SCIENCE

VOL. 86 FRIDAY, DECEMBER 10, 1937 No. 2241

SCIENCE: A Weekly Journal devoted to the Advancement of Science, edited by J. MCKEEN CATTELL and published every Friday by

THE SCIENCE PRESS

New York City: Grand Central Terminal
Lancaster, Pa. Garrison, N. Y.

Annual Subscription, $6.00 Single Copies, 15 Cts.

SCIENCE is the official organ of the American Association for the Advancement of Science. Information regarding membership in the Association may be secured from the office of the permanent secretary, in the Smithsonian Institution Building, Washington, D. C.

HYDROLOGIC RESEARCH

By Dr. ROBERT E. HORTON

VOORHEESVILLE, NEW YORK

COORDINATING AGENCY

THE fact that hydrology has largely grown up in the families of sister sciences, and the tremendous pressure for hydrologic research created by recent activities in soil and water conservation, have created a situation which seems to call for some pertinent discussion of the objectives and methodology of hydrologic research. This is especially true in view of the fact that practical applications of hydrology are running away from the scientific development of the subject. There is a consequent tendency to concentrate research on specific objectives rather than to direct it toward the development of a complete, well-rounded body of scientific knowledge.

From different view-points the objectives of hydrologic research are manifold, but, while hitherto not generally recognized, the fundamental objective of such researches, stated in its most general terms, is to determine the independent variables which govern the phenomena and the relations between them.

It is recognized that scientific research can not be standardized and that researches which have proven to be of the greatest utilitarian value have quite generally been carried out by individuals and from purely scientific motives, without regard to the application of the results. On the other hand, experience has shown that wholly undirected or uncoordinated research does not usually lead to the best results. This is especially true of researches conducted by individuals or by separate governmental bureaus or agencies. For economic reasons or through lack of interest, the research is carried only as far as needs be for the specific problem in hand. It is often true that with little additional effort, variables could be measured and the scope or limits of the research extended in such a way as to make the results valuable with reference to other re-

lated problems. This too often is left undone. The situation seems to call for some central coordinating agency, governmental or otherwise, the function of which would be to encourage, direct and generally supervise hydrologic research rather than to carry out the actual field and laboratory investigations.

It is true that in many hydrologic researches, financial aid from the government, states or other political subdivisions will be required. The expenditure of government funds is not in general permitted except through duly constituted governmental agencies. A similar situation exists in research laboratories of educational institutions. For this reason, as well as others, it is probably necessary—perhaps not undesirable in most cases—that the work should actually be done under the immediate direction of some governmental or other regularly constituted research agency.

Hydrology, even more than most other sciences, is undergoing a rapid transition from a largely qualitative to a definitely quantitative status. To attain the latter, the use of mathematical methods in the analysis of research data is necessary. It should, however, be kept in mind that mathematical analysis adds nothing to the data or assumptions on which it is based. It merely puts the results of the data and assumptions and their relations in a more concrete and intelligible form.

All hydrologic phenomena are in reality physical phenomena and are governed by the fundamental laws of physics. Many otherwise excellent hydrologic researches have suffered from lack of adequate consideration of the physical processes involved and from failure to use mathematical methods. A central coordinating agency should be able to furnish assistance of competent physicists and mathematicians to research workers, both within and outside government bureaus.

Advisory Council

It is to be borne in mind that all those engaged in water supply, water power, navigation, drainage and irrigation are directly interested in hydrologic research, but this group by no means includes all who are interested. Agriculture, forestry, environmental botany or ecology are largely dependent on hydrology. Altogether, there are far more persons directly interested in hydrologic research outside than within governmental agencies. These persons are entitled to have, and in the interests of science should have, a far more extensive part in planning and carrying out such researches than they would get if the research was carried out on a close communion basis within some governmental bureau or bureaus.

It is not an overstatement that inter-bureau jealousies often exist in relation to overlapping functions. Under these conditions coordination of scientific research among government bureaus becomes a difficult matter. This fact makes it highly desirable that there should be in every case a disinterested agency to advise in relation to the planning and execution of the work.

Before any new, comprehensive hydrologic research is undertaken, an advisory council should be set up by the coordinating agency. This council should consist of men each one of whom has outstanding knowledge of some phase of the subject. The advisory council should report to and work under the general direction of the coordinating agency. Two of its most important functions would be: (1) To prepare a correlative research report on the topic to be investigated; (2) to act in an advisory capacity in the planning and execution of field and laboratory research.

Perhaps it goes without saying, but certainly can be said without reflection on governmental employees, that men of the highest degree of knowledge and experience in hydrologic matters are not likely to be employed on governmental salaries and, if so employed, much or most of their time is taken up with administrative duties. Such an advisory committee, therefore, gives the government an opportunity to secure the benefit of the knowledge and experience of the best qualified men available. Again without any intentional reflection on governmental employees, it may be said that practicing engineers and others whose bread and butter depends more or less upon the validity of their conclusions, are likely to have a keenly whetted sense of relative values and so are well qualified to direct research in such a way as to avoid waste of time and money on unimportant matters and at the same time produce results of the greatest usefulness as well as the greatest scientific value.

In selecting an advisory board, the interrelation of hydrology to other sciences should not be overlooked. Transpiration by vegetation, for example, is one of the most important hydrologic processes, as may readily be seen from the fact that the transpiration stream of vegetation the world over transports from within the soil to the atmosphere a volume of water of the same order of magnitude as the total volume of water transported to the oceans by all the rivers of the earth. An advisory board on evaporation and transpiration research should obviously include representatives of botany, ecology, agriculture and engineering. A similar situation exists with regard to other topics.

Correlative Research

Scientific research may be broadly classified as (a) correlative, (b) laboratory, (c) field. Before any field or laboratory research is undertaken on an important topic, a thoroughgoing correlative research should be carried out to determine just what has been done on

the subject and what most needs to be done. The correlative research corresponds to the making of a map of existing highways before undertaking to complete the highway system of a region. Its importance can not be overstressed.

The correlative research should show the scope, character and results of each research previously carried out on the same subject in sufficient detail so that (a) reliable comparison can be made with other researches, (b) the future research worker can use the correlative research report with a minimum of labor in looking up library references, translating articles from foreign languages and comparing results and formulas. This means that the report on correlative research should contain a fairly complete abstract of each important previous research on the subject, giving the results, a summary of the experimental data and, if the paper contains formulas, these should be given, together with their derivation or a statement of the variables and assumptions on which they are based, and formulas for the same thing appearing in different papers or researches should be reduced to a common notation, their results compared and their limitations pointed out. As an example, there are several formulas for height of capillary rise in soils. No two of them are in the same notation and scarcely two of them are based on the same independent variables or apply within the same limits of soil texture. If empirical formulas are given in preceding work, they should be examined to determine whether they hold true for limiting conditions of the phenomenon. This is a point which is too often overlooked in the development of empirical formulas to fit a set of observations.

The preparation of an adequate correlative research on a hydrologic topic is by no means a simple matter, because of the interdigitation of different branches of hydrology and its interrelation with other sciences. There are few other sciences—perhaps none—where so large a body of existing knowledge has grown up largely unassimilated for so long a time, and is so widely scattered, as in hydrology. The data of hydrology are largely found in the literature of meteorology, botany, ecology, geology, glaciology, soil science, agriculture and engineering, in various languages and in various countries. Given an adequate correlative research as a starting point, future research workers will have at the start the benefit of the knowledge and advice of a well-qualified group, different members of which have studied the subject from different angles. In addition, the research work can be carried out with assurance that nothing of importance in previous work has been overlooked. The field and laboratory research can, on the one hand, be so limited as to avoid unnecessary repetition and, on the other hand, extended to fill gaps in previous research and provide a well-rounded body of knowledge.

Finally—and perhaps most important of all—the correlative research report should be published in full so that it may be available to all research workers interested in the subject. What is required is a small edition, a few hundred copies, of a full report containing, in abstract at least, all data and results of previous work. It may be pointed out in this connection that the defect of most present review papers published by governmental agencies on scientific topics is that a large edition is printed, with all the original data left out. Only the author's conclusions or those of the bureau or agency are thereby made available, the original data going into some governmental archive or vault where, as has been aptly stated, "only the spiders can read them."

PUBLICATION

No hydrologic research should be undertaken until provision has been made to publish the results in an adequately complete form, including at least a comprehensive summary of the experimental data. Among reasons for this are:

(1) This will permit others to use the experimental data for purposes different from that for which they were taken. It is a matter of general experience that research data may be far more valuable for some other use than that for which they were obtained. A classical example is that of the use of Picard's observation of an arc of a great circle of the earth by Sir Isaac Newton in verifying the law of gravitation.

(2) The data should be given so that any qualified person can check the conclusions. It may well be stated frankly that more than one government bureau has some idea which is practically a fetish. The bureau is loath to permit the publication of anything which conflicts with this idea. The thing needed in the publication of hydrologic research results is a relatively small edition, in reasonably complete form. This may cost little if any more than the usual, much larger, edition of a report containing only conclusions and generalities.

Another reason why research data are often omitted from publication is the unfortunate division of responsibility as between research and publication. The research agency often has little authority over the matter of publication. The head of the bureau or other research agency which secures an appropriation for research in hydrology should see to it that adequate provision for publication of the results is made at the time the research project is adopted and funds provided therefor.

INDIVIDUAL RESEARCH

There are certain forces at work which tend strongly to concentrate hydrologic research in government bureaus and to hamper outside research. This condition arises in part from the fact that research can not progress without adequate data. Herein the government agency, with its prestige and power of taxation, has a marked advantage over the individual research worker. The heads of government bureaus should, however, recognize that scientific data collected through their agencies are paid for by the public and are not private property. When a scientific research is made by a government bureau, using such data, the results of the research may quite properly be withheld until the research is completed. The distinction between basic data and researches based thereon is not as clearly kept in mind as it should be. To withhold the basic data, thereby preventing any other qualified person or agency from duplicating the research or checking the results obtained by the government bureau, is a practice which can not be too strongly condemned. Many persons give great and often undue weight to research conclusions emanating from government bureaus, failing to recognize that a government employee is merely a more or less glorified human being and is sometimes subject to human foibles and errors. This is an additional reason why the basic data collected by governmental agencies for research purposes should be available to others who are qualified to check and verify published conclusions based thereon.

There are many qualities desirable on the part of one who is to direct scientific research, particularly research on a subject like hydrology. These include unfailing patience, creative imagination, both perspicacity and perspicuity, and, above all, the ability of the research worker to observe natural processes disinterestedly and at the same time sympathetically. He must interpret as well as observe natural phenomena. Nature will always reveal her secrets if given a fair chance. Invariably it is the human and not nature who is at fault, where natural phenomena and their processes are not fully understood. Too often this results from the fact that the worker, obsessed with preconceived notions, is unable to see what lies plainly before him.

There are many men who have the patience, energy and enthusiasm, and are excellent collectors of data, but very poor scientists. It is largely for this reason that government bureaus often serve better as collectors of basic scientific data than in the conduct of research based thereon. Men possessing, even in a moderate degree, the high qualities desirable in a person who is to direct a scientific research, can not be picked at random from the personnel of a government bureau or a university faculty.

There are many instances where the best results could probably be obtained at the least expense if some degree of governmental aid could be given to individual research workers. In addition to guidance and correlative background, such workers often need, and can not themselves afford to provide, competent assistance in compiling and analyzing data and preparing drawings and other material for publication. In setting up any central organization to guide or direct hydrologic research it should be made sufficiently flexible so that in cases where desirable such assistance could be furnished.

In relation to the place of individual research in the general scheme, the following quotation from a recent paper by Samuel W. Fernberger[1] is appropriate:

> In these days when huge sums are spent—and certainly most properly spent—upon research, it is interesting to note that, with only a small plot of unused garden at his disposal, with a few common garden tools at hand in any case and with a handful of dried peas; working alone and without advice of colleagues, but with infinite imagination and with the utmost care and persistence, Gregor Johann Mendel worked out one of the great laws to be found in the history of science.

There should be no monopoly of scientific research.

ON THE ORIGIN OF THE SARATOGA MINERAL WATERS

CRYPTOZOON: PLANT NATURE AND DISTRIBUTION

By Dr. WINIFRED GOLDRING
NEW YORK STATE MUSEUM, ALBANY

IN late Cambrian time (Lower Ozarkian of authors) a notable succession of barrier reefs, composed entirely of species of the calcareous alga Cryptozoon bordered the Adirondacks, stretching from the east around the southern end of this oldland through the Mohawk Valley area and westward to an unknown distance beyond the present site of Utica. Three species of Cryptozoon are known: *C. proliferum* and *C. ruedemanni* occur only in the Hoyt limestone, which is preeminently a reef formation; *C. undulatum* in both the basal Hoyt

[1] Samuel W. Fernberger, *Jour. Franklin Inst.*, 223: 2, 147–172, February, 1937.