An Insight into Arterial Drainage

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WHEN we see an Office of Public Works (O.P.W.) Land Rover pulling up beside a bridge and two engineers and probably four labourers alighting we are witnessing the beginning of Survey Field Operations and the natural question which springs to the mind of the observer is—

"When will they do the river?" "do" referring more specifically to drainage works.

Before we try to answer that question we must take a quick flash-back to history.

Until 1842 drainage works were mostly on a do-it-yourself basis, but in 1842 the first important land drainage Act was passed. Under this Act the O.P.W. surveyed and prepared small schemes on behalf of riparian owners. Much good work was done—e.g. from the very middle of the famine (1847) to 1852 saw 40,000 impoverished souls improve over a quarter of a million acres.

The effectiveness of this Act died out in the late 1850's and we had the Arterial Drainage Act of 1863 to succeed it. This left the responsibility for the schemes in the hands of the landed proprietors with O.P.W. having a consultative capacity generally.

Again much good work was done—over 130,000 acres were improved under this Act. However, with the rapid rise of tenant ownership, after the Land Acts of 1881 and subsequent years, drainage saw a period of entire stagnation. This was bad in every way, for with no new schemes coming, and lapsed maintenance on the ones which had been done, we had very severe deterioration throughout the land. The advent of Native Government resulted in the passing of the 1924 Drainage Maintenance Act which helped to repair the damage to former schemes. This was rapidly followed by the 1925 Arterial Drainage Act which resulted in a large number of new schemes. We haven't time to examine the weaknesses of this legislation—but a special Government Commission in 1938-40 examined all aspects of drainage and produced a report which was the basis of the 1945 Arterial Drainage Act.

This differed from all the previous Acts in four important ways.

(1) In future all Arterial Drainage Works would be carried out by O.P.W. on the basis of entire catchments and entire catchments only.

(2) Construction costs would be met entirely from State funds.

(3) Maintenance would be undertaken in future by O.P.W.

(4) Cost of maintenance would come from County Councils concerned, as a county-at-large charge.

The whole concept of drainage was thus changed. Previously all schemes were to provide relief on lands immediately affected by making improvements on perhaps a couple of miles of channel. Finance had been more of a problem in the old days, when it was all pick and shovel work, and rock had to be taken out by lighting large fires on it, and cracking it with water, followed by the wedge and feathers. There had often been a tendency to do drainage made easy—by leaving out the parts that were difficult. And whilst we must pay respect to those stone-masons who built monuments to their craftsmanship, we could truly say that the bad old days were surely gone.

From 1945 the scene has changed. We do not consider a couple of hundred acres here and another couple of hundred there. Now we take the catchment as a whole. Firstly, we examine the entire catchment area which is drained into a river basin. This is done by the valuers section of O.P.W., a group of dedicated young men, who not only mark on their 6″ O.S. Maps (6″ to One Mile Ordnance Survey Maps) the extent of the land which will benefit from drainage but also carefully evaluate the actual potential improvement. Gone are the days when we could merely say that so many thousand acres were improved; to-day we can estimate the actual extent of the improvement. When all the damaged land in a catchment has been marked, it is up to the engineering staff to survey the channels required to drain this land and to prepare a scheme, estimate the cost and examine the economics of the various rivers and streams. And so the picture that finally emerges is this:—Here is a Catchment—it has an area of C,000 acres, it has A,000 acres of damaged land, B,000 of which can be improved to the O.P.W. present standards for a cost of £D,000. That is the final stage of a proposed scheme—to achieve it the engineering staff have to start the ball rolling in their examination of the problem. This is where we came in, with our pair of engineers leaving their Land Rover.

By this time they have gone some distance up the river and we'll have a look at what they are doing.

The first fellow, aided by his pair of workmen, is "pegging and barring". He is driving pegs into the bank of the river at regular intervals, ensuring at the same time that these pegs are not a hazard to man or beast. He knows exactly where to place the pegs because he has a "legged" 6″ map with him, i.e. a map with markings, or "leggings" as they are called, giving the position of the various cross-sections which will be taken. These cross-sections are marked at 100 yard intervals on major rivers and extended to 200 yard intervals on small streams. As the position of each cross-section has been previously marked on the map by scaling, the engineer needs only to locate the position by pacing or "legging" from the nearest identifiable fence. This system replaced the old laborious one of chaining and whilst it seems a small point, in fact, it makes for many times faster and much more accurate work. Now let's see what this "barring" is all about! The workmen are driving a hexagonal steel bar into the bed of the stream and, as the engineer watches its progress and inspects the materials adhering to the bar when withdrawn, he decides the classification of the types of material to be found in the bed strata. The types of material occurring in the banks are evident to the eye. The frequency of this barring varies somewhat, according to the engineer's assessment of the geological situation, but frequently where the leggings are 100 yards apart the barrings may be at 25 yard intervals.

In the event of rock or heavy boulders occurring this will understandably be reduced to barrings every 5 yards. On wide rivers both sides are barred simultaneously, whilst on small streams with 200 yard "leggings" barring at 50 yard intervals is adequate. Unless he hits rock or other impenetrable stratum, the engineer makes sure that the bar is driven to below what he considers to be the probable new design bed level. In the case of small streams, usually four feet is adequate, except near swampy terrain where an extra couple of feet are advisable. For small rivers six feet might be a popular choice, for major rivers perhaps eight feet, and for isolated short lengths where a deep cut may be envisaged, depths up to 12 feet below the bed may have to be considered.

In grouping the strata into the O.P.W. Classification the engineer is not primarily concerned in the geological considerations as an end in themselves, but rather as a method of placing the material in the correct category for a certain machine output. This is essential when it comes to pricing the quantities.

Heretofore the following six classifications of materials have been used :—

Type One	Solid Rock—identify it.
Type Two	Interlocking or continuous boulders.
Type Three	Hard boulder clay with frequent large boulders.
Type Four	Medium boulder clay with occasional boulders. Also hard gravel.
Type Five	Medium Gravels. Mixed Excavations. Hard Clays, etc.
Type Six	Soft Excavation, Soft Clays. Alluvial deposit and Soft Marls. Shingle. Topsoil. Turf, etc.

These classification details are supplemented by notes on the nature of the materials seen in the banks and in the case of large and medium-sized channels by trial pitting.

Trial pitting involves locating suitable pits about 6 ft. long $\times$ 2 ft. wide by 6 ft. deep at one end, to endorse the engineer's opinion of the strata, or to make him revise it. In the light of experience gained since the introduction of work study principles to excavation works, the time has come to re-examine our grouping system for classifying materials and this matter is being considered at the moment. Various scientific alternatives have been offered over the last decade, but we have not yet been able to select anything which will beat barring, on the basis of information obtained at such relatively low cost.

Frequently the writing up of the general features is the slower operation for the engineer than booking the actual barrings.

The general features comprise a detailed description of bridges, weirs, mills, etc. down to ditches, drains, post and wire fences, channel flow, self cleansing capabilities and general channel and bank behaviour. This engineer will also be using bar and sledge in his endeavours to obtain depths of foundations for most of the minor bridges. He will still be faster than his colleagues who will be doing all the levelling, but this arrangement enables the survey of each stream to be completed 'at one fell swoop'.

Let us have a quick look at what the levelling engineer is doing. Starting from an Ordnance Bench Mark—or much more frequently from a pair of pegs of known levels, this engineer will run a line of levels on the tops of the pegs at all the points corresponding to the leggings. He will reduce the levels of these so as to evaluate the height of the top of each peg above mean sea level—i.e. Ordnance Datum. This is a stage where accuracy is of paramount importance. Accordingly, on one very major survey recently concluded, the maximum permissable closing error was 0.10 ft., irrespective of distance, for the main river and for all major rivers and tributaries; whilst a maximum closing error of 0.25 ft. was permitted on the smaller streams which had no tributaries of their own. That this standard of accuracy was maintained reflects a measure of thanks to the Ordnance Survey Office who very kindy gave details of levels of their O.B.M's to three decimal places, which enabled their use to the second decimal place.

This engineer will also be levelling the cross-sections at each pegged chainage. He uses the level of the peg for O.D. level and all points above water level are measured by centre hair and stadia. The number of levelled points taken is determined by the detail necessary to plot a close profile of the section of each bank, and by the extent of the callows. Those lands, back from the bank of the channel which we can improve by Arterial Drainage are called the callows. In locating the levels of the river bed, three methods are used but the principal is the same in each. On really small streams (say up to 6 feet from bank to bank) the bed levels are determined by dipping with a graduated rod made from one inch round timber. On large streams and minor rivers a tagged rope is thrown across the channel and from it is suspended a graduated weighted board—say 4″ × 1″ by 6, 8 or 10 ft.—this is the dipping board. On large rivers where use of a dipping board is impractical a tagged rope is stretched across the river and dippings are taken with a long weighted rod from a boat. In addition to doing the long-levelling and the cross-section levelling this engineer also measures and levels all detailed features, i.e. bridges, mills, weirs, etc. en route. Thus the survey field operations are completed for that channel and when the last watercourse on the season's programme has been surveyed, it is a case of a final check on the equipment, wind-up and return to Dublin. But what happens when the survey party gets to Dublin?

The next stage is to plot on squared paper all the relevant survey data to assist in the preparation of a comprehensive drainage scheme. This is usually plotted on rolls of paper with one inch to 1/10th inch squares. Cross-sections are normally plotted to a natural scale of five feet to one inch, whilst longitudinal sections are plotted to a scale of five feet to one inch vertically and one hundred yards to one inch horizontally. For a typical cross-section see Fig. 1.

Where we have

(1) Present suveyed profile of the channel.
(2) Levels and distances from the bank of various callows to right and left of the channel.

These are plotted immediately the survey is completed for the season —together with details of materials, in bank and under bed, obtained during the survey.

The information on barrings and materials is omitted from Fig. 1 in the interests of clarity.

The D.F.L. (Design Flood Level) and the various choices of a proposed new channel will be added later, during the design, but more about this anon.

Simultaneously with the plotting of the cross sections we have the plotting of the longitudinal sections.

For a typical piece of a longitudinal section see Fig. 2.

We have :

(a) Left Bank. (L.B.).
(b) Right Bank (R.B.).
(c) Design Callow (D.C.).
(d) Water Level.
(e) Bed Profile.
(f) Representation of features—illustrated by a Bridge and a Weir.

Subsequently, at the design stage, other data will be added, such as

(g) Design Flood Level (D.F.L.).
(h) Final Design Invert Level (D.I.L.).
(i) Final Design Base Width.
(j) Final Design Depth of Flow.
(k) Design Run off.
(l) Design Discharge.
(m) Final Design Velocities.

$\left.\right\}$ Omitted from Fig 2 in interests of clarity.

(n) Final Design Grade.
(o) Data on Materials, etc.

TYPICAL CROSS SECTION

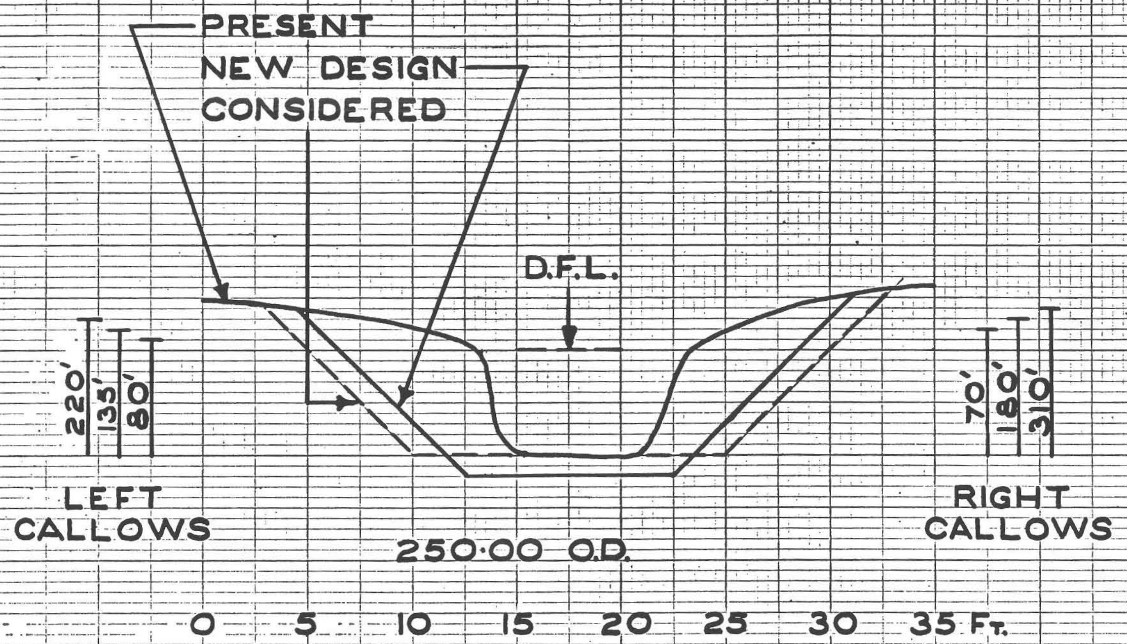
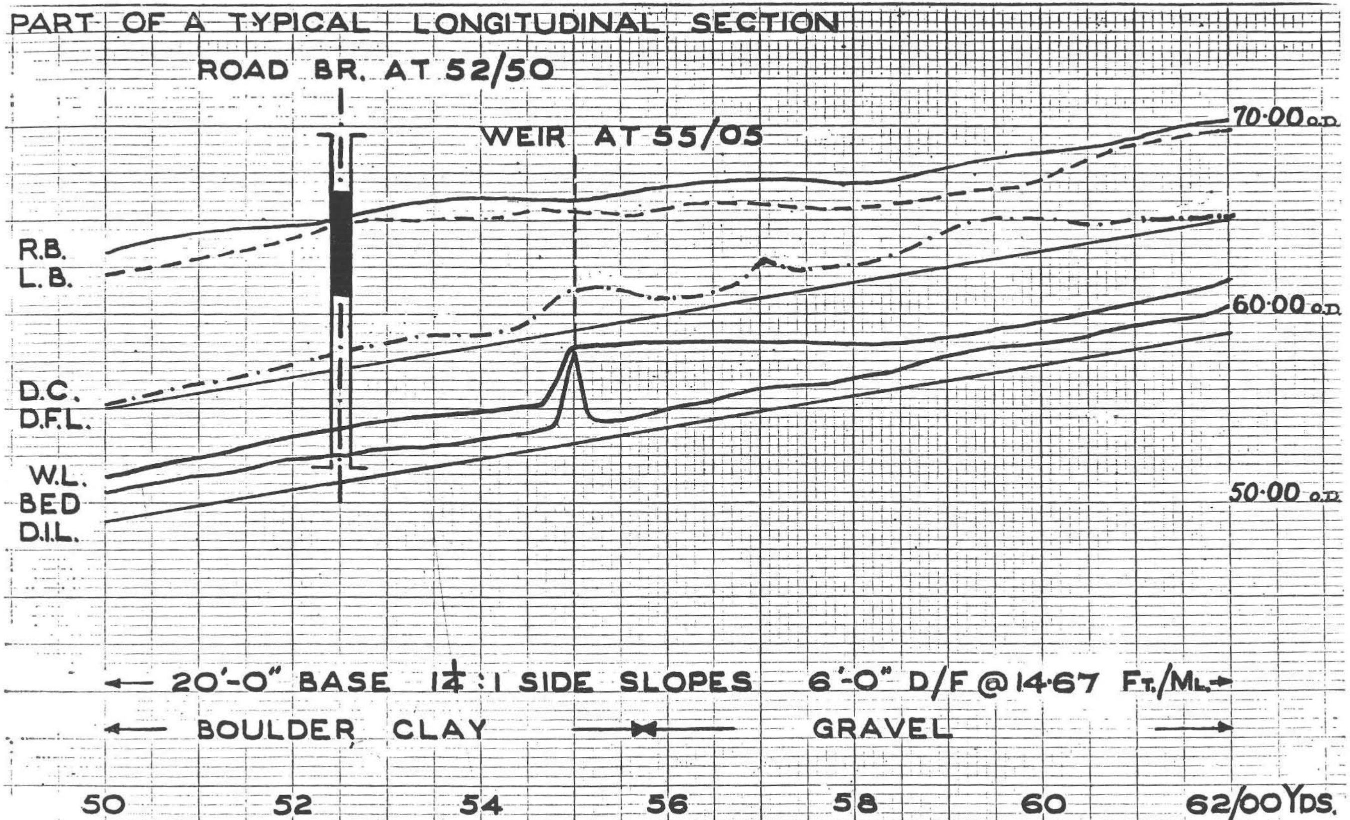


FIG 1



PART OF A TYPICAL LONGITUDINAL SECTION
ROAD BR. AT 52/50
WEIR AT 55/05
70·00 O.D.
60·00 O.D.
50·00 O.D.
R.B.
L.B.
D.C.
D.F.L.
W.L.
BED
D.I.L.
← 20'-0" BASE 1¼ : 1 SIDE SLOPES 6'-0" D/F @ 14·67 FT./ML. →
← BOULDER CLAY → ← GRAVEL →
50
52
54
56
58
60
62/00 YDS.

FIG. 2

But more about this when we come to take a quick glimpse at design procedure.

We have not place in an article of this length to enter into the field of channel design. In appending these very brief notes on the subject, we may have a moment's reflection on an occasional important matter and those familiar with the problem are asked to treat the obvious and numerous omissions with an extended charity of silence. If some of the points mentioned provide matters for general interest, the folly of attempting this subject in a few paragraphs will really have been a risk worth taking. Having plotted all the survey data on our rolls, i.e., cross-sections, longitudinal sections, and detailed features, we contemplate the kernel of the problem. What measure of improvement do we provide and how is it obtained?

We must digress slightly. Throughout the country the O.P.W. have a number of small sentry-box affairs frequently near major road bridges, on all major and most minor rivers. These are the automatic recording gauges. They operate continuously and the weekly chart on the drum shows clearly the water level at each hour of the whole week. By analysing these records, together with certain flow measurements, it is possible to plot accurate rating curves for the present pre-drainage discharges; thus we can know the amount of water passing down the river according to the height (depth) of water at the gauge. The availability of a continuous record enables flood frequency analysis to be investigated mathematically, and these can be converted to post-drainage flood frequencies. The complicated problems of rainfall analysis and catchment characteristics—such as size, shape, medial (average) slope, river network, etc. together with other run-off factors, soil, subsoil, cultivation, afforestation and other ecological data are examined.

Our hydrometric organisation has been the subject of frequent praise from eminent overseas authorities and we are proud of having a comprehensive coverage which is rarely equalled in the world to-day.

In one very specific instance, a method of obtaining and analysing the slope factor of a catchment was discovered, in a large and wealthy country, at a research institution which had very substantial funds at its disposal, and on publication it was discovered, that practically the identical methods and solutions had been developed here, and were being used for the previous twelve months by O.P.W. engineers, who, of course, have no research grant and whose primary function is to solve the day to day problems of the Board.

To return to our fields, one question frequently asked is what standard of protection do you give by Arterial Drainage.

Generally we cater for the three year flood. Having stated this we must immediately enlarge and offer a number of reservations. In certain circumstances floods far in excess of the three year flood form the design criteria.

What is the three year flood? It is the flood which will occur or be exceeded—on an average of say ten times in 30 years. This is a loose definition and it is totally wrong to suggest that this will occur or be exceeded once in three years. The three year flood could, of course, occur twice in any one year alone, but *over the long period* it will only be *equalled or exceeded* once per each three year period *on an average.*

If the "equalled or exceeded" tends to suggest, as it does, that if one designs for the "equal" part, we are not equal to the "exceeded" part, we conclude that perhaps some three year floods may be less equal than others—from the design view-point!

Such pessimism can be evaluated mathematically, and when we know the three year or say design flood, we know the value of say the six year flood, which is of course much higher, and which will occur "or be exceeded" five times in a thirty year period on an average. To complete the debit side of the picture, there is the occasional, but very rare, instance where a small pocket of low callow adjacent to a major river is such that to offer the "three year flood" standard of protection might cost thousands of pounds, in extra deepening of main river plus extra under pinning of bridges, and the callow in question might be little better than five acres of cutaway bog.

The credit side is much more frequent and requires more consideration.

Firstly, whilst the line of the Design Flood Level will go over the occasional callow level by perhaps a couple of inches, for every callow level it will go above there will usually be dozens which it will go below, and in a particular instance where the depth of flow is say 6 ft., the callows 6 inches above this flood line, would be enjoying the "twenty year flood" standard of protection. Secondly there are frequently occasions where the design is for a flood much greater than the "three year flood", for portions of a scheme. Thirdly, for large and medium sized sub-catchments the Design Criteria will be to convey the "three year flood" which will flow at or below the design flood level, nevertheless there is a second criterion which we provide. We are providing Arterial Drainage, and we have mentioned flood prevention, we must now turn to the matter of drainage. Again, normally (with reservations) we provide approximately 4′ 6″ of drainage below the design callow level. By this we mean, that we are providing drainage, such that the normal summer water level in the channel is approximately 4′ 6″ below the level of the callow lands.

In the event that the callow lands extend for any considerable distance from the banks of the channel, then extra deepening must be effected to enable the water table to be lowered sufficiently beneath these callows.

If the callow lands in question tend towards swampy conditions, then removing the water will, of course, cause a lowering of the level of these lands due to shrinkage.

The minimum sized channel that is excavated, i.e. 4 ft. base perhaps, 1 :1 or $1\frac{1}{4}$:1 side slopes has now taken over much of the mileage of channel on some schemes. Taking a specific, yet frequent example, of where a channel drains only a relatively small catchment area, for its size; the "three-year-flood" may only produce a depth of flow of say 3′ 0″. If the callow levels are 4′ 6″ above even the new bed level—and this is usually the minimum, then in that circumstance the callow lands would be flooded only once in 123 years on an average—say eight times in a thousand years.

Fourthly, whilst the "three-year flood" will only be equalled or exceeded once in three years on an average—most of these floods will occur during the winter months. And if we consider the principle growing period to be, say early March to mid-October, then the "three year flood" will only occur or be exceeded—from once in ten years to once in fifteen years—depending upon the catchment and its characteristics, during the principal growing period.

Other considerations arising include the problems of mills and water rights, of water supplies, of local amenities, of fisheries, of lakes, etc.

In the actual selection of the Design Flood Line itself, questions, of back water calculations, draw down calculations and stretches of non-uniform flow will have to be considered and problems of velocities, etc. will have to be solved from their various aspects.

When the Design Flood Level has been fixed the problems associated with going a little deeper to reduce excavation quantities, and to limit excavation costs are of major concern for each reach of main river channel. See Cross-Section Figure I. The deeper proposal illustrates a case of where by excavating deeper, with a narrower base, of course, the total area (or quantity) to be excavated is actually less. But there are practical limits to the depth you can go, and in the event of additional depth incurring harder and more expensive materials, you can reach a situation where the deeper proposal, although involving a reduction in the actual quantities, requires an increase in costs.

Channels which are highly efficient hydraulically, may create high velocities during flood conditions which could entail expensive bank protection. In extreme brevity it may be accepted that the most efficient channel hydraulically will usually not be the cheapest; and most often the "best buy" will be a channel which is neither the most efficient, nor the cheapest although frequently not far removed from either.

These considerations may entail several designs for various depths, with corresponding base widths, for each length of major channel designed and estimated for. The best results will always be obtained by a consideration of all the facts guided in the light of experience and in the final analysis on the question of design there is no formula to replace sound judgment. All this means, of course, having several lots of quantities and an equal number of estimates for main channel prior to making our final selection.

And so we get our final scheme, B,000 acres improved to a known potential percentage for £D,000.

Having examined all channels which have any possibility of inclusion in the scheme, there comes the problem of eliminations; primarily due to cost—perhaps some of the channels investigated may warrant a financial outlay, out of all proportion to the benefit to be accrued, either in terms of cost per acre improved; percentage of improvement of the potential of the land; or the actual increase in value of the land.

And so we get to our final scheme, draw up the Exhibition Maps, that is those maps which are displayed locally to enable the beneficiaries and others to examine the proposed scheme. The exhibition of maps and the other legal documents are advertised in the newspapers and all interested parties should examine the maps and attached schedules.

At the conclusion of the exhibition period, the observations of the interested parties have to be considered; other Government Departments have to be consulted; and the scheme has to be sent to the Minister for Finance for confirmation, before works can be commenced.

We have described all too breifly some of the procedures involved before we reach this stage but the question "WHEN will they do the work" remains unanswered. To answer "it would start when all the processes described together with a few others have been completed" would not be a fair answer. In present conditions in the engineering situation, one factor has loomed larger than the others in providing the answer. When the final quantities on a particular watercourse have been taken out, together with preparing a financial estimate, the channel is classified under the type of machine, and the duration of the job. It is axiomatic that large rivers are more efficiently and cheaply excavated by large machines. The larger machines are very expensive but as they travel upstream they will eventually reach a point where it is more economical to replace them by smaller machines. If these large machines are on a scheme, and do their job until smaller machines take over, then, after a period of overhaul, a second scheme must be ready to take them without delay and this is the indicator which often fixes the deadline.

Since Chief Engineer Manning produced his universally used formula, staff of the Board at all levels have engaged in minor research and in the field of design have produced innumerable charts, tables and diagrams which have helped and continue to help us reach the deadline.

This has been slightly offset by the application of work study and bonus schemes to Arterial Drainage works resulting in reduced costs, increased outputs and, of course, reduction in time of duration of a scheme. This presents a new challenge which those preparing a scheme readily welcome.

In the Second Programme for Economic Expansion, Agriculture has been set a target of an annual increase in gross agricultural product of 2.70%; Arterial Drainage contributes towards this achievement and also helps Forestry towards its target.

In this connection the Arterial Drainage programme over the past few years have averaged an improvement of nearly 20,000 acres per annum and the potential improvement of the land has averaged over 70%, and in the case of one scheme, in which over 21,000 acres benefited, the improvement was 110%.

In addition the O.P.W. Arterial Drainage Division has a large maintenance commitment on schemes which were carried out under the 1945 Arterial Drainage Act, and at present watercourses are being maintained which benefit 200,000 acres of land under this heading—at an Annual Gross Maintenance Cost of aproximately 1% of the cost of "doing" the scheme initially. Viewed another way, when an Arterial Drainage Scheme has been completed the engineer will be provided each year with a sum of about $\frac{1}{6}$th of the amount of the annual interest on the capital cost of the scheme, to maintain those watercourses.

We have long overshot our allotted space—and we haven't even mentioned the benefits accruing to Arterial Drainage from Afforestation.

On the subjects we have mentioned we must plead guilty to hedge-hopping.

We will have to conclude—but before doing so, some acknowledgements are necessary.

Firstly, whilst accepting full and sole responsibility for the contents of this article, the writer wishes to emphasise that any views expressed are entirely his own and are not necessarily the views of the O.P.W., at the same time he would like to offer a sincere word of thanks to the Chief Engineer and engineering staff and to all who have so freely made information available.

Secondly, the Presidential Address of Mr. Candy to the Institution of Civil Engineers of Ireland in 1948, has been the source of much of the information on the references to the various Drainage Acts from 1842 to 1945. Whilst this was the only paper specifically consulted, a large number of scientific and technical papers have been published by O.P.W. staff and others, on related subjects for over a hundred years. In addition to what has 'percolated' from these sources, a considerable body of technical data has been available in the day to day working in the office. The writer wishes to express acknowledgement, wherever it may be due.

Lastly, the Commissioners of Public Works are sincerely thanked for kindly consenting to publication.