept at main centres of population (e.g., Auckland and Wellington) it is on the more remote areas of the country that the greater part of the annual precipitation falls. The remoter areas are for the most part at high altitude, constituting the larger part of the major river catchments and therefore contributing most of the flow. A lack of adequate rainfall data for these areas is a most serious matter and every effort should be made to ensure that daily rain-gauges and automatic recording rain-gauges are installed in the more remote areas, where hitherto only monthly rain-gauges have been considered practicable. Improved access within these regions, or greater use of helicopters, would improve the present position.

(2) **Run-off.** Facilities for the measurement of run-off or stream flow must also be extended, to ensure that the opportunity of observing extreme values is not lost. No person or group of persons can foresee with any accuracy what the needs in the field or water resources may be in the next 50 to 100 years; but it should be ensured that adequate records are kept now so that the problems that may arise in the future will be capable of investigation using adequate records.

Run-off from a catchment is dependent upon many variables:

(a) Precipitation.

(b) Interception by vegetation. The magnitude depends upon the nature of the vegetation and also the rate and time of the precipitation. More knowledge is required on the value of conifers, deciduous trees, and native forests in intercepting precipitation. The effects of the varying types of pastoral management also need more analysis.

(c) Interception by surface cover. This implies a geological appraisal of the depth of the surface soils. The geology of the surface, and its slope, play an important part in determining

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whether or not water infiltrates, whether permeable layers facilitate the movement of the water into the ground, or impermeable layers impede infiltration and promote a rapid rate of run-off from the surface. Sometimes, during prolonged heavy falls of rain, the surface soils become fully saturated and infiltration may be temporarily prevented. There are many gaps in our knowledge in this sphere.

(3) Sediment. The loss of capacity and other damage that may result from the silting of reservoirs, and the general pattern of bed changes in any silt-laden river, make it important that regular records should be kept of sediment discharge. In New Zealand, most rivers are short and rather steep and coarse shingle is carried along the bed in the lower reaches. Accurate methods of determining bed-load movement and of sediment carried in flow are rather difficult to obtain and to compare. Nevertheless, it is most important that steps should be taken to enable regular and systematic samples to be obtained. These records would also provide an indication of major changes or trends in the erosion pattern of the upstream catchment.

DESIGN PROBLEMS

The civil engineer faced with preparing proposals for major works, which depend upon a sound knowledge of hydraulics, is beset with many problems in the field of hydrology. A brief summary of the variables involved in planning these scheme is provided.

(1) Water Supplies

These include supplies for industrial undertakings, and rural and domestic supplies. In this country most water supplies are drawn from the river systems, and it is therefore imperative to ensure that sufficient control is exercised over the rivers to reserve adequate water of a quality sufficient for communal requirements. For large water-using industries the location of the plant is governed by availability of an adequate water supply—e.g., freezing companies and timber processing. Moreover, the supply of water must be adequate to serve the present demand and still leave a surplus for future increases. Water shortages should not be contemplated when considering municipal or industrial users.

Because abstraction of water direct from rivers involves problems of water treatment, the adequate control of river pollution is also essential as part of any river control scheme. Low flow records and details of sediment load and pollution are important to the engineer faced with the design of any water supply, and permanent recording stations are being installed in many streams for this purpose. The data recorded are suitable for processing by computer, thus eliminating earlier problems of time and manpower.

(2) Hydro-electricity

The utilization of water by hydro-electric development is most desirable. Nevertheless, it is important to show that the cost of production is less than or equal to alternative means of generation and, while the economics of hydro-electric plant is necessarily based on present-day costs, the effects of rising fuel costs make hydro-
electric plant more profitable as time goes on. There is no pollution or contamination in a hydro-electric scheme, nor is there any wastage of the water. The mean annual flow of the river is the most important measurement for the engineer designing a hydro-electric scheme, and this is determined from daily records that are obtained from the permanent recording stations established on most major rivers. Modern methods using punched tapes in recorder units enable the records to be processed by computer.

The maximum flood flow is also important in the design of the spillway, although it is generally possible to adopt a fairly conservative figure within the economy of the structure.

(3) *Flood Control*

Flood control is concerned with the maximum rate of run-off, and the selection of a maximum flood discharge and its degree of frequency. In this respect it is interesting to note that, while most flood control schemes in New Zealand aim at providing for a 1 in 100 year flood, with some freeboard, the main banks in Holland that form part of the Delta Scheme are designed for a 1 in 10,000 year flood and the lesser banks for a 1 in 4,000 year frequency.

In many areas the ability to pay for a scheme is often the governing factor and in New Zealand this is generally the basis adopted, with arbitrary limits being set when assessing the benefits that are provided. However, no consideration is given to assessing a realistic monetary value for loss of life or human suffering. It is also considered that it would be better to judge each scheme on the broad basis of national rather than local benefit, and that economic benefits should be assessed over a period of time well beyond the loan repayment period. There should not be any flood problems in a properly planned catchment.

Reliable rainfall records, including rates of rainfall intensity, are most important; and maximum flood heights and river gauging at the high flood stage are all essential parts of flood analysis.

(4) *River Training*

Engineering works to control the courses of rivers have generally evolved from practices, many of them centuries old, that used available local materials and hand labour. The methods used today are still largely unsophisticated and depend to a considerable extent upon the availability of suitable material.

The main objects of training works are to prevent damage to the banks of the rivers by excessive erosion and to prevent undue build up or deterioration of channel capacity. River training, in its modern sense, started in Europe in the last century for the improvement of navigable rivers. The object was to maintain a deeper and better channel for navigation, which had been developing along with industrial expansion. In the design of river training works there are no standard procedures, as in the case of a dam or a bridge. However, with the development of the science of experimental hydraulics, the method of model testing has been found most useful in solving many problems on river training. Works of river training vary greatly from one river to another and, although considerable theories have been developed, the planning and design
Flood Level raised, bed silt ing prevented

Capacity increased, flood level lowered

Stopbanks

Channel Widening

Velocities improved, flood levels upstream lowered

Diversion Cut

Floodway

Wide flat valley floor required for maximum storage capacity

Storage Reservoir

High water table upstream

Sediment deposited

Seepage

Erosion increase downstream

Uplift

Dam

Fig. 2: Examples of typical river works.
of river training works in general have still to rely upon the judgement of experienced engineers. As no two rivers are alike in all particulars, the local application of the results of experience elsewhere is no easy matter and is liable to misinterpretation.

(5) Wildlife and Recreation

It is generally agreed that adequate recreational facilities are now more than ever essential for affording some relief from the strains and tensions of life today. Within a catchment there may be a wide variety of recreational facilities. In the rivers and lakes, angling will always occupy an important position, and in wet lands wildfowl are needed. In the reserves of the upper catchment, deer and other game animals are in demand; while tramping, hiking, boating, and yachting all contribute to the healthy wellbeing of the nation. Adequate facilities should be provided for as wide a range of these activities as possible. Projects to encourage the promotion of wild life should only be undertaken with the advice of a biologist. An ability to shoot deer and catch fish is no guarantee of knowledge required for adequate management of them, but it should be recognized that an adequate supply of wildlife can make a worthwhile contribution to the general wellbeing of a catchment.

Where there is considerable demand for recreational facilities of a varied nature, areas may need to be zoned to preserve privacy and to provide separation of conflicting uses.

RIVER WORKS

A large variety of works are undertaken by civil engineers in or upon rivers, each of them having some effect upon the river. In some cases the effect is beneficial but in others it may not be. In many instances there may be more than one effect. Consider, for example, effects of the following types of construction works.

(1) Dams

A dam is an artificial structure designed to retain water above the level that it normally occupies at the site of the dam. The flow of the river downstream can thus be regulated. The underground water conditions upstream of the dam are changed, the level of the water-table being raised to at least the water level of the reservoir at its perimeter, with consequent changes of decreasing importance as the distance from the lake increases. Below the dam the water-table level may be lowered, or may fluctuate as the rate of discharge from the dam varies. The dam structure itself exerts extremely high unit pressure on the underlying foundations and, as these are submerged well below water level in the reservoir area, they are also subject to hydrostatic pressure—which in the case of very high dams is quite appreciable.

A hydro-electric dam occupies an important place in any catchment plan. It can be utilized to control the flow in the river, thereby reducing the peaks of floods and providing stability in the low flows. Care must be taken to ensure that adequate capacity is provided, not only for the storage of water but also for deposition of the silts and sediments that will fall to the bottom of the
reservoir as the velocity of flow decreases. There are many records of large dams that have been rendered ineffective by rapid filling of the reservoir behind them with water-transported material. Therefore, an essential part of the investigation in connection with the construction of all dam structures is an assessment of the amount of sediment normally carried by the stream that is to be dammed.

Conversely, on the downstream side of the dam the problem becomes one of erosion. The design of the spillway, which takes a large flow of water at a high velocity, is critical and there has been extensive research work done in this field. Nevertheless, the river downstream of any spillway will always require careful study.

The operation of a hydro-electric station may also affect the condition of the river banks. Most hydro-electric stations in New Zealand operate at peak loads with a low load factor and as a result there may be a wide fluctuation of flow passing through any station within a 24-hour period. These fluctuations or waves can be the cause of considerable bank erosion downstream.

(2) Stopbanks

The simplest and most obvious method of controlling floods in rivers is by constructing a stopbank on either side of the river to restrict the spread of floodwaters. These banks are generally constructed on the flood plain of the river and set back some distance from the main channel. They come into contact with water only during floods and they are not usually subject to high velocities.

One of the main problems encountered in the design of a stopbank system is in the treatment of tributary streams and contributing drains. One possible method is to construct banks along the tributary to the same height as the main river stopbanks; another is to construct floodgates at the confluence of the tributary with the main river. This means that, during a period of high levels in the river, no discharge from the tributary is possible and the internal water must be held in storage.

Ponding areas or reservoirs in the upper reaches of the tributaries may reduce flows during floods in the river; but for low-lying land adjacent to the main channel the most suitable method of handling excess water during high river levels is by the use of flood pumps.

Construction of stopbanks to confine floodwaters has the effect of raising flood levels. The height of the stopbank is related to the extent of overall flood reduction. It is therefore extremely important to ensure in the case of urban areas that a limit is placed on the height of the banks and that a high standard of construction is combined with an adequate factor of safety — because people are in greater danger in the event of a breach or failure of high embankments than they would have been if subject to the gradual rise of a natural flood.

(3) Channel Enlargement

A second method of solving flooding problems is to enlarge the main channel to a size sufficiently large to carry the maximum flood discharge within the banks of the river without overflowing. There
are, however, quite definite limits to this method. A natural river channel is formed and maintained by the river and its size is dependent upon the dominant discharge. There is still some uncertainty about the magnitude of this discharge, but it is generally agreed that it is less than maximum. In some case it may be considerably less, so that the bankfull discharge of any natural river will be smaller than the maximum flood discharge. As an example, the Whakatane River in the Bay of Plenty has a maximum discharge approximately four times the bankfull capacity—so that to prevent overflows during high floods it would be necessary to increase the channel size to roughly four times the present capacity. However, unless the enlarged channel is kept continually dredged, it will ultimately revert to its natural size.

The disposal of the large amounts of spoil required to maintain the capacity would constitute an ever-increasing problem. During low flows, when the depth of the water is shallow and velocities low, there is excessive weed growth and the formation of stagnant pools, so that maintenance works increase.

Improvements of channel capacity by widening are therefore limited to rivers that have a very steady flow.

(4) Diversion

River diversion works are generally constructed to improve an existing poor alignment. When properly located they can eliminate sharp bends and the development of further meanders. By shortening the course of the river and passing it through a better aligned channel, a reduction in flood levels may be obtained upstream of the diversion cut and bank erosion may be reduced. The reduction of flood levels upstream of the diversion cut will enable a reduction to be made in the height of stopbanks beyond that point and in some cases this may amount to a considerable saving.

The use of models to assess the value of any major river diversion works is an essential part of the scheme investigation and valuable information can be provided from this source.

In many areas pilot channels have been constructed as the first stage in a river diversion—generally for economic reasons. However, the use of pilot channels should be carefully assessed because the failure of a pilot channel to enlarge by scouring could cause additional problems. It is therefore recommended that, wherever possible, a diversion cut should be constructed to provide ultimate capacity.

(5) Overflow Channels

This method incorporates the construction of a bypass channel to carry the excess floodwaters safely past the area to be protected. This solution has none of the disadvantages of the channel enlargement scheme, as the natural channels are untouched and continue to carry the normal flow. The overflow channel is used only when the bankfull capacity of the normal river channel is exceeded.

A typical example of an overflow channel is provided by the Manawatu River Scheme. The main river channel has been improved to maximum capacity and a barrage of sluice gates has been constructed at the intake of the overflow channel. These are opened
at a rate sufficient to maintain the maximum flow in the river channel and to pass the excess above this limit down the overflow channel which is kept well grassed and grazed. The location of the intake sluices prevents any excess of silt load being drawn from the natural river.

(6) Storage Reservoirs

The provision of storage reservoirs in the upper catchments of major rivers has considerable public appeal. This is an obvious method of reducing the flow through a flooded area. Despite its advantages, particularly in regard to its flood control value, the method has not been used to a large extent in New Zealand. There are two main factors that have contributed to the limited use of this method in New Zealand. First, the costs of constructing the works are generally very high in proportion to the flood benefits obtained from other methods and, secondly, there are not many suitable sites. However, it is considered that better use could be made of this method of water conservation and flood protection. The approach to this problem to date has been hampered by the “single purpose reservoir” attitude, and it is strongly recommended that multipurpose reservoir use should be considered in all future major dams.

An outstanding example of multipurpose planning is the Tennessee Valley Authority which was investigated as a single unified programme in which there are approximately twenty dams which are multipurpose structures embracing flood control and power, together with navigation. All of these uses are planned on a co-ordinated basis so as to meet the requirements of the various interests and contribute to the reduction in frequency of flood damage in the Lower Mississippi.

Other good examples of this type of planning include the Snowy Mountains Authority in Australia and Damoda Valley Authority in India. It is interesting to note that each of the authorities quoted has been able to carry out its work so successfully probably because it was freed from political interference.

(7) Training Works

A brief summary of some of the methods used for river training follows:

Groynes. These are training structures constructed so that they obstruct the flow of the river and extend from the bank. Groynes are usually constructed in series at defined spacing to promote the accumulation of silt and thereby form a permanent alignment. They may be constructed perpendicular to the bank lines or facing slightly upstream and generally need to be strengthened at the head because there is usually greatest disturbance to flow at this point and a tendency for excessive scouring to occur. It is generally desirable to start with a short groyne and extend it. There are broadly speaking two types of groyne—the permeable and the impermeable. The former is preferred in areas of high velocity currents and heavy shingle movement, while the latter is preferred in the lower reaches of rivers with a high silt load during floods.
Bank Protection. Continuous bank protection is placed parallel to the river flow and is used extensively throughout New Zealand in a wide variety of methods, depending upon the locality. There are several types of construction using heavy cables anchored to piles or anchored to the bank and then tying large trees (preferably willows) to the cable. The presence of the mass of branches close to the bank causes a reduction in the velocity of the current and results in a build-up of silt. The willows held in the water send out large numbers of roots and, given average conditions, a dense protective mat of willows is soon established. Regular maintenance of these trees is required, however, to prevent their becoming too large and topheavy.

A more permanent method, that is finding favour as the costs of labour increase, is the use of rock rip-rap. Where suitable supplies of good rock are readily available, this method forms a good permanent protection. It is reasonably flexible and when scouring occurs the rock is able to adjust to the new channel shape. Maintenance is relatively simple and there is a growing preference for this type of protection.

CONCLUSION

It is hoped that the foregoing will have provided some indication of the part played by civil engineering in the catchment plan and to show that they are aware of their responsibilities in their partnership with foresters, hydrologists and agricultural scientists. It is also hoped that the vital significance of the development of a catchment plan is acknowledged, for it is considered that not until the concept of multipurpose planning of water and soil resources is accepted will any real progress be made in the development of these two most important assets.