AMERICAN GEOPHYSICAL UNION

Forty-Second Annual Meeting
April 18-21, 1961

A NEW METHOD of HYDROLOGICAL RESEARCH in ARID REGIONS

By J. RODIER

Chief Engineer, Electricité de France

Head of the Hydrological Service of the
Office for Scientific and Technical Research Abroad (ORSTOM)

Coordinator of the Panel of Hydrological Correspondents
of the Commission for Technical Co-operation in
Africa South of the Sahara

March, 1961

AMERICAN GEOPHYSICAL UNION

Forty-Second Annual Meeting
April 18-21, 1961

A NEW METHOD of HYDROLOGICAL RESEARCH in ARID REGIONS

By J. RODIER

Chief Engineer, Electricité de France

Head of the Hydrological Service of the Office for Scientific and Technical Research Abroad (ORSTOM)

Coordinator of the Panel of Hydrological Correspondents of the Commission for Technical Co-operation in Africa South of the Sahara

March, 1961

In the arid regions of the tropical zone, surface runoff rarely provides an answer to the problems of water supply. Under prevailing conditions, evaporation (about 13 ft per year) would absorb the greater part of the water which could be stored in dams. It is nevertheless necessary to study this form of flow for the following reasons : in the particular case of very deep gorges traditional type reservoirs may be envisaged ; knowledge of certain data pertaining to surface hydrology is necessary to the creation of reserves in the sands of river beds ; lastly, the ground water recharge cannot be studied from the quantitative aspect unless measurements of the various processes of the water cycle are recorded.

If the arid areas are defined as those areas receiving annual rainfall of less than 8-12 inches (200-300 mm), it is found that, in Tropical Africa, the water-table cannot, in géneral, be supplied by direct infiltration of rainfall. A necessary condition to such supply is previous concentration of surface runoff, whence the need to study this runoff.

However, such research presents difficulties : flow takes place in the form of rare floods of short duration ; low density of populations hinders the organization of a system of permanent observation ; the river beds are constantly changing.

The irregularity of flow, in time, defies statistics and, in space, once the watershed exceeds an area of several square kilometers, transposition is difficult because of hydrographic degradation. For these reasons, the objectives to be aimed at must be limited, e.g. : What is the volume of flow in an average year ? Throughout what period ? What are the characteristics of flow for one wet year of any given frequency ? Are there years without flow ? What is the approximate volume of flow during heavy spates ? Is it possible to obtain an idea of the maximum spate flow ? Finally, in the very rare cases of permanent flow, what is the annual minimum ?

The data normally available is too limited to provide answers to these questions. It consists in : measurements recorded from a single rain-gauge and scarcely representative of the area's climate ; more or less incomplete and always qualitative indications of the flow in certain wadis.

It is difficult to remedy this situation, for the low density of population and the lack of any considerable economic activity in such areas do not justify the considerable expenditure required to carry out the necessary research.

South of the Sahara where floods are only likely to take place during a three-monthly period, from July to September, a particular method of research has given satisfactory results. It is based on the following principles :

- During a short period - 3 years - rainfall is observed over the whole study area. Record obtained from the Reference Station provide sufficient data for the study of inter-annual variations in rainfall.

- One or two experimental catchments serve for estimating spate flow resulting from each individual storm in the hilliest areas which, in fact, alone supply the water courses.

- Extensive study of spate flow of the large water courses provides direct information concerning their hydrological systems. This information is complemented by the results from the experimental catchments.

In practice, three series of operations are undertaken :

- a) A general network of rain-gauges, mainly comprising long period storage gauges, is installed from the beginning of the research project. Whenever possible, the intensity of the individual storms should be recorded by a rainfall intensity recorder, intensity being a particularly important factor in volume of surface runoff.

- b) Rainfall and flow are observed simultaneously on an experimental catchment particularly representative of area. Depending on its area, this catchment is equipped with 6 to 12 rainfall gauges and 2 rainfall intensity recorders which, moreover, are integrated in the general network. Flow is recorded at a river gauging station equipped with a water level recorder. It is sometimes possible to locate the experimental catchment near a large water course. In such cases, a river gauging station is installed on the water course facilitating constant observation of flow.

- c) Extensive study is carried out by effecting a series of rounds during the season when there is likelihood of storms. Observation of the experimental catchment (or catchments) is also limited to this period. When itineries cut across the main water courses at several points the marks left by the most recent spates are noted and a series of measurements is taken if the stream is flowing. The storage gauges are visited at the same time. Observation of the level of ponds or reservoirs also provides precious information.

Complementary studies of evaporation and sediment load are effected on the experimental catchment.

The research work is carried out by specialists : a senior hydrologist and an assistant. The senior hydrologist carries out an extensive study of the water courses. Such study requires nice measurements and still nicer reconstitution of flow. At the same time he checks the rain-gauge network and directs work on the experimental catchment.

The assistant's task consists in making observations and taking measurements on the experimental catchment and at the weather station installed there.

Research in these desert areas takes on a special character because of the very difficult conditions in obtaining them :

- 1°) Transport is almost always a problem, theft or sabotage of instruments is frequent, outlay for research must be kept down to a minimum. Consequently, installations are of a summary nature and equipment is light. For example, the long-period storage gauges consist in simple recipients provided with a standard ring at the top. A layer of oil prevents evaporation. The hydrologist personnally sites the rain-gauges in a heap of large stones in places known only to himself (and which he will be able to find again).

Natural weirs can sometimes be used as river gauging stations on experimental catchments. Small, very light cableways are also used. In certain cases, the beds of small water courses are stabilised with gabions. Stations on large water courses are simply equipped with a light cable provided that section width is not too great.

The use of masonry or concrete in any quantity should never be envisaged. Even the foot-bridges composed of iron tubing of the type often used on experimental catchments in wetter regions are ruled out.

Regular gauging of very strong spates would require very costly installations. Thus floats for which correct use methods have been perfected are constantly employed. The great difficulty with this method is to follow the variation of the cross section as the spate develops. As far as possible stable cross sections are to be used for measurements involving this method.

- 2°) The very low density and the nomadic nature of the population is a handicap to the installation of a network : all sedentary inhabitants able to read are provided with an ordinary rain-gauge. The isolated long-period storage gauges are protected by a watchman if possible. In order to increase the number of readings of rainfall intensity recorders the senior hydrologist takes one with him on his round. This instrument provides him with perfectly valid data provided that rainfall conditions are homogeneous. This recorder is often of the direct reading type, consisting in a simple gauge with an aperture and a measuring tube. As rain constitutes one of the rare diversions as well as the main interest of the hydrologist it is certain that he will draw a first-rate graph.

- 3°) The only particular characteristic of research work on experimental catchments lies in the very small number of people engaged on them. This is because of the great difficulty in obtaining supplies.

- 4°) The rounds involving long distance set problems both of measurements and of transport. Whenever possible, the points of the itinerary which cut back on to the water course must be control sections with a stable bed. Limnimetric staff can be installed permanently at these points. If the water course is in spate when the hydrologist arrives there he is generally prevented from continuing on his way, but this is no handicap because his task then is to measure flow until the spate reaches a fairly advanced stage of subsidence. He next hurries to see if there has been any flow in the adjoining catchments and, losing no time, picks up the same water course further downstream in order to try and take further measurements there, continuing just as far as the dissipating area at the downstream limit where he checks the degree of flooding. Often, he will arrive too late. Nevertheless, in the desert, by arriving a short time after the flood, it is marked by small debris which do not disappear until at least a fortnight afterwards. The use of a maximum staff may facilitate this task, although none of these staffs give complete satisfaction. Flow can then be calculated from a topographical study of the bed and a flow formula, e.g. MANNING'S formula. The value of the coefficient is determined from regular measurements already taken on water courses of the same type.

For example, it has been found that, in the case of even beds of 30 to 300 ft width, with slopes ranging from 1,5 to 5 $^{o}/oo$ and a depth of water of 1 to 2 ft, the coefficient generally varies between 0,028 and 0,034. It may be as high as 0,065 if flow is very weak and the bed cluttered up with rocks and bushes. On the other hand, for the same slopes, the coefficient may drop to 0,02 if depth exceeds 3 ft and if the bed is very even. The itinerant hydrologist seeks, meanwhile,for the marks of old spates. There again it is not a point but a line of maximum level which is to be sought. This obviates all error and facilitates calculation of flow.

Naturally, observation of the filling up of ponds, lakes and reservoirs provides precious information.

Whenever possible a permanent measuring station or a simple recorder is installed, the latter being placed in a stony section as far as possible. It is checked by the itinerant hydrologist and often has to be protected by a watchman.

It is evident that the person responsible for the extensive study must possess the gift of observation and a critical mind as well as a good knowledge of the phenomena of the flow in these regions.

- 5°) Results obtained vary greatly depending on transport facilities. If vehicles of the "jeep" type can be used, and this presupposes that itineraries do not cross flood plains on clayey soils, the hydrologist can travel much faster than spate flow. Under these circumstances he can form a good overall idea of flow during the rainy season. But if he is obliged to use camel transport his observation of flow is much more fragmentary.

- 6°) On the other hand, climate South of the Sahara presents a favorable element : storms from which flow is likely to result take place only during the period July-August-September, thus the time spent on the terrain by the hydrologist is limited to 3 or 3-½ months and that spent by the assistant to 4 or 5 months. They are assigned to other research for the rest of the year and this considerably reduces costs.

The first research of this type was undertaken in 1957 in the ENNEDI Massif, North-East of Tchad. No great hopes were founded on this trial in an area of very low annual rainfall (about 4 inches) (1). In spite of a year of lower than average rainfall surprising results were obtained. It was possible to draw up an approximate rainfall map which brought out the low value of the rainfall gradient as a function of altitude.

Several direct measurements of flow were taken and numerous estimations of maximum flow were made a posteriori. A rough estimate was made of the annual volume of flow from several small water courses. Study of the experimental catchment showed the high percentage of runoff comming from the storms of even less than ½ inch as well as the violence of spates on small catchments. The first values of evaporation using evapometric pans were also obtained for these areas. It was decided to continue research the years following.

In 1958, again in ENNEDI Massif, a second programme of research was implemented. Heavy rainfall that year made possible the evaluation of spate flow of unusual frequency : return period of 5 to 20 years for a certain number of water courses and return period of 10 years for the experimental catchment. The following figures were obtained :

---

(1) In these desert areas, the expression "mean annual rainfall" has a very restricted sense as annual totals are extremely variable.

- For catchments of 3 to 4 square miles :

  200 to 800 cubic feet per second per square mile (1).

- For catchments to 50 to 70 square miles :

  70 to 160 cubic feet per second per square mile.

- For catchments of 150 to 230 square miles :

  35 to 90 cubic feet per second per square mile.

- For catchments of 380 to 600 square miles :

  2,3 to 10 cubic feet per second per square mile.

In 1959, a third research programme was undertaken in the Ennedi Massif. It comprised, in particular, the thorough study of a medium-sized water course. The effect of hydrographic degradation on spate flow was brought out clearly in this study and shown to be not more than 0,05 cubic feet per second per square mile for a catchment of 3.000 square miles.

Research of the same nature was carried out simultaneously in the AIR Massif in the North of NIGER Republic. This massif receives an annual rainfall of 5 to 6 in. and the fact that vehicles could be used (though not without difficulty) and that the experimental catchment was located near a large water course made it possible to obtain much more complete results. It was possible to estimate the total volume of runoff coming from the massif. In a fairly wet year total runoff is $5,3 \times 10^9$ cubic feet for an area of 10,500 square miles.

Thus it was possible to estimate the figures for spates of fairly rare frequence (5 to 15 years) in the AIR Massif :

- For a catchment of 1 square mile :

  1.500 cubic feet per second per square mile.

---

(1) depending on the catchment.

- For a catchment of 40 to 60 square miles :

  90 to 450 cubic feet per second per square mile depending on soil and slope.

- For a catchment of 450 square miles :

  40 cubic feet per second per square mile (little hydrographic degradation)

Runoff from this massif is probably greater than from any other South of the Sahara. Solid load, evaporation and underflow were studied. Here again it was found that the pluviometric gradient is low.

In the same year (1959), a similar research programme was carried out in BRAKNA and TAGANT Massifs, in the South of MAURITANIA, on two experimental catchments, one of which had been under observation for two previous years. Once again a spate flow of fairly rare frequency and the annual volume of flow for various frequencies were calculated providing fundamental data for the installation of reservoirs projected for the area.

Research of this nature cannot provide measurements or estimates of flow values of the same precision as in the humid regions. This is not a particularly grave handicap as the great inter-annual irregularity of rainfall would make it impossible to get as much out of the figures as might be expected. Furthermore, such research is scarcely to be envisaged in the case of total annual rainfalls of less than 2 to 3 inches for in such cases, at least one year out of two, the results obtained would be worthless.

A final point is that such research involves great hardships for those who undertake it : summer is the most trying season of the year and the necessity of keeping on the move at all costs imposes veritable feats of endurance. However, up to the present, this method seems to be the only effective one for obtaining quantitative data on runoff in these areas.