SYMPOSIUM ON RELATIONS OF HYDROLOGY TO OTHER BRANCHES OF GEOPHYSICS

THE RELATION OF HYDROLOGY TO THE BOTANICAL SCIENCES

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Hydrology has a more or less intimate relation to all the geophysical sciences. There are other sciences which are terrestrial, although not counted as geophysical, where the interrelations with hydrology are especially marked. I refer in particular to the biological sciences. Direct interrelations of animal life to hydrology are not wanting. Examples are furnished by the relation of the migration of fishes to fresh-water floods of streams and by the life-habits of many oysters, which seek the transition-zone between salt and fresh water for elements vital to their existence and for protection from their enemies, and suffer if the ordinary course of the hydrological cycle is disturbed. Darwin directed attention to the agronomic importance of earthworms, but it remained for Lawes, Gilbert, and Warington (The amount and composition of drainage-waters collected at Rothamsted, J. R. Agr. Soc. Eng., v. 27, 275, 1881) fifty years ago to point out that in some of the best agricultural soils earthworm perforations apparently provide the principal means of entrance of rain-water to and escape of air from the soil, thus permitting the underground phase of the hydrological cycle to be enacted and moisture-supply for vegetation provided.

It is the interrelations between hydrology and certain of the botanical sciences, particularly plant ecology, to which attention will be particularly directed.

A plant which has its root-system in the soil leads a sort of double life. Its aerial portion is in an environment of air, light, sunshine, and radiation. Its root-system lives in an environment of soil, soil-solution, and soil-air. If the conditions in the two environments are harmonious, the plant thrives. If the environment of one part of this Siamese duality is unfavorable, both parts suffer. Thus the plant may die of frost in its aerial or drought in its underground environment when conditions in the other environment are favorable to life and growth.

As regards the water-relations of plants, the reciprocal arrangement is still more marked. The root-environment derives its moisture-supply from the atmospheric environment, while the aerial plant derives its water-supply from the soil-environment.

Plant ecology and hydrology are so interwoven that it is impossible to fully describe their relationships without writing a treatise on one or the other subject.

The science of hydrology centers around the phenomena of the hydrologic cycle--rainfall, runoff, evaporation. The most familiar example of the stage-setting in which this cycle is enacted is, of course, the drainage-basin of a stream. But a plant, with its bit of soil-environment and its bit of aerial environment, forms all the stage-setting necessary for the enactment of the hydrologic cycle. The transpiring stream takes the place of the Nile or the Amazon in the drainage-basin by transporting the water from the collector to the evaporator. This is illustrated by the familiar experiment of growing a plant in a closed space. The ecological classes of plants are based on their hydrological preference of environment--hydrophytes, hygrophytes, mesophytes, and xerophytes.

There is a fact of sufficiently widespread application that it might even be called a law of interrelation between the hydrology and natural vegetation of a region. The natural vegetation of a region tends to develop to a point where it can utilize all of the infiltrated rainfall. The word "tends" is used above in expressing this relationship because evaporation from the soil always takes its toll and because fulfillment of the law may be inhibited by other factors. Much the same idea, stated in converse form, is known in France as the "law of Dausse." Dausse found that there was no accretion to the water-table as long as water-losses exceeded the rainfall.

The process by which soil-moisture is conserved for plant-use has only recently been clearly recognized (Veihmeyer and Hendrickson, Soil-moisture conditions in relation to plant-growth, Plant Physiology, v. 11, No. 1, 71-82). Owing apparently to the fact that soil structure is cellular or vesicular as well as capillary, the soil can hold a certain quantity of moisture in equilibrium against gravity at all heights above the water-table. This quantity is designated the "field-moisture capacity." Water used by plants lies in the zone between the wilting point and the field-moisture capacity. If there is a deficiency in field-moisture, all infiltration goes to replenish this deficiency until the field-moisture capacity is restored. Thereafter the excess percolates downward to the water-table. Thus all the water which can be utilized by vegetation is retained in the soil and only the excess is rejected.

Excepting for loss by evaporation from the soil, the law stated is apparently nearly fulfilled in many arid and semi-arid regions, where little infiltration is allowed to escape downward to the water-table (Rainfall interception and consumptive use of water in the Santa Anna River Valley and Coastal plain, Bul. 33, Dep. Public Works, Water Resources Div., Sacramento, Calif., 1930). In humid regions the law is generally fulfilled during the growing season. In regions of dry agriculture its fulfillment is approximated, since grain crops utilize not only all or nearly all the summer infiltration but the equivalent of several inches' depth of infiltration from winter precipitation stored in the soil.

Rainfall minus runoff equals the water-losses for any area. The water-losses are of three kinds: (1) Interception of rainfall by vegetation; (2) transpiration by vegetation; and (3) evaporation from the soil.

It happens that the stomatal cavities within which transpiration takes place are necessary to the absorption of CO_2 and the escape of oxygen. Botanists are not fully agreed as to the extent to which the escape of water-vapor from the stomata by transpiration is a necessary physiologic function and the extent to which it is an unavoidable waste. The transpiration-stream maintains turgor in the succulent tissues of the plant and supplies them with needed minerals from the soil. Since there is a close correlation between transpiration and growth, transpiration may be considered hydrologically as a necessary and beneficial use. Interception is a loss incidental to plant-growth, though generally detrimental by reducing the ground rainfall. Evaporation from the soil is unavoidably concomitant to growth, since it is derived from soil-moisture, like transpiration, and is closely correlated with transpiration. While, of course, water losses occur by evaporation alone from bare areas, it is fair to say that on a vegetated area all the kinds of water-losses are either necessary, incident to, or unavoidably concomitant with the growth of vegetation.

The determination and separation of these items of water-losses are matters in which the hydrologist, ecologist, and agronomist are all vitally interested.

To those whose interest lies primarily in hydrology rather than in botany, it is pleasing to note that a vast amount of work of first-order importance to scientific hydrology has been carried out by biological investigators. To Poiseuille, the physiologist, we owe the law of capillary flow. For quantitative knowledge of transpiration, the most important of the hydrologist's triumvirate of water-losses, we are indebted solely to botanical and agronomic investigators from Hellriegel, Wollny, and other pioneers down to Briggs and Shantz and others still working in this important field.

Determination of the transpiration by trees, particularly mature trees, is a difficult matter, on which, with the exception of the work of Höhnel (Robert E. Horton, Transpiration by forest trees, Mon. Weath. Rev., v. 51, 571-581, 1923, contains a translation of Höhnel's data), little has been accomplished. The leaf crop of a forest is not harvested and cannot be used as a basis of estimating water-requirements, as is done in the case of agricultural crops. Better knowledge of water-losses from forests, particularly natural stands of trees in forest-covered areas, is greatly to be desired. In closing I wish to suggest a method by which this result may be accomplished.

The extensive system of stream-gagings maintained in the United States by the United States Geological Survey and other agencies furnish a basis for determining the total water-losses and hence approximating the vegetational use of water over a large portion of the area of the United States. Heretofore, owing to inability to make needed corrections for gain or loss of soil-moisture and ground-water storage, it has been possible to determine the water-losses only for average conditions or relatively long periods. Following the pioneer work of W. S. Auchincloss at Bryn Mawr, Pennsylvania (Waters within the Earth and the laws of rainflow, Philadelphia, 1897), and two British hydrologists, Samuel Hall (Stream-flow and percolation-water, Trans. Inst. Water Eng., London, v. 23, 92-127, 1918) and D. Halton Thomson (Hydrological conditions in the chalk at Compton, West Sussex, Trans. Inst. Water Eng., London, v. 26, 228-261, 1921), a method has recently been developed by the author whereby it is possible to determine with considerable accuracy from rainfall and runoff not only the underground water-losses but the accretion to and draft from the soil-moisture zone for any chosen time-interval. Thus, for example, if a forest area of a given type covers an entire drainage-basin, the runoff from which has been gaged, it is possible to follow the march of transpiration from this forest somewhat closely. The method can only be applied to areas underlain by a perennial water-table. Given such an area, it requires only the existence of good daily records of rainfall and runoff, although its accuracy and the facility of its application are increased if ground-water-level records are also available.

The labor involved in its application is small compared with the tedious process of soil-moisture determinations from field-samples, now sometimes used for determining the amount of water consumed by growing vegetation.

This method is cited as affording an instance where hydrologic data collected primarily for other purposes may be of direct use in connection with various sciences comprised under the general heading of "botanical science."

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RELATION OF METEOROLOGY TO HYDROLOGY

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As the sections of Hydrology and Meteorology in the Geophysical Union are organized and the respective fields of activity are defined, the interrelation of interests of the two sections is so obvious as to appear to render discussion unnecessary. Their fields added to that of oceanography cover that never-ending cycle of motion of water wherein it condenses in clouds, is precipitated as rain or snow, flows over and through the Earth's crust, accumulates largely in oceans, is taken into the air again by evaporation and transpiration, and is again condensed into clouds and precipitated. The Section of Hydrology works within that portion of this cycle that is represented approximately by the passage of water over and through the Earth's crust, the Section of Meteorology works within that portion represented approximately by the passage of water through the atmosphere, and the Section of Oceanography works within that portion represented by the oceans. Each field of activity begins, therefore, where another ends, and the work of one section is related to and must be consistent with the work of each of the others. The obvious points of contact between the sections of Hydrology and Meteorology are in those phases that relate to the transfer of water from the atmosphere to the Earth's crust (precipitation) and to the reverse action of transfer from the Earth's crust to the atmosphere (evaporation).

The statistical records and the results of scientific researches in both hydrology and meteorology are of great interest and value to man because of the information afforded thereby as to the supplies of water, both on the surface and underground, that are or may be made available. The data are also used in scientific studies regarding the effects of water on the structure of the Earth's crust and other problems in geomorphology. Such information derived within the fields of activity of both sections is essential to safe developments of agriculture by irrigation, municipal water-supplies, industries needing large quantities of water for process uses, power-plants, both hydraulic and steam, and for planning bridge and culvert openings, elevations of surfaces of highways, and many other uses related to the work and play of man. For many of these purposes, water is the limiting factor. It limits the area that may be irrigated, the size of power and industrial plants, and the size of cities. The information is used by engineers as a basis for design, by financiers as a basis for investment, by attorneys and courts as a basis for adjudication, and by State officials as a basis for administration. Information with respect to water has therefore much more than abstract scientific value. Reliable information with respect to it is always sought because of its practical and continuing relations to man's activities along many lines.