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MODELS FOR FLOODS IN URBAN AREAS OF WEST AFRICA

by

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MODELS FOR FLOODS IN URBAN AREAS OF WEST AFRICA

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SUMMARY

The phenomena of urban development places the hydrology specialist in a very special situation where he is obliged to reconsider the action that he takes at all stages. As soon as the water reaches the ground it is effected by the conditions that have been artificially created by man. Only the precipitation itself remains an almost natural phenomena unlike surface retention, infiltration and run-off.

The hydrology specialist who normally uses an equation, in the case of a natural catchment area, to transform precipitation into the flow of water in the hydrographic network, is not only obliged to use an alternative procedure but he must also work with respect to other objectives where the concept of comfort replaces the concept of danger.

Following the collection of data, as a result of studies in the region of NIAMEY and BRAZZAVILLE, which was used with the usual models representing typical catchment areas, using the run-off coefficient, the concentration time and the mean hyetograph, the Hydrology Service of ORSTOM (Office de la Recherche Scientifique et Technique Outre-Mer) is now developing a new procedure specifically for Urban Hydrology.

We studied the phenomena of run-off on elementary surface areas that were as small as possible: run-off surfaces up-stream from the drain inlets. Combining the elementary flows of each drain inlet is a hydraulic problem that can be dealt with by a model, it is not a hydrology problem. We do, however, pay particular attention to the distribution of the rainfalls in time and space, the surface retention and the natural or artificial retention.

In fact we study the effect of urban development on all phases of the water cycle, the final objective being to establish a chronological series of data in order to assess different proposals for development and drainage. We hope to make a contribution in the comparative study of different projects, not only with regard to capital cost but also with respect to comfort, health and the repercussions with regard to flooding as well as the down-stream behaviour of water and the hydrologic balance.

ORSTOM are at present concerned with this type of research in the urban areas of LIBREVILLE and OUAGADOUGOU. Other studies are due to begin in 1975 at LOME and ABIDJAN, and others are planned for BOUAKE, BAMAKO and CAYENNE.

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J. CRUETTE

In making calculations concerning the drainage system for urban areas, the Technical Services of West Africa have frequently used procedures based on the General Circular 1333 of the Ministry of Reconstruction and Urban Development. This Circular, dated 1949, is based on the CAQUOT equation established for the Paris region. It has often been noted, however, that in tropical areas, the drainage systems that have been dimensioned to remove water from ten year rain storms, are in fact unable to deal with annual floods.

Thus the Hydrology Service of ORSTOM has been obliged to make measurements of run-off in urban areas and to consider the problems of drainage. In the first instance, the urban catchment areas have been considered as representative catchment areas in accordance with the usual hydrology procedures. Equations have been established for determining the maximum flow of water to be removed.

1 - GENERAL MODELS : EQUATIONS FOR URBAN RUN-OFF

1.1 - Results of Run-off Measurements

ORSTOM have made systematic measurements of run-off for different catchment areas in the urban region of NIAMEY (Niger).

Three catchment areas were concerned:

- catchment area No. 1 which is located in a dense urban area of a traditional African type of habitat,
- catchment area No 2, half of this area accommodating the administrative and commercial centres and the living quarters of traditional habitat,
- catchment No. 3-4 located in a residential area accommodating villas with gardens and provided with a rather poor drainage network, the land being somewhat permeable.

Before this work ORSTOM had previously made measurements, in a somewhat summary manner, in BRAZZAVILLE (Congo) in the catchment area of MAKELEKELE.

More recently measurements have been made in the catchment area of MFOUNDI which drains the town of YAOUNDE (Cameroons).

Table 1 brings together the results obtained from these five catchment areas. The entries in this table give the surface area in km^2 and the maximum flow observed during the three years of measurement expressed in l/s and $l/s.km^2$. The table also gives the coefficient of run-off observed for the same flood in each case.

Applying the usual ORSTOM procedures involving an analysis of the run-off factors and a reconstitution of the observed hydrographs, an estimation of the ten year flooding was made on the basis of the three years of observations. The maximum flows and the coefficients of run-off resulting from this procedure are given in the following three columns of this same Table 1. Thus these figures constitute an extrapolation of the observed values and they should be considered simply as giving orders of magnitude of the required values.

We applied the so called PARIS and MONTPELLIER versions of the CAQUOT equation for the same five catchment areas, respecting as carefully as possible the recommendations given in the General Circular 1333. The values assumed for the slopes and the coefficient of run-off are given in the following two columns of Table 1. The flows obtained as a result of applying this equation are given in the next two columns. It will be seen at once that the flows obtained by the

TABLE 1

	S km^2	Summary of observations made						Application of CAQUOT equation				CIEH equation l/s
		Maximum observed flood			Ten year flood estimate in accordance with measurements made			Slope		PARIS equation l/s	MONTPELLIER equation l/s	
		Q max l/s	Q max l/s.km^2	C	Q max l/s	Q max l/s.km^2	C	I	C			
NIAMEY												
Catchment area												
No. 1	0.564	5480	9700	0.36	7000 to 9500	12000 to 17000	0.31	0.0069	0.55	2600	3150	7000
No. 2	1.061	8400	7900	0.54	10000 to 13500	9000 to 12500	0.40	0.0070	0.70	6000	7400	14000
No. 3	1.542	2600	1700	0.05	3100 to 4600	2000 to 3000		0.0050	0.20	1800	2600	
BRAZZAVILLE												
Makelekele	3.080				12000 to 15000	4000 to 5000		0.0035	0.30	4400	6900	
YAOUNDE												
M'foundi	38.800	23900	615	0.20	42000	1080	0.18	0.0062	0.20	21000	39000	56000

PARIS equation are clearly less than those observed during the three year period. For the series of flows observed the levels were exceeded on average more than once per year. Thus we are a long way from the ten year flood. The MONTPELLIER version of the equation gave flows greater than those of the PARIS version but they were again too low except perhaps for the large catchment area of YAOUNDE.

1.2 - ATTEMPTS TO ADAPT CAQUOT'S EQUATION

In order to establish a general equation applicable in Tropical Africa, it would be necessary to have a greater number of results from flow measurements. The results of such measurements will, however, not be available and suitable for use for several years. Thus it is of interest, at the present time, to make a theoretical approach to the problem with a view to establishing provisional equations that can be used by engineers and planners and that will give results that are closer to the conditions in Africa.

The first idea which comes to mind is to try and adapt the CAQUOT equation by modifying the different coefficients that appear in the general form of that equation:

$$Q = K \; I^{m} \; C^{n} \; A^{p}$$

where:

Q is the required flow in l/s

K is a numerical coefficient

I is the average value of slope for the complete traverse of the water (in mm)

C is the run-off coefficient for the catchment area

A is the surface area of the catchment area in hectares.

This equation can also be written as follows:

$$Q = \left[\frac{10^{3} \cdot a}{6 \; (\beta + \delta)\mu^{b}}\right]^{\frac{1}{1-bf}} \cdot C^{\frac{1}{1-bf}} \cdot I^{\frac{bc}{1-bf}} \cdot A^{\frac{1-bd-\varepsilon}{1-bf}}$$

where:

= 0.75, = 0.1, = 3.7, c = 0.363

d = 0.366, f = 0.20

The parameters a and b define the climate in the Montana type equation which relates the intensity to the duration of the precipitations.

$$i_{(mm/min)} = a \cdot t_{min}^{-b}$$

Substituting values for the parameters a and b, corresponding a ten year rainfall gives the following for the PARIS and MONTPELLIER versions of the above equation:

PARIS $Q = 1\,340\ I^{0.30}\ C^{1.17}\ A^{0.75}$

MONTPELLIER $Q = 580\ I^{0.16}\ C^{1.09}\ A^{0.82}$

1.2.1 Application to the Ivory Coast

The above adjustment to the equation was tried for the Ivory Coast by the Bureau National d'Etudes Techniques de Développement (BNETD) and the engineers concerned used the following four equations for the different climatic zones of the Ivory Coast.

a) Coastal zone (ABIDJAN, SASSANDRA, AGBOVILLE)

$$Q = 1\,260\ I^{0.18}\ C^{1.10}\ A^{0.84}$$

b) Central-east region (BOUAKE, DIMBOKRO, BONDOUKOU)

$$Q = 2\,270\ I^{0.27}\ C^{1.15}\ A^{0.80}$$

c) Central-west region (MAN, GAGNOA, DALOA)

$$Q = 1\,800\ I^{0.25}\ C^{1.14}\ A^{0.84}$$

d) North region (FERKESSEDOUGOU, KORHOGO)

$$Q = 1\,250\ I^{0.18}\ C^{1.10}\ A^{0.87}$$

Graphs have been drawn up by BNEDT for a rapid application of these four equations.

1.2.2 Application to the Sahel-sudan region

For the Sahel-sudan region, a similar study to the above has been made by the Hydraulic Department of the l'Ecole Inter Etats des Ingénieurs de l'Equipement Rural at OUAGADOUGOU.

For the countries of Tropical Africa in the Sahel-sudan region we are able to refer to the results of studies made by Y. BRUNET-MORET and to information provided by ORSTOM. Thus available intensity-duration-frequency curves for the different countries give the following values for the parameters a and b in the Montana equation:

b is sensibly constant and equal to 0.5

a varies between 7.0 and 7.8 with an average value of 7.5 for the following four countries: MALI, UPPER-VOLTA, NIGER, CHAD and for the strip of land lying between latitudes 10° and 15° north. For SENEGAL we can assume a value of a = 8.5.

Allowing for the limited accuracy of the equation we consider that the intensity of the ten year rainfall in this area is given approximately by the equation:

$$i_{mm/min} = 7.5 \cdot t_{min}^{-0.5}$$

for rainstorms having a duration of less than 90 minutes.

Substituting the values of a and b in the general CAQUOT equation gives:

$$Q = 850 \; I^{0.20} \; C^{1.11} \; A^{0.80}$$

The application of this equation to the experimental catchment areas of NIAMEY gives respectively:

for catchment area No. 1 with $I = 0.007$, $C = 0.55$ and $A = 56.4$ ha

$Q = 4\,070$ l/s

for catchment area No. 2 with $I = 0.007$, $C = 0.07$ and $A = 106$ ha

$Q = 8\,800$ l/s

The above figures must be reduced respectively by 15 and 10 % to allow for the elongation of the areas, giving 3.500 l/s for catchment area No. 1 and 7.900 l/s for catchment area No. 2. These values are a little better than the results given by the MONTPELLIER version of the CAQUOT equation but they are still less than the experimental values.

The coefficients for the different equations mentioned above are listed in Table 2.

TABLE 2

	K	m	n	p
PARIS (M. GRISOLLET)	1340	0.30	1.17	0.75
MONTPELLIER (M. GODARD)	580	0.16	1.09	0.82
IVORY COAST (BNETD)				
Coastal region	1260	0.18	1.10	0.84
Centre-east	2270	0.27	1.15	0.80
Centre-west	1800	0.25	1.14	0.84
North	1250	0.18	1.10	0.87
HAUTE VOLTA (CIEH)				
Ouagadougou	850	0.20	1.11	0.80

Different adjustments to the CAQUOT equation $Q = KI^{m}C^{n}A^{p}$

1.3 - Establishing an equation more suited to African conditions

The mediocre results obtained as a result of adapting the existing equation, as described above, leads us to question the validity, for African countries, of the different assumptions which form the basis of CAQUOT equation.

If we make a detailed study of the different parameters which make up the indices in the CAQUOT equation, we note that apart from the two parameters a and b which define the rain-storm conditions, CAQUOT uses seven parameters to which he assigns very precise numerical values based on observations made concerning the operation of the drainage system in the Paris area. The use of these parameters results in a multiplication and addition of possible errors in a way which is difficult to predict. In order to establish an equation more suited to African conditions, it would seem to be logical to abandon methods based on the use of the CAQUOT equation in favour of a procedure based on the rational method, in spite of the objections that this procedure can lead to a systematic over-dimensioning of the drainage system, no account being taken of the storage capacity of the system.

We will try to establish our final equation so that it has a single valued form similar to that of the CAQUOT equation. This form of equation clearly has some imperfections but its use is justified by the fact that we can only hope to obtain approximate results. In fact by assuming that the flow can be given by an equation of the form $Q = f(I) \cdot g(C) \cdot h(A)$ we imply, which is no doubt in contradiction with real conditions, that the three parameters effect the flow independently. The advantage of this form of equation is that it leads to a method of analysis which is simple and easy to use pending the availability of a sufficient number of results of actual run-off measurements which will allow a more detailed analysis concerning the inter-action of the different parameters.

We should remember that the equation only gives approximate results and we should not define decimal indices with two or three significant figures, giving a false impression of acuracy.

The flow is given by the equation $Q = K \cdot C \cdot i \cdot A$

where Q is the flow, K a numerical coefficient whose value depends on the units involved, C the run-off coefficient, A the catchment surface area and i the intensity of the rain-storm occurring every ten years having a duration equal to the concentration time for the catchment area.

In order to take account of the unequal distribution of the rainfall over the area we can use a reducing coefficient and we propose an index related to the area having a value of 0.95.

The intensity of the rain-storm is related to the duration by a Montana type of equation of the form:

$$i = a\, t^{-b}$$

The equation giving the flow is then:

$$Q_{l/s} = \frac{1\,000}{6} \quad C \quad i_{mm/min} \quad A_{ha}^{0.95}$$

where $Q_{l/s} = \frac{1\,000}{6} \cdot a \cdot C \quad t^{-b} \quad A^{0.95}$

All that remains is to determine the concentration time as a function of the hydraulic parameters: slope of the network I and the longest distance followed by the water L. Expressing the speed by means of a Chézy type of equation ($U - K\sqrt{I}$), the traversing time through the drainage system can be expressed in the form:

$$t_1^{s} = \frac{L\,metres}{U^{m/s}} = \frac{L}{K\sqrt{I}}$$

In order to take account of surface run-off outside the drainage network we increased this time t_1 by 25%. Furthermore, allowing for the average characteristics of the drainage ducts we can assume that K = 25. This gives for the concentration time:

$$t_{second} = \frac{1.25\ L_m}{25\sqrt{I}} \quad \text{or} \quad t_{min} = \frac{1.25}{60} \cdot \frac{100}{25} \cdot \frac{L_{hm}}{\sqrt{I}} = \frac{1}{12}\ L_{hm}\ I^{-\frac{1}{2}}$$

If we substitute the above value in the equation for the flow we have the following general equation:

$$Q_{l/s} = 167 \cdot 12^{b} \cdot a \cdot C \cdot I^{b/2} \cdot L_{hm}^{-b} \cdot A_{ha}^{0.95}$$

a) <u>Application to the Sahel-Sudan region</u>

We have seen that for this region we can assume as a first approximation, for rain-storms having a duration of less than 90 minutes, a = 7.5 and b = 0.5.

Substituting these values in the general equation gives:

$$Q_{l/s} = 4\,330 \cdot C \cdot I_{m/m}^{0.25} \cdot L_{hm}^{0.5} \cdot A_{ha}^{0.95}$$

We applied this equation to the first two catchment areas of NIAMEY and the larger area of YAOUNDE. The value obtained for the latter was definitely too high, which is not surprising since the concentration time for this area is clearly longer than 90 minutes. On the other hand, the values obtained for the first two catchment areas were much closer to the experimental results (see last column of Table 1). It will be seen that for catchment area No. 1, which is rather elongated, the calculated value is lower than that measured whereas the calculated value is a little high for catchment area No. 2. This could be a result in particular of the very different values assumed for the run-off coefficients for catchment areas having rather similar performances.

It should be noted incidentally, that the BNETD equation for the KORHOGO region would have given values of 6900 l/s for the catchment area No. 1 and 16000 l/s for the catchment area No. 2, following application of a reducing coefficient to take account of elongation.

The index related to surface area is no doubt a little too high for an equation which does not take account of the length of the catchment area and this results in an over estimation of flow for large (catchment) areas.

We have also seen that for the Sahel-sudan region the coefficient b does not vary very much about its mean value of 0.5 whereas the value of the coefficient a varies between 7.0 and 7.9 according to the country involved. It should be noted that variations in the value of a only effects the numerical coefficient in the equation and not the indices. This numerical coefficient, namely

$167 \cdot 12^{0.5} \cdot a = 577\ a$, ranges between extreme values of 4050 and 4600 with a mean value of 4330 that was used in the case of NIAMEY. For SENEGAL with a = 8.5 the numerical coefficient becomes 4900.

b) Application to the coastal region

Application to the coastal region is more difficult since there is less knowledge regarding the character of the rainfall which is much more variable.

Attempts to adjust the equation using the intensity-duration-frequency curves plotted by the GHANA meteorological service for the KUMASI station result in the following expression:

$i_{mm/min} = 12.7 \cdot t^{-0.5}$ for rain-storms having a duration lying between 10 and 90 minutes, that is a = 12.7 and b = 0.5.

For the coastal town of AXIM the curves plotted by the same service give the following equation:

$i_{mm/min} = 10 \cdot t^{-0.4}$ that is a = 10 b = 0.4.

Using these coefficients gives the following equations:

- for the interior forest regions

$$Q_{l/s} = 7\,325 \quad C. \quad I_{m/m}^{0.25} \quad L_{hm}^{-0.5} \quad A_{ha}^{0.95}$$

- for the coastal zone

$$Q_{l/s} = 4\,500 \quad C. \quad I_{m/m}^{0.20} \quad L_{hm}^{-0.4} \quad A_{ha}^{0.95}$$

1.4 Choosing the recurrence frequency

We can substitute in these last equations not only the rainfall measurements for a ten year recurrence frequency but also those for any frequency. Given that the parameter b is practically independent of the frequency and that the flow is proportional to the parameter a, it is possible to draw up a table of correcting coefficients giving recurrent periods of 1, 2, 5 and 20 years based on the calculations made for the 10 year period. This calculating procedure assumes that the different factors of the equation are independent but there is no evidence that this is the case for rainfall measurements and the run-off coefficient. The correcting coefficients are listed in Table 3.

TABLE 3

Recurrence period (years):	1	2	5	10	20
Sahel-sudan region (b = 0.5)					
- value of a	5.4	6.0	6.9	7.5	8.2
- correcting coefficient	0.72	0.80	0.92	1.00	1.08
Senegal (b = 0.5)					
- value of a	6	6.75	7.6	8.5	9.1
- correcting coefficient	0.71	0.80	0.90	1.00	1.07
Coastal region: AXIM-ABIDJAN (b = 0.4)					
- value of a	5.6	6.7	8.9	10	12.6
- correcting coefficient	0.56	0.67	0.89	1.00	1.26
Coastal region: ACCIA (b = 0.4)					
- value of a	4.6	5.3	6.8	8.5	9.2
- correcting coefficient	0.54	0.62	0.80	1.00	1.08
Forest region: KAJMASI (b = 0.5)					
- value of a	7	8.9	11	12.7	14.3
- correcting coefficient	0.55	0.70	0.87	1.00	1.13

1.5 Conclusions

These attempts to adapt the CAQUOT equation at least have the advantage of approximating to reality by using relatively recent results of rainfall intensity studies.

The fact remains, however, that all these equations require a knowledge of the run-off coefficient. Since this coefficient appears to have an index which is equal or slightly greater than 1, the result obtained is almost directly proportional to the estimated value of this coefficient.

2 ESTABLISHING A HYDROGRAPH FOR THE FLOOD WATER TO BE EVACUATED

The equations developed above facilitate calculation of the maximum flow of flood water to be evacuated and they constitute useful tools in the absence of any better technique. In this second stage we try to obtain results that are both more precise and complete.

1.1 Maximum flow and volume of the flood water

Evacuation of flows having a ten year frequency generally result in large capital costs. Thus it is useful to consider the use of rain water reservoirs which will store the volume of water resulting from a flood such that it can be subsequently evacuated with a low rate of flow over a very long period. It is to be hoped that with this procedure the rate of flow of water to be evacuated can be reduced by a factor of 1/100 which will result in an appreciable reduction in the capital cost involved. The procedure has its own difficulties with regard to the hydrology since it is necessary to know not only the maximum flow but also the maximum volume of water to be evacuated. The previously described equations do not give information regarding this volume. The equations only give the maximum flow whereas we need to establish the hydrograph for the flood water to be evacuated.

2.2 Hydrology problems

As soon as we deal with the problem from this aspect we find there are several difficulties:

- With rainfall measurements, an attempt toproduce a mean hyetograph for the catchment area being considered is associated with a certain probability and there is no future in this approach. Assuming that such a hyetograph exists and can be established then the flood that it produces will certainly not have the same probability particularly when we are obliged to consider both the maximum flow and volume. In fact so far as drainage systems are concerned it is the probability of failure that is important and there does not appear to be, in principal, any simple relation between this latter probability and that associated with the rainfall.

- With regard to the catchment area it is also very difficult to make use of the concept of concentration time generally associated with such an area. This time is of course a function of the general topography of the area but it is also affected by the nature of the urbanisation and the type of system that is to be used for evacuating the water and it is precisely the latter that we wish to determine. Urbanisation "deforms the unit hyetograph" so that it is of no practical use.

- Finally, the problem of the run-off coefficient, not properly resolved in the previous work, remains and in fact constitutes a greater diffuclty when it is a matter of installing rain water reservoirs since it is necessary to determine the value of this coefficient not only for heavy rain storms but also for the lightest rainfall.

To sum up, particularly for areas involving urban development, the hydrology is concerned with a catchment area and a hydrographic network which are non existent.

2.3 Hydrology upstream from the drain inlet

The working procedure actually adopted by the Hydrology Service of ORSTOM, consists of a study of the run-off phenomena in urban conditions, on the smallest possible elementary surface areas, areas which can be defined as catchment areas upstream from a drain inlet. Measurements are actually proceeding in accordance with this procedure at LIBREVILLE and OUAGADOUGOU. It is also planned to make similar measurements at LOME, ABIDJAN, BOUAKE, BAMAKO and CAYENNE.

The rainfall measurements are made by recording the intensity over a very short period of time - of the order of two minutes. The recordings are made using a number of measuring instruments precisely distributed with respect to time so that information is obtained concerning not only the average intensity of the rainfall during a very short period but also concerning its displacement (speed and direction).

Measurements of flow are made downstream from the small catchment areas care being taken to precisely relate these measurements, in terms of time, with the rainfall recordings.

Finally to facilitate analysis of the results we are at present drawing up quantified descriptions of the urban areas in order to define the characteristics of the catchment areas.

We envisage descriptions aimed at determining the volume of run-off water, this information to be used in place of the usual run-off coefficient: percentage of impervious surface area, nature of the imperviousness, liaison between the surfaces and the hydrographic network (natural or artificial), percentage of surface area having no outlet to the sea (natural or artificial), percentage of "natural" surface area according to the mode of the use (traversing area, cultivated area...), map showing possible infiltrations...

Other descriptions will be aimed at defining the form of the hydrograph and this information will be used in place of the concentration time: slope of the course actually followed by the run-off water, nature of the soils in the areas where there is a first concentration of run-off water.

2.4 Use of the results

It is planned to make use of the results of measurements and observations on each small catchment area in accordance with the following procedure:

- a hyetograph recording is considered to be valid for the whole surface of the small catchment area

- an imaginary catchment basin having the same surface areas as a real catchment area and giving an instant transformation of rain into flow would give a "potential flood" that can be easily determined given a knowledge of the hyetograph and the surface area.

- the descriptions mentioned above will be used to explain differences between the flood actually observed and the "potential" flood.

Attempts will be made to extrapolate these results in two ways:

- given the hyetograph at several points for the same rainfall we will try and establish a method of analysis that will allow a hyetograph to be established for the rainfall at any given point.

- it should be possible to extrapolate the descriptions applying to the catchment areas where the measurements were made to other small catchment areas where measurements have not been made.

Thus we hope to be able to establish flood hydrographs for all envisaged drain inlets, this being done for the longest possible periods of time.

The combination of these hydrographs for the different branches of a drainage system, extending as far as the downstream extremities, is no longer a matter for the hydrology specialist. The matter must be studied with a model based simply on the laws of hydraulics. The hydrographs which serve as input data for the model will then be independent of the conception of the drainage system. These hydrographs constitute hydrology data which will facilitate a comparison of the effectiveness of different proposed drainage systems. We then have the normal problem of simulating the operation of an installation.

3 DRAINAGE AND URBAN PLANNING

In this third stage we propose as hydrology specialists, to consider our possible intervention not simply at the stage where the drainage system is considered but at an earlier stage that is at the beginning of the urban planning and the first proposals for land use. We consider in fact that evacuation of the run-off in urban areas is not necessarily the only way of intervening in the water cycle in such areas. We are now considering our intervention in accordance with a procedure that will have to be defined in cooperation with other specialists and that needs to be adapted to each specific case.

In the first place, we consider the area to be studied as being divided into a certain number of "compartments" that are similar to the elementary catchment areas upstream from the drain inlets as mentioned above but having in addition the following characteristic: whatever the drainage system installed, the run-off in one compartment can not run into another compartment.

We then assume that the run-off does not exist and that rain water remains on the surface. Thus the ground is flooded for each fall of rain and we try to determine, as a function of the land use for each area, the number of hours or days of flooding that is tolerable. Where the flooding presents a risk for people or facilities this time is zero. When, however, the flooding presents a simple inconvenience or a slight reduction in comfort this time can be defined as the acceptable period of flooding commencing with the end of the rainfall. In this way we can draw up a map showing the tolerance to flooding, the compartments being the units of surface area.

We then consider the problems of pollution by determining the compartments which necessarily require an evacuation and treatment of rain water. This can involve contaminating centres (abattoirs, hospitals, ...) or polluting industries The run-off water in these compartments must be treated as soiled water and evacuated in the drainage network for such waste material.

The next step is to prepare, compartment by compartment, maps showing possible infiltrations, bearing in mind that infiltration can be prevented or reduced providing that the matter is given attention at the beginning of the project.

Using the results of the proceeding steps and knowing the characteristics in each case then each compartment can be considered as a source of water that has to be evacuated and these compartments can be classified into several types.

The compartment type 1 will be that where it is necessary to evacuate all the potential flood water.

The compartment type 0 will be that where evacuation is not necessary the infiltration and evaporation being such that the potential flood water is absorbed in all cases.

The compartment type 1 will also not give rise to any surplus flood water to be evacuated and in addition will be able to absorb potential flood water from another compartment of equivalent surface area.

It seems to us that in view of the problems of urban development, the hydrology specialist must endeavour to ensure that this his special knowledge is made avaialble to other disciplines. He must try and do more than apply the equation for run-off which gives the maximum flow and consider the flood water itself that needs to be evacuated. He must then cooperate with the urban planner in attempting to limit run-off before calculating the dimensions for the drainage system.