of wholetime fieldmen employed previously has been dispensed with and the fieldwork is entrusted to the locally stationed district staff of the Land Records Department. For administrative convenience and a more even distribution of work, the revenue circle has been adopted as the unit for sampling in place of the *tahsil* though this change is not likely to lead to any further increase in statistical accuracy of the yield estimate. Two villages per circle where the cotton area is below 20,000 acres, and three for higher acreages is the scale of sampling adopted. This modification has resulted in the selection of a large number of villages, 335 against 204 in the last year, and made possible their distribution in proportion to the cotton acreage. The increase in the number of villages will be advantageous for both reasons. There are three fields under experiment in each village and the experiments in each circle are in charge of the Revenue Inspector of the circle. The supervising staff for each district also belongs to the department. The projected survey will be watched mainly to test the working efficiency of the organization, to detect its possible shortcomings and devise suitable remedies for these. With its conclusion the end of the experimental stage will be reached, and we may then expect with confidence that the provincial administrations will undertake yield surveys on this plan under technical direction as an annual routine.

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RIVER FLOOD CONTROL*

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NATURE AND EXTENT OF THE PROBLEM

ALL over the world the problem of combating the destruction and damage caused by river floods is confronting the engineering profession. From the earliest times China has been affected by the floods of the Hoango and the Yangtse, as also our own mother-country, India, particularly parts of Bengal, Bihar and Orissa on the east, and the Indus Valley on the west coast. The Continent of America has figured largely during the last two centuries or so, where the engineers have been constantly at work during this period trying to tame the mighty Mississipi and other rivers. In the Continent of Europe flood protection works have been carried out during the last six or seven centuries, especially in Spain, France and Russia. In no country finality has yet been reached.

Fortunately, the State of Mysore, being situated on a plateau, is practically immune from inundations of rivers and consequent damages, though here and there are some towns which are affected to a small extent by floods. However, it behoves us as engineers to study this world-wide problem and keep ourselves abreast of the work that is being done by the engineering profession abroad. My object in reading this paper is thus to stimulate study and research by the members of this Association, some of whom may in future years be called upon to tackle flood protection works.

II. COLLECTION OF ESSENTIAL DATA

2. The first thing to be done in devising measures for river flood control is the collection of data under several heads, such as

(1) rainfall statistics in the catchments of the rivers extending from the head to the mouth for as many years as may be possible and for as many stations as are available;

(2) study of the topographical features of the catchment and the climatic conditions, and preparation of maps showing the areas affected by floods at different stages of the rivers;

(3) gauging of river flood discharges at vital reaches and correlating them to the rainfall and comparing them with calculated discharges based on river sections and slopes or with the recorded flow over weirs or at bridges;

(4) the extent and nature of damages caused from time to time, the population affected and the average annual loss caused to the people, the government, public utility companies, etc. This information has to be separately collected for urban and rural areas.

The study and collection of data should be a continuous one extending over several decades. This is especially so with regard to the calculation of flood discharges. It may be mentioned as an example that, in the case of the Mississipi river in America, a Special Commission was constituted by the Federal Government nearly four score years ago, and it has

* Paper read before the Mysore Engineers' Association at their Conference held in 1945.

been sitting since then collecting necessary data and carrying out measures for protection from time to time, but yet no complete protection has been afforded. Records of flood discharges show that anticipations made in the earlier years have been far exceeded by the actual flow in later years. It is stated by a certain authority that in the case of big rivers the highest floods occur once in a century or two or even at longer intervals. When data extending over longer periods are not available, some kind of forecast based on other similar rivers has to be made. After comparing discharges of the various rivers in the United States, one Mr. Weston Fuller has shown that the great floods of each river bear certain definite relations to the average annual floods on the respective streams. From these ratios he has deduced the following table showing the frequency of maximum floods of different magnitude:

Time in years	Ratio of maximum to average-hour flood-rate
5 ..	1·6
10 ..	1·80
25 ..	2·12
50 ..	2·36
100 ..	2·60
500 ..	3·16
1000 ..	3·40

These ratios cannot, however, be successfully applied until the average can be determined fairly approximately and they should be used only to supplement the local data.

III. Causes of Floods

3. The causes of floods and the factors affecting the intensity of floods have to be found before suitable remedies can be applied. Flood discharges vary a great deal, depending upon the intensity and duration of rainfall, the size, shape, topography and the geology of the catchment, the extent and nature of forest growth, climatic conditions of the region, etc. Floods of great rivers are caused by general heavy rains of considerable duration and also, more or less, by a series of local storms. If a watershed is long and narrow, it may have a less rate of flood run-off than if the catchments were circular or fanwise. Basins with very gentle slope serve more or less as detention reservoirs, while those with steep slopes bring about rapid floods. When slopes are gentle and the rainfall is of low intensity, the rain water is absorbed by the soil to a larger extent than otherwise; when the soil is of sandy and gravelly nature the percentage of absorption is still greater. Surface vegetation is also another factor moderating the intensity of run-off. The existence of natural lakes and ponds brings about greater uniformity of flow and reduction of the peak floods. Though afforestation or deforestation may not affect floods very materially, the former reduces the rate of run-off, while the latter tends to increase it.

The discharges derived from rainfall records have to be verified by actual river gaugings at selected reaches. A hydrograph showing the daily flow throughout the year and extending over a number of years will be found of great use. A proper block survey of the tracts affected by floods should be made and the areas actually flooded at different stages of the river above the bank-ful stage clearly indicated on the maps.

Inundation of marginal lands is caused by the river flow over-topping the banks on account of the undue silting of the river-beds, which, in deltaic country, are found to be higher than the marginal lands. The raising of the river bed has often been the result of suffient waterway not being available in the river to carry the heaviest floods which thus spill over the banks. There is a definite relation between the quantity of water flowing in, and the silt conveyed by, a river. If the volume of flow is reduced by spilling, the silt is deposited on the bed resulting in the rise of the bed level. The waterway being thereby reduced further, succeeding high floods have necessarily to spill over the banks more and more and the tendency for the bed to silt up increases from year to year. The marginal lands are scoured by the floods spilling over and their level gets gradually lowered and subsidiary river valleys deeper than the original river are thus formed. This is how in deltaic regions the main rivers are generally found to be higher than the marginal countryside and a number of new rivers are formed—lower than the original river, which may die out in the course of centuries.

It is thus obvious that, in a system of works designed to prevent damages by floods, wherever possible, the original river should be made to function. Levees will be of use in making the rivers carry more water and silt than they can without such aid and clear their own beds. The quantity of silt carried by a main river will not be transported in full when it breaks up into two or more branches. Such breaking up should be prevented if the main rivers should remain in an efficient condition.

Sometimes it is found that floods are caused by encroachments on the natural waterway of rivers by structures artificially raised in towns and cities, authorisedly or unauthorisedly, or by railway and road embankments and such other works interfering with the river courses. It is most desirable that when any flood protection work is undertaken, a system of control on the construction of buildings, towns, factories, or other structures, etc., along river banks should be effectively enforced. Without such control it will soon be found that protection afforded at heavy cost will be nullified by unauthorised encroachments.

IV. Measures for Protection

5. When full data have thus been collected measures for protection can be designed. These measures may be grouped under three heads:

(1) Flood prevention,
(2) Flood diversion and
(3) Flood protection.

Under the first head will fall reservoirs and detention basins, afforestation, etc.

Flood diversion involves temporary or permanent diversion of peak floods from places along rivers where harm is likely to result to other places where a flood is less objectionable or to a valley which can carry the extra floods safely.

Under the third head are included levees, river channel improvements, such as, cut-offs, enlargements, etc.

It has been found by long experience in America and elsewhere that no single method can give hundred per cent. protection against floods. A thorough examination of every possible method of solution has to be made and conclusions reached after a full consideration of all the factors. The question in each case will be, not which method to apply, but how much of each will be most advantageous.

A study of practical measures adopted in many countries brings out the fact that there is a place for all remedies above mentioned. It may be generally stated that the best measure is the one that involves the least initial cost, reasonably low working expenses and that which most nearly fits in with popular ideas.

The expenditure involved should bear a reasonable proportion to the losses to be averted and the benefits to be secured. If the protection of big cities and industrial areas are involved, half-way measures will not do. The protection against floods must in their case be absolute and certain. If, however, only agricultural interests are to be protected, the aim should be more to prevent loss of life, both of men and animals, and serious damage to crops. In this case it may not be necessary to avoid flooding of agricultural lands altogether, as a certain amount of flooding of crops will not result in their total destruction, while there may be some advantage gained by partial flooding. The remedy need not, therefore, aim at complete protection, as in the case of cities and industrial areas, but only partial relief. The success of such protection has to be tested by the rapidity with which the farmers can rehabilitate themselves after an occasional crop loss.

Thus, after a full preliminary investigation of the several methods, it would be possible to eliminate or defer some of the more costly alternatives and confine detailed investigations to the cheaper remedies and save time and money.

6. I shall now offer a few brief remarks on each of the methods referred to above.

(b) *Flood Prevention.*—Storage reservoirs and what are called detention basins, afforestation, ground water storage and such like measures are included under this head. Storage dams, if built of the required capacity, have no doubt, the effect of moderating floods, *i.e.*, reducing the heights of extraordinary maximum floods. If reservoirs are to be effective against such floods, they must be kept empty in order that high floods may be absorbed at any time during the season in which such floods are expected. But if a reservoir is to be constructed for flood protection alone it will not be an economical proposition. It has, therefore, been usual with such schemes to combine generation of hydro-electric power or to improve the means of navigation along the rivers or to supply water for irrigation, for industrial purposes or city water supplies. Though these purposes are somewhat antagonistic to those of flood protection, if all these purposes are borne in mind when designing and sufficient capacity allowed for every one of the objects aimed at, a reservoir may be practicable. The design should be absolutely secure against any possibility of failure, as any such failure will result in a more disastrous flood than the one which the reservoir is intended to prevent. The situation of the dams has to be carefully selected, not merely with reference to its engineering and geological features, but also with reference to its distance from the flood-affected areas. Head water reservoirs will for example be of little use if the lowest reaches of the river are to be protected.

Detention basins are based on the principle of interpolating a high dam across a river with some openings in the structure constantly functioning. The idea of constant functioning is that the action will be automatic depending on nobody's discretion. Such basins are used in France. The effect of these basins is to retard the flow by partial absorption of high floods and to bring down the maximum to safe limits.

Ground water storage is secured by forming terraces in the catchment area and also by raising cover-crops which absorb rainfall to a certain extent, both of which will thus reduce the ratio of run-off. It is stated that these two methods have been adopted in the Tennessee Valley in America and they are found to absorb about four inches run-off on the catchment, proving a valuable supplement to storage by dams, the main means of control.

Coming now to the effect of forests on rainfall, I may say that there are conflicting views, one holding that forests act as equalisers of the flow of streams by diminishing in general the frequency of freshets and increasing the water flow in the non-rainy months. The other school holds that forests are of little or no benefit at all in respect of either. Such extreme views have to be avoided. There can be no doubt that the existence of forests will have a restraining effect upon run-off, ensure better regularity of flow in the high flood season and increase the summer flow. They also prevent erosion of steep mountain sides. The prevention of erosion is an important factor in any system of flood protection as erosion will result in undue silting of river beds, which is one of the main causes of destructive floods. The conservation of forest growth is, therefore, as necessary as any other measure of protection.

7. (c) *Flood Diversion.*—This method aims, as already stated, at temporary or permanent diversion of floods from places where damage is likely to result to less objectionable places. The diversions are effected by high level escape channels whether controlled or uncontrolled. The quantity of floods to be diverted has to be based on the carrying capacity of the river channel lower down and the safe pre-determined capacity of the escape channel. The head of the diversion channel should generally be located on the convex side of the stream and the velocity throughout the

channel must exceed the velocity in the section of the stream immediately opposite the diversion channel.

When not prohibitively costly, regulators should be provided to control the flow either through the diversion channel or the original river channel to the desirable or necessary extent.

Where the existing mouths of rivers are following a tortuous course or are blocked by bars, diversion is effected by opening fresh direct outlets to the sea. In such cases care should be taken to see that sea-water does not flow back along the river and flood culturable lands with salt water and make them unfit for cultivation.

IV. (d) Flood Protection

8. The most popular and common method of protection against floods is *by means of levees or embankments*. This system has been extensively used in America. It has also been in vogue in India in several of the river deltas in Madras, Orissa and parts of Bengal. The construction of these embankments is generally attended with difficulties as they have to be formed by the soil obtained near about the river banks, which consists mostly of sand and silt. The material being porous the banks get saturated in high floods and slips may occur. They have, therefore, to be made broad enough and the slopes sufficiently flat and turfed or otherwise protected and maintained carefully. Percolation drains will have also to be provided. The heights of these levees are generally limited to about 20 or 30 feet.

The natural banks of rivers are subject to scouring action by the moving currents of water, and the artificial embankments are thereby endangered. In such places the banks have to be protected by stone revetment or, as in modern days, by flexible concrete mats. It may be found that this method may often be more costly than constructing new levees by retiring them to safer areas beyond the river margins. In towns and cities, however, such shifting may not be possible as acquisition of properties will be very costly.

Retired embankments are also provided when adequate waterway cannot be secured otherwise.

9. At one stage the Mississipi River Commission considered that the only safe solution for flood protection was by levees. But later experience has shown that they have not afforded the extent of safety desired or necessary and reservoirs have been found to be quite necessary along with other measures, such as diversion by means of spillways. The chief objection urged against levees is that when they fail they cause much greater damage than the natural river would have done by flooding marginal lands. This difficulty, however, is common to other remedies also, and on that ground the levees cannot be ruled out. At any rate all over they have taken precedence over other measures of relief, and have been more extensively used than any other means. Care should be taken in designing them properly with reference to foundations, nature of soil available for formation, duration and stage of high floods, the margin of free board to be allowed in the case of agricultural lands or in city limits, etc. When proper precautions are thus taken for making levees substantial and strong, failures can be minimised.

In city and urban areas masonry walls are generally built as they occupy less area than the earthen embankments and involve also less risk.

IV. (e) River Channel Improvements

10. I now pass on to river channel improvements which are generally combined with levees. Improvements are effected by increasing the sectional area of the rivers either by deepening or widening or by both and straightening river channels. Bends are eliminated by cut-offs and the channel surface is smoothened by removing obstructions. In carrying out the above measures the energy of the flowing waters during floods should be made use of to the maximum possible extent for clearing the dredged material or excavated spoil or enlarging pilot channels and such other processes.

At places where rivers divide themselves into branches the currents should be so guided that each branch takes its due share of the flowing water and of the proportionate sand burden. Regulators may be necessary at the forks and provided when cost can be afforded.

IV. (f) Model Experiments

11. It is very desirable that model experiments should be conducted at special Research Stations and the effect of each kind of remedy tested. This is necessary because the effect of some of the improvements has been found in many cases to be very temporary. For example, dredging of hard spots proves effective for some time, but after a few years it is found that the silt and sand brought down from the higher reaches accumulate at the very place and soon make up a simliar obstruction. The same is the case with cut-offs. Unless the surface fall of the flowing waters is increased right from the point of the first cut-off down to the mouth, the effect of individual cut-offs will be found to be local. This is due to the fact that while the flow line level above the cut-off is increased in slope, that below is reduced, unless the next cut-off downstream and the next and so on are tackled in series. The study, therefore, by means of experiments will demonstrate the success or other of the remedies proposed. The cost of such experiments will be a trifle compared to the advantages they secure.

IV. (g) Flood Warnings

12. In modern systems of flood control, warnings are given to the people in advance by means of telephones, radios and telegrams. Radio sets will be found very useful during floods as even telegraph or telephone communications are liable to fail during heavy storms.

IV. (h) Aerial Cloud Streams

13. In the *Scientific American* of October 1938, a remarkable phenomenon was alluded to in an article by one Mr. Alexander Maxwell. It would appear that, just as is the case with ocean currents, there are aerial currents which appear like meandering clouds. These air currents instead of evenly distributing rain-

fall get concentrated in some restricted area or other, causing very high floods there. These aerial streams, it would appear, "snake and twist" like giant firehoses and change their course from one ocean to the other, say from the Atlantic to the Pacific. There is, however, one factor of safety as unlike earthquakes or tornedoes which come without notice, these streams appear, it is said, several days in advance of their discharging the burden and it is, therefore, possible to predict the appearance of a phenomenal flood. Though at a short notice of a week or a few days it may not be possible to devise effective protection works, it would be easy for the people to get out of the way of a flood in advance and save themselves and their property.

V. Financial Responsibility and Advisory Board of River Control

14. The works of flood protection are to be permanent ones, benefiting the future as well as the present generation. There must be, therefore, no undue burden thrown on a single generation. The works should be spread over many years and, as actual experience is gained from time to time, the nature of remedies should be developed by stages. The cost of protection works has no doubt to bear a certain proportion to the value of ascertained damages to be averted. When the local population is likely to derive benefit from the betterment of their property they will have to bear some part of the expenditure incurred.

In America the Federal Government has been financing protection works on big rivers like the Mississipi traversing many States. Individual States will not be able to finance costly works and it is but right that the Central Government should bear the burden.

The case is even stronger in India, where the Provincial finances are generally too slender to meet such liabilities. The Central Government should come to the aid of the local Governments even in cases where only one Province is involved as in the case of the Mahanadi delta in Orissa, and more so when more than one Province is concerned.

It would be indeed desirable, considering the huge interests involved, that the Government of India form an Advisory *Board of River Control* for the whole of India to examine all major schemes of flood protection and advise them as to the extent of financial help that may be rendered in each case.

VI. Conclusion

15. I have endeavoured to give in the foregoing pages an outline of the causes of destructive river floods and the remedial measures generally adopted for protecting life and property. It is not possible in the course of a paper of this kind to deal exhaustively with the various methods. Each area to be protected will have its own peculiarities and remedies will have to be adjusted to local causes and conditions. There can be no uniformity of method applicable to every case. Patient study and research extending over many decades will be needed for protecting large extents like the deltas of big rivers in India.

A careful examination of the flood problems will reveal that every kind of remedy has its place somewhere. "It is by a knowledge of the fundamental principles and ingenuity in their application that flood problems could be solved with assurance that the works would be economical and effective."

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PROPOSAL FOR WORLD UNIVERSITY

A Proposal for an International University from which lectures could be broadcast to students in their homes all over the world is to be discussed at the United Nations Education Conference in London. The idea has been sponsored by Professor Mikolaj Olekiewicz, teacher of Mathematical Statistics at the newly founded University of Lublin and one of the Polish delegates to the Conference.

Professor Olekiewicz, a fugitive from Germany during the occupation, believes that an International University would provide a practical answer to many problems in Europe where text-books had been burnt, schools destroyed and teachers killed. But he would at the same time like to see the University made permanent.

He adds: "My concept of the Faculty is this—prominent men of science, art and letters will be appointed from all countries of the United Nations. These men could deliver their lectures in their own studies merely by hooking up to the University's network. There would be no resident students. Young men and women all over the world could listen in their homes and at the same time enrol in correspondence courses conducted by the University. Once or twice yearly, students of the University should be given an opportunity of meeting other students—it would be fairly easy to arrange that."