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**The effect of flood-elimination works on the flood frequency
of the River Wandle†**

by

James Edward Nash, M.E., A.M.I.C.E.I.

Discussion

Mr T. O'Donnell (Lecturer in Civil Engineering, Imperial College of Science and Technology) observed that if each of the effective rainfalls causing each of many pre-works hydrographs coming off a catchment was known in detail, and there was a prediction of a post-works unit hydrograph for that catchment, then the calculation of the post-works hydrographs appropriate to those effective rainfalls would be a straightforward, if tedious, matter. The detailed distribution in time of effective rainfalls was, however, not easy to estimate accurately and confidently from rainfall records, particularly if those records consisted mainly of daily rainfall figures, as presumably had been the case for the Wandle records. Even with continuous autographic records of incident rainfall, there was the further problem of sorting out the effective fraction.

32. Far better, then, was the Author's neat and bold device of eliminating the need for explicitly deriving the effective rainfalls, for all but one of the recorded pre-works hydrographs, in his method of transforming from pre- to post-works conditions. In essence, the Author had eliminated the effective rainfall from any given transformation, treating it as an unwanted "unknown" in two "simultaneous equations":—

$$\begin{array}{l} \boxed{\text{Effective}} \quad \text{with} \quad \boxed{\text{Pre-works unit}} \quad \text{yields} \quad \boxed{\text{Pre-works}} \\ \boxed{\text{rainfall}} \quad \quad \quad \boxed{\text{hydrograph}} \quad \quad \quad \boxed{\text{hydrograph}} \\ \\ \boxed{\text{Effective}} \quad \text{with} \quad \boxed{\text{Post-works unit}} \quad \text{yields} \quad \boxed{\text{Pre-works}} \\ \boxed{\text{rainfall}} \quad \quad \quad \boxed{\text{hydrograph}} \quad \quad \quad \boxed{\text{hydrograph}} \end{array}$$

and manipulated three of the remaining four factors in such a way as to "solve" for the second "unknown", viz. the post-works hydrograph. The need for establishing the pre-works unit hydrograph caused the one exception to this welcome sidestepping round the problem of precise determination of effective rainfall quantities.

33. Clearly, the accuracy of such an analysis hinged on the correctness of the estimation of the pre-works unit hydrograph and the correctness of the prediction of the post-works unit hydrograph, however, those two responses were obtained.

34. In the case of the Wandle, the Author had selected a single flood and derived a pre-works short-period unit hydrograph in the usual way (§ 11). Figs 4 and 5 showed that the shortest durations of effective rainfall for the floods from which selection was made were 2 hours in the case of Wandle Park, and 2½ hours for Middle Mills; the floods selected might well have had durations longer than those times. The unit hydrographs derived, listed in Table 3, were shown plotted in Figs 8 and 9, but with the caption to those Figures reading: "... instantaneous unit hydrographs. ..." The Author had rightly pointed out in § 18 that his transformation did not demand the use of instantaneous unit hydrographs, but nevertheless he had gone on to stress the desirability of doing so. Were the effects of approximating such short-period (period 10% or more

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of the total duration of the unit hydrographs) as equivalent to instantaneous unit hydrographs negligible, or acceptable within the limits of accuracy of the unit hydrograph concept as applied in that particular context? The preparation of an effectively instantaneous unit hydrograph from short-period unit hydrographs by the normal process tended to be inaccurate in practice. In any case, it was still an approximation in theory, since that process must always end up with a still finite-period unit hydrograph. A method of finding the true instantaneous unit hydrograph directly from effective rainfall and run-off hydrograph data is mentioned in § 36. That would avoid the use of the approximation. Whether or not that point was of importance, might it not have been prudent to derive and compare unit hydrographs from the other floods shown in Figs 4 and 5, before selecting a representative one? One would then feel more confident that one of the two key factors in the pre- to post-works transformations had been safely determined.

35. The prediction of the post-works unit hydrograph was based first, on the dimensions of the pre-works unit hydrograph (thus making the accurate determination of the latter even more important), and secondly, on the lag ratios listed in § 10 and determined from Fig. 2. Without questioning the correlations and assumptions used in deriving Fig. 2, the question arose: what would be the effect of choosing a different position for the assumed relation line shown in that Figure? The quantitative answer to this was, of course, try another position and repeat the calculations. Qualitatively, a higher position of that line would give longer lag times for the post-works unit hydrograph and smaller values, therefore, of the lag ratios, and vice-versa. The higher the position chosen, the closer would the post-works unit hydrograph approach the pre-works unit hydrograph. Consequently, the smaller would be the difference between a transformed post-works hydrograph and the recorded pre-works hydrograph on which it had been based. The latter could have only positive values, so, to the reasons given in § 19 as possible causes of negative values in the transformed hydrographs, there might be added:—

- (d) over-generous margin of safety in positioning the assumed relation line in Fig. 2 too low.

It might be of significance to note that for the post-works hydrographs presented in Figs 10 and 11, negative values occurred for Wandle Park transformations for which the lag ratio used had been 1.6, whereas the Middle Mills curves, for which the slightly lower figure of 1.5 had been used, showed no negative values. Possibly a suitable criterion governing the choice of position for the assumed relation line arose from this: find, by trial, a position which just ensures that no negative value occurs in any transformed hydrograph.

36. The Author was aware that Mr O'Donnell had developed a method of evaluating the instantaneous unit hydrograph directly from effective rainfall and run-off data, via a technique of harmonic analysis and synthesis. The process had been programmed for use on the London University Mercury computer. Preliminary results, based on data supplied by the Author, were encouraging, and the work was being prepared for publication. Using the Author's notation of § 15, the existing Mercury programme could be used without modification to find x , the effective rainfall, from u , a pre-works unit hydrograph, and y , a run-off hydrograph due to that rainfall. In this case, u would be a truly instantaneous unit hydrograph derived, as by the Author, from selected pre-works data, but evaluated via the harmonic analysis and synthesis programme. Thus, the approximation discussed in § 34 would be avoided. A second programme already existed also for finding y from x and u , or, more pertinently, for finding z , the post-works hydrograph from x and v , the post-works instantaneous unit hydrograph. A combined programme, based on these two existing programmes, could be written and used to compute z from data relating to y , u , and v , as did the Author's ingenious matrix inversion programme. This combined programme would compute values of x en route to its determination of z , but this was no disadvantage. It would need to be written to store x -values as they appeared from the first half of the computation prior to using

them in the second half. It would need a very simple instruction to print these x -values, as well as the z -values at its completion, if so desired.

37. If there was no other difference between the two techniques of finding z from y , u , and v , then there would be little to choose between the matrix inversion method and the harmonic analysis and synthesis method. However, as pointed out in § 17, "... the capacity of any high-speed computer is limited. ..." The limit was set by the number of storage locations available in the computer for accepting data or instructions. Comparing the number of storage locations needed to handle a flood defined by, for example, forty equally-spaced ordinates, it was estimated that the matrix inversion method would need about 1,700 locations, whereas the harmonic method would need about 200 locations. The Author circumvents the capacity limit by the neat device of breaking down a complex hydrograph into a number of simpler ones with fewer ordinates and operating on these individually. The harmonic method would be capable of handling a proportionately more complex hydrograph before reaching the capacity limit of a given computer without the necessity of subdivision. In addition, though the enormous speed of a modern computer made for very short computing times in either technique, the times taken would increase rapidly as the number of flood hydrograph ordinates increased; it was considered that the *rate* of increase was appreciably greater for the matrix inversion method than for the harmonic method. The time taken by the computer in reading the input programme and printing the results would take up a proportionately larger slice of the total time in the shorter method, so the net difference would not be so marked.

38. For advice and the carrying out of the computer aspects of his work, Mr O'Donnell acknowledged his indebtedness to D. G. Burnett-Hall, M.A., Department of Mathematics, Imperial College of Science and Technology.

Mr A. B. Huntley (Assistant Borough Engineer, Croydon) observed that the basis of the Author's argument was that the flow regimen of the Wandle in its post-works condition might be predicted from that of the Beverley Brook and Hogsmill, which had been improved and were not now obstructed by weirs and inefficient sluices as was the Wandle. Since the object of the works was flood elimination, was satisfactory evidence available to show that the Beverley Brook and Hogsmill were now free from floods?

The Author, in reply to Mr Huntley, observed that while it was very likely that the post-works Wandle would be more free from flooding than the other catchments were at present, there was little doubt but that those catchments were very much closer to the post-works Wandle than to the pre-works Wandle. In fact, drawing the lag-slope relation in Fig. 2, below the Wimbledon Common and Grange Road points, provided for a somewhat higher degree of drainage in the Wandle (§ 10). The comparison with the Beverley Brook and Hogsmill provided only one of the many possibilities, indeed certainties, of inaccuracy. However, in the present state of knowledge the method chosen might not be good but had to be the least objectionable of those available. In this work the principle followed had been to avoid unsupported theory as much as possible and to rely on the records of floods in the catchment. Some modification of those records to allow for changes in the flood-frequency regimen due to the river improvement works was obviously necessary. An estimate of this effect had been made, which depended on a forecast of the change in the instantaneous unit hydrograph. The forecast had been made by comparison with the neighbouring catchments and by consideration of the recorded change in the Brosna due to extensive flood relief works. The alternative would have been to try to predict the post-works flood-frequency regimen by analogy with other catchments. That would obviously have been much less reliable than predicting the change in a fairly well established pre-works relation.

41. Mr O'Donnell had accurately summarized the method used in §§ 32, 33. The accuracy of the method certainly depended on the accuracy of the pre- and post-works unit hydrographs, but more on the relation between them, than on their absolute values.

The ratios between the lags of the instantaneous unit hydrographs was the same as the ratio between the lags of any pre-works flood and that of its post-works counterpart. The pre-works lag had been obtained for a number of floods and the post-works lag from the correlation. Before the transformation of the record it had been necessary to have a pre- and post-works pair of floods for use as $[u]$ and $[v]$ in equation (3). Therefore some assumption had had to be made about the change in shape of one flood. In general the shapes of a flood and of its post-works counterpart might be quite different, but it was common knowledge that all floods due to short intense storms resembled one another closely in shape, even when the floods occurred on widely different catchments. That was the basis for the use of a fixed-shape instantaneous unit hydrograph (e.g. Commons⁷ and many others). Therefore, because the range of possible shapes was more limited, it was better to assume that the shape of a flood due to a short intense storm was unchanged between pre- and post-works, rather than to make the same assumption for a more complex flood. The instantaneous unit hydrograph was the ideal short-period flood. Mr O'Donnell had suggested that an attempt might have been made to obtain this unit hydrograph from one or more of the Middle Mills and Wandle Park floods. Theoretically this could be done either by using Mr O'Donnell's application of harmonic analysis or by simply solving for $[u]$ in equation (1) applied to such a flood. However, small errors in the records, the base flow separation, the theory, or the definition of the effective rainfall frequently produced a very "saw-toothed" short-period unit hydrograph when a complex storm was so analysed. That meant that the shape of a unit hydrograph so derived was highly unreliable. The saw teeth had to be smoothed out and probably the best way to do it was to smooth towards the shape of a recorded flood due to a short intense rainfall, thus preferring the shape of such a flood to that of the derived instantaneous unit hydrograph. In the Paper, the shape chosen in each case was that of the flood which appeared to be most free from random fluctuations; little would be gained by comparing this shape with those of other floods which were manifestly less regular.

42. Mr O'Donnell had suggested (§ 35) a further possible explanation of the negative ordinates in the transformed floods at Wandle Park, and, tacitly assuming this to be the only cause, had suggested that the maximum lag ratio might be determined by the criterion of non-negative ordinates. Apart from the fact that such a criterion would ignore the other causes of the negative ordinates mentioned in the Paper, it was not possible to attribute the negative ordinates at all to excessive lag ratio. The negative ordinates implied negative effective rainfall, because all the ordinates of the post-works unit hydrograph were positive. The effective rainfall was obtained from the pre-works unit hydrograph and the pre-works flow record. Therefore the negative rainfall had to be attributed to one or both of these. The reason why there were no negative ordinates in the transformed Middle Mills record was that the presence of the base flow provided, as it were, a positive store which could be encroached upon. (See particularly the flood of 17.4.47, Fig. 11.)

43. The Author awaited with interest the publication of Mr O'Donnell's harmonic method and hoped to see some worked examples.

REFERENCE

7. G. G. Commons, "Flood hydrographs". Civ. Engng, N.Y., vol. 12 (1942) p. 571.