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CURRENT PROBLEMS IN RESEARCH

Hydrology

An understanding of water in relation to earth processes requires the collaboration of many disciplines.

E. L. Hendricks

Hydrology is that branch of the earth sciences which treats of the storage and movement of water on the earth, the physical and chemical reaction of water with its environment, and the relation of water to living organisms. The central concept of hydrology is the hydrologic cycle, which denotes the circulation of water from the oceans, through the atmosphere to the land, and thence, with numerous delays, back to the oceans by overland, subterranean, or aerial routes. Hydrology is concerned mostly, however, with the continental phase of the cycle—that is with water from the time it is precipitated on the land until it returns to the sea or the atmosphere. In broad view it includes, also, meteorology and oceanography insofar as these sciences relate to processes of the hydrologic cycle.

The general pattern of the water circulation system is shown in Fig. 1. At any given time, water is stored in the atmosphere, in the ice caps, underground, in natural lakes and river systems, and above all, in the oceans. There is a continual movement of water between these storage reservoirs through the process of evaporation, transpiration, condensation, precipitation, and gravity drainage. Although the amount of water in the system remains virtually constant, the distribution of this water is continually changing.

The occurrence of water in an area is determined primarily by the climate of the region. The climate, in turn, depends on the location of the area within the world-wide circulation pattern of the atmosphere, but physiographic features may modify the local climate. There is, of course, a great variation of the climatic factors in time and space. These factors include the magnitude and distribution of precipitation, the occurrence of snow and ice, and the effect of wind, temperature, and humidity on evaporation.

Although climate controls the net water supply of an area, the volume of storage and the rate of movement in the land phase of the cycle are determined largely by structural geology. The porosity and transmissibility of the rock material determine the volume of storage and the rate of movement of water in subterranean aquifers. The slope and pattern of surface stream channels, the infiltration characteristics of soils, and the character of the vegetation are also directly related to geology.

The early approach to hydrology was simply to measure the storage and movement of water in the continental phase of the cycle. Beginning about 100 years ago, continuous records of rainfall, streamflow, evaporation, and lake and ground-water levels were obtained at selected locations. In addition, water samples were analyzed for chemical and sediment content. These measurements provided a history of the availability of water at a particular site and defined in broad terms the quantity of water in the different phases of the hydrologic cycle.

The science of hydrology has been developed mostly during the past 40 years. The motivating force was provided by the increased use of water and the need for its control. Today, the hydrologist seeks to explain the mechanics of water movement in such processes as evaporation, transpiration, infiltration, and flow in saturated and unsaturated porous media and in open channels and to predict the regime of flow and the quality of the water in subterranean aquifers and overland channels. Further, the hydrologist is collaborating with other disciplines, such as meteorology, oceanography, geology, ecology, geochemistry, and geomorphology, to develop a complete understanding of the relation of water to earth processes.

Current Problems in Hydrology

The major problems in hydrology today are those relating to the trends in climatic and hydrologic data over periods of time, the mechanics and control of transpiration and evaporation, the statistical evaluation of the effect of changes in hydrologic environment, control of the quality of water, the movement of water underground, the mechanics of flow in tidal estuaries, and the optimum development and management of water.

There are, of course, many other problems relating to the mechanics of water movement. Foremost among these are the mechanics of flow in unsaturated media, diffusion in open channels, sediment transport in streams, density flow in reservoirs, and steady flow in natural channels.

Still other categories, which relate to man's efforts to modify the natural cycle in his favor, include the recharge of ground-water aquifers by water spreading, the removal of salts from brackish water, the reclamation of water

The author is chief of the Surface Water Branch, Water Resources Division, U.S. Geological Survey, Washington, D.C.

from sewage or vegetation, weather control, and the lining of canals with clays to prevent loss through seepage.

Only a few of the many problems in hydrology are discussed here. Several of the more basic ones are chosen to illustrate the scope of the science and the many disciplines that are contributing to a better understanding of hydrologic processes.

Trends in Hydrologic and Climatic Events

A science may be gaged by its ability to predict. Hydrologists wish to predict trends in hydrologic and climatic events and the frequency of occurrence of specific events. For example: How will the mean flow of the Colorado River during the next 50 years compare with the mean flow during past years? What is the probability of occurrence of a discharge of 80,000 cubic feet per second on the Coosa River at Rome, Georgia? At present these predictions must be based on statistical interpretation of a very small sample of data on the time scale. Recorded climatic data date back only about 100 years; streamflow data, about 50 years. These data show considerable variability and are inadequate to define either past or future distribution of hydrologic or climatic events. The observed record has, with some degree of success, been extended backward in time through studies of documentary, geochronologic, dendrochronologic, and geologic evidences. By this means, a long, though gross, record of climate is traced to reveal the position of current conditions in geologic time.

Throughout geologic history there have been extremely long periods of fairly stable climatic conditions. These normal, equable conditions have prevailed for about 99 percent of the time (*1*). However, at intervals of about 250 million years (*2*, p. 177) there have occurred periods of major glacial activity, during which glacial climate prevailed, as opposed to the more normal climate. Each such ice age usually followed close after widespread crustal activity that caused major geologic changes on the earth's surface. During each major glacial age, alternate periods of advance and retreat of the glaciers occurred, accompanied by corresponding changes in climate. The changes between advance and retreat are triggered by fairly sensitive conditions (*2*, pp. 31–45), but the mechanism is not fully understood.

During most of geologic time the continents were smaller, mountains were lower, and seas were higher than during glacial periods. Precipitation, runoff, and erosion were less, ocean and air temperatures were higher, and aridity was not as widespread or as extreme. The variations in climatic features were not so great as in glacial times. Changes of weather were infrequent and less severe. Whereas the normal climate of geologic time was equable and stable, the glacial climate is subject to extremes and is highly erratic.

The entire life span of man has fallen within the most recent glacial age. We are still in this ice age, though probably at the tail end of it. Before it ends, however, there may be several further advances and retreats of the glaciers (*3*). We can see, therefore, that all man has ever experienced has been the stormy, erratic, and shifting glacial climate that is typical of only 1 percent of all geologic time.

It may be asked what we are trying to define in our study of climatic and hydrologic variations during the past 100 years. We are in a poor position to define the normal characteristics that man has never experienced and may not experience in the next 50,000 years. If change is the primary element in climate as it has affected and will affect us, then it is change and its characteristics that we must study.

Research is needed, first for improved delineation of past climate by geochronologic means. More intensive investigation is needed in all possible fields, such as the study of varves, tree rings, peat, lake levels, paleotemperature, and ocean, lake, and river terraces. Through recent advances in dating by radioactive elements, the accuracy of all such methods can be improved. The value of geochronology for hydrology can be greatly enhanced through quantitative correlation of annual precipitation and streamflow with geochronologic features.

Research is also needed to improve statistical methods for analyzing time series. In the past there has been much controversy over whether or not there are cycles and trends in climatic data. Because of the earlier lack of proper statistical techniques or because of recent failure to use those we now have, interpretations have been subjective, varied, and inconclusive (*4*). Recently, more powerful methods of analysis have been developed. These include the allied techniques of periodogram (*5*), periodoscope, autocorrelation, correlogram, and power spectrum analysis (*6*). With these methods the presence of recurrent cyclical trends can usually be detected. Other components of the time series are (i) a random component imposing short-term variations and (ii) long-term trends whose change in direction cannot now be predicted and which therefore are equivalent, on a long-term basis, to a large-magnitude random component. By means of the statistical methods now becoming available, it may be possible to separate the individual components of the time series, to define the variation attributable to each, and to define the combined variability to be expected under various assumptions as to the major trend.

The statistical analysis of past climates provides answers, in terms of probability, as to what may be expected in the future. However, increased knowledge of the physical system would allow better prediction of specific events than is possible when predictions are based on a probability concept. Increasing this knowledge is an arduous task for research, and the goal is distant. It requires that we establish the causes for major shifts between glacial and nonglacial periods and between periods of glacial advance and retreat within an ice age, for if we can predict the terrestrial or extraterrestrial events responsible for these changes, we can predict trends and changes of climate on the earth. The solution of this problem will require research in many fields and may perhaps advance only as fast as we can increase our knowledge of the physics of the universe.

Evaporation and Transpiration

About two-thirds of the precipitation falling on the United States is returned to the atmosphere by the process of evapotranspiration. Although a part of this large volume of water is used to support beneficial plant life, the major part returns to the atmosphere without serving any function useful to man. Hence, considerable attention has been focused on the mechanics of evaporation and transpiration, and on methods of reducing this flow of water into the atmosphere.

Evaporation from a free body of water is proportional to the net thermal energy supplied by solar radiation and advection, minus the increase in energy stored in the body of water. The proportionality factor, known as Bowen's ratio, is a function of the atmospheric pressure, the temperature of the water surface and of the air, and the difference between the saturated vapor pressure at water-surface temperature and the vapor pressure of the air. Water loss studies at Lake Hefner (*7*) indicate that the instrumentation presently available for measuring the received and the reflected energy is inadequate to determine evaporation for short periods of time by the energy budget method. However, the total evaporation for periods of 10 days or more was successfully measured. The remaining problems in developing this

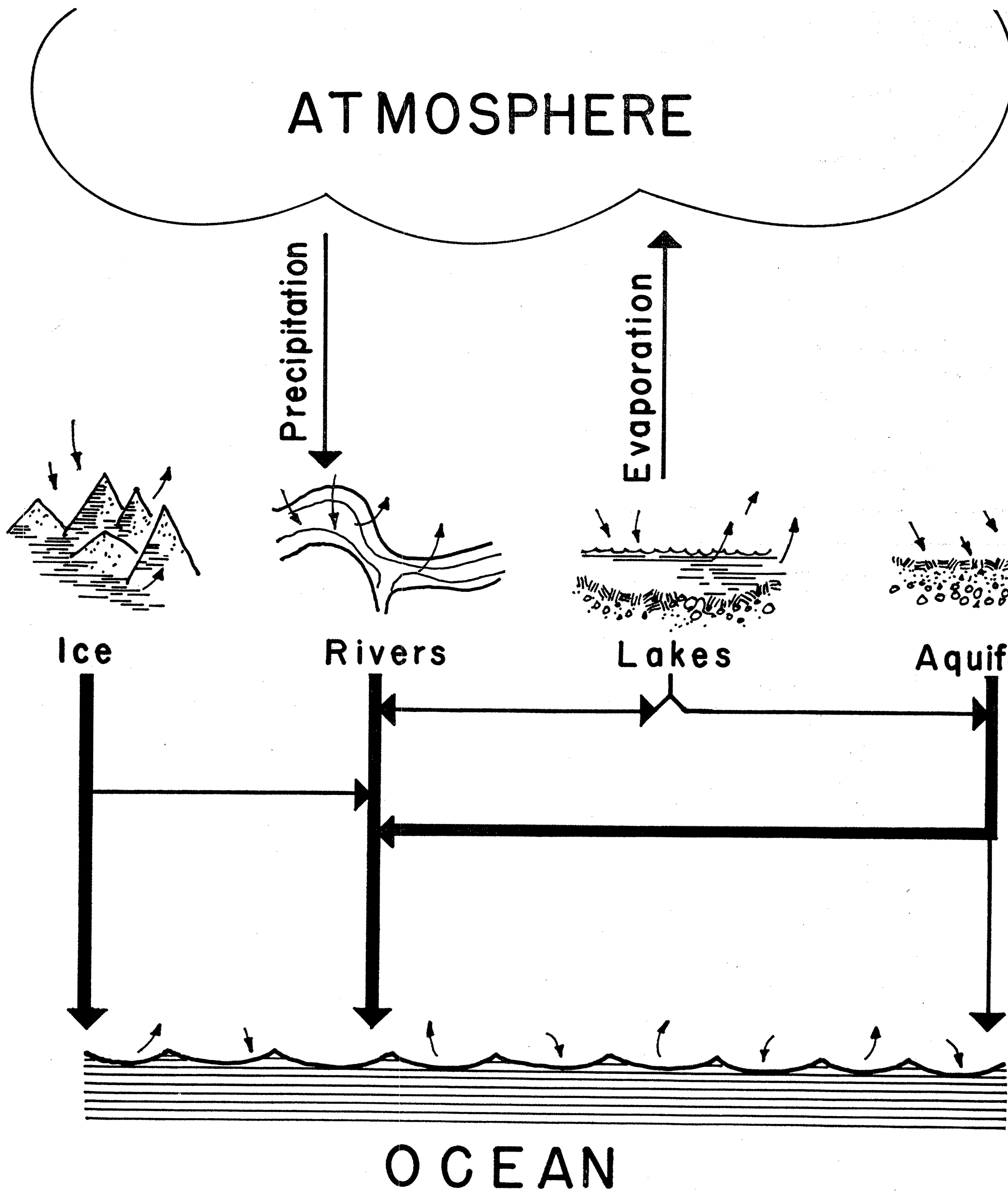

Fig. 1. The hydrologic cycle. A dynamic movement of water occurs both on the earth and between the earth and its atmosphere.

basic method of evaporation measurement are the development of simple but more accurate instrumentation to measure the net transfer of energy between the earth and the atmosphere and better definition of the Bowen efficiency factor. Experiments in a suitable wind tunnel would probably yield useful results.

Evaporation has also been treated as a mass-transfer problem on the basis of the boundary-layer theory. At the present time, however, a truly theoretical equation based on this concept cannot be developed because boundary-layer processes are not fully understood. A precise wind law is still not available, for example, nor are laws governing the variation of humidity with height above the water surface. Better definition of appropriate roughness parameters is also needed.

An evaporation equation which embodies some of the principles of the mass-transport theory was developed in the Lake Hefner studies (*7*). Evaporation was found to be proportional to the product of wind speed at a height of 8 meters and the difference between the vapor pressure of saturated air at water-surface temperature and the vapor pressure of air at 8 meters. More recent studies have shown that the proportionality factor varies over a twofold range and is a function of the surface area of the body of water.

Mass-transfer techniques are also applicable to the determination of evaporation and evapotranspiration from land surfaces. In the past, the magnitude of these quantities has been approximated through determining precipitation minus runoff. Once the mass-transfer theory has been fully developed and tested, it can be used to directly measure evapotranspiration losses from different types of vegetation for various conditions of water supply. Much research to perfect the theory and measurement techniques is needed.

Ground-Water Resources

One of the basic problems confronting the hydrologist is that of determining how long a supply will last under the stress of our increasing demand for water. Geologists understand reasonably well the forces of nature responsible for the formation of the rock and earth materials constituting ground-water reservoirs or aquifers. Engineers have learned how to describe and interpret the forces that influence the rates and directions in which ground water moves through various kinds of permeable earth materials. Both groups of scientists have learned well how to combine their respective talents and apply them to the difficult problem of inventorying this underground resource. An inventory, however, is no longer adequate, in view of the unquenchable thirst of our civilization. The significant question concerns the life of the supply: How will water levels in wells decline with time as pumping continues and increases?

In seeking the answers to these and other equally practical questions, the hydrologist must turn his attention from observation and analysis of past events to well-considered predictions for the future. In so doing he has been quick to realize that, although he can describe the shape and extent of the ground-water reservoir, the nature and extent of the permeable water-bearing materials, and the manner in which ground water moves in the vicinity of existing wells or group of wells, the task of analyzing mathematically this mass of data and translating the results into reliable long-term predictions of decline in water levels is formidable and immensely complex. The most powerful mathematical techniques of the most versatile high-speed commercial computers hold little promise of providing the required solutions.

In the past few years research scientists have pioneered in the development of electric analog models to simulate ground-water reservoirs and the water-level changes that would result from any proposed pattern of water development (*8*). The analog model shown in Fig. 2 consists of a network of electrical resistors and capacitors assembled in a scale model of the aquifer, an electric pulse generator to simulate the drawdown produced by pumping a well, and an oscilloscope to display the changes in water level as a time-drawdown graph. The resistivity of the model is inversely proportional to the hydraulic conductivity of the aquifer, and the storage characteristic of the aquifer is proportional to the electrical capacitance of the model.

Models have been constructed to simulate specific field problems of streamflow and ground-water movement in the Bitterroot Valley, Montana, in the San Simon Valley in southeastern Arizona, and in a small watershed north of Daytona Beach in northeastern Florida. Additional models are under construction, or are contemplated, for the analysis of field problems in 11 other states.

Theoretically, analog model techniques can be used to describe ground-water movement in any aquifer system regardless of its complexity. The cost of some models, however, would be so great as to be prohibitive. Further research is needed to reduce the cost of constructing such models and to simplify the electronic linkages necessary to describe the more complex ground-water systems. An example of this complexity might be a series of artesian and water-table aquifers and other geologic formations whose hydraulic properties are of an intermediate nature. Another would be a system involving the movement of fluids of changing density and viscosity, such as one containing waste fluids, or a coastal aquifer whose development would induce the landward movement of salty ground water. Additional research is also needed to develop methods for describing the geologic environment in significant quantitative terms so that aquifer characteristics can be simulated in the model.

Chemical Quality of Water

Proper interpretation of the results of chemical analyses of water requires a general understanding of the many influences that can be expected to affect the quality of water. One influence obviously of major importance is the nature of the rock material with which the water has been associated. This relationship may be comparatively uncomplicated, as in the case of an aquifer which receives direct recharge by rainfall and from which water is discharged without coming into contact with any other aquifer or water. Or the situation may be rendered very complex through the influence of one or more interconnected aquifers of different composition, the mixing of unlike waters, a chemical reaction such as base exchange or adsorption of dissolved ions, and other factors. In surface water and certain shallow ground waters, the composition of the soil and the factors involved in soil formation may have a great influence on the quality of the water.

Although the primary controls on the chemical composition of water are geologic, continuity of transport of solutes is also an important factor. Generally, waters draining igneous and metamorphic rocks contain small amounts of dissolved solids, calcium and bicarbonate usually being dominant ions. So long as the solutes are kept in solution, materials such as evaporites, salt crusts, caliche, and black alkali soils cannot develop. If the loss of water as vapor is greater than the supply of water, the salinity will probably increase and water problems may result. In general, calcium carbonate is the first precipitate formed during evaporation; a hard water then results. The solution, upon further loss through evaporation, becomes increasingly saline. The dominant cation nearly always is sodium; the dominant anion may be sulfate (either through solution or from oxidation of sulfides), chloride, or in unusual situations, borate. Where sulfate and chloride are not equivalent to sodium, a sodium bicarbonate water may result, if no such exotic anions as borate are present.

It should be noted that climate is not a primary influence on the quality of water. The important consideration is the continuity of transport of solutes; if the transport is continuous and not extremely slow, no features associated with aridity can develop, no matter what the climate. On the other hand, geologic controls *are* primary. If the minerals present are but slightly soluble, as is the case with igneous rock and many metamorphic terranes, a large water loss need not be accompanied by serious change of water quality. If the geologic formation was itself the product of discontinuous transport, waters will be highly concentrated and the solutes will precipitate readily. Thus, there is a tendency for the precipitates to persist in regions of relatively low evaporation until they are redissolved in fresh water.

The quality of water may depend also upon biological processes. From a given inorganic condition determined by climate, geology, and physiography, the environment is modified by the life processes of the biota. These life processes constitute the metabolism of the community of organisms and may be divided into "production" and "respiration." Production is the formation of new organic matter from inorganic materials by means of radiant energy; respiration is the reverse reaction, in which organic matter is broken down, with release of energy. Solutes and solids in fluvial transport are continually undergoing physical and chemical changes due to these complex reactions, and the quality of water in a given reach reflects in part the state of equilibrium between production and respiration.

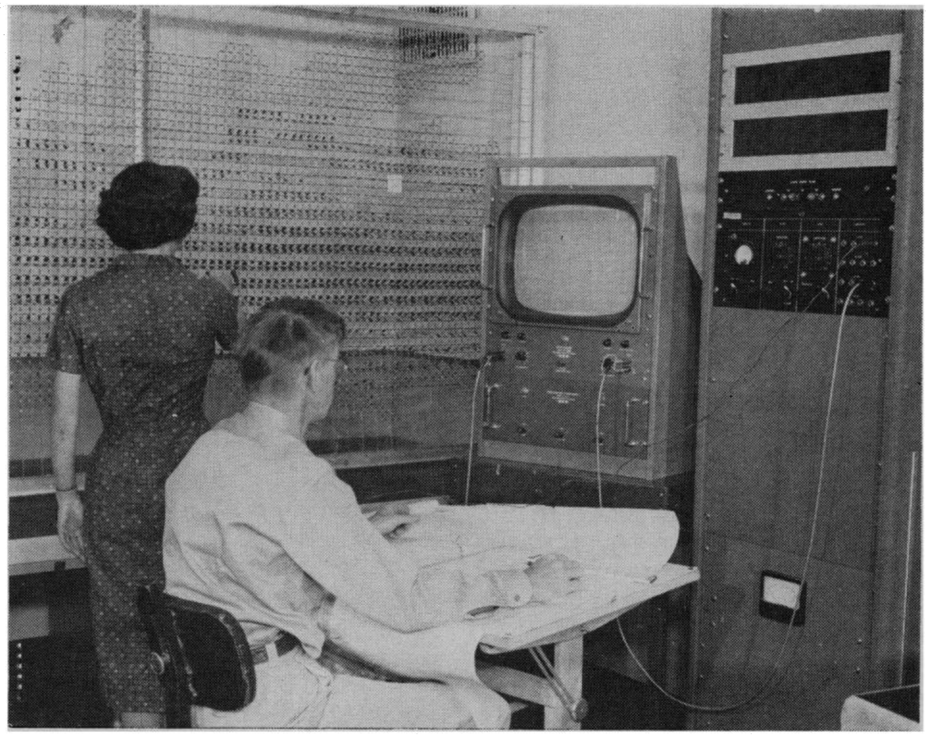

Fig. 2. An analog model of a ground-water aquifer. The analogy between the flow of electricity and the flow of water enables us to use electronic equipment to simulate and therefore solve certain types of hydraulic problems.

The influence of the biota on the quality of the water is greatest in water of high organic productivity. Just as soils differ in their inherent capacity to support plant growth, so do bodies of water, and for many of the same reasons. The addition of nutritive materials, either through natural processes or through mass activity, can greatly change the rate of organic productivity and hence the chemical quality of the water. For example, the growth of alders, a nitrogen-fixing plant, greatly contributed to the fertility of Castle Lake in California (*9*). The nitrogen content of alder leaves is about 35 percent higher than that of other species.

Biological processes are greatly influenced by light, temperature, and other climatic features. In many streams a fairly definite annual algal cycle exists: a flowering of attached algae in early spring; a decrease to moderate levels in summer; a second, smaller peak in autumn; and a winter minimum. There are other significant seasonal cycles, such as, for example, the autumn accumulation of tree leaves in streams during annual low-flow periods. This is a widespread phenomenon that has a profound influence on small streams. The implications of these and other seasonal variations in productivity have not been adequately investigated.

Investigation is also needed on the influence of biota on the abundance and translocation of chemical elements in surface waters, especially minor elements and radioactive materials. Such an investigation requires a knowledge of the physiology and biochemistry of various elements. Experimental techniques could be applied in studies of natural or controlled streams and in the laboratory. Radiochemical techniques already have contributed greatly to our understanding of a few cycles of chemical constituents in lakes, such as the phosphorus cycle, which was studied with P^{32} as a tracer. These methods should be extended to studies of flowing waters and of waters containing other elements.

Knowledge of microhabitats in natural water also must be considered prerequisite to an understanding of the exchange phenomena and other biological influences. Ultimately, all metabolic processes occur at the level of the individual organism or of discrete cells in the organism. Frequently water must come into intimate contact with the living tissues in order to be affected. Thus, knowledge of the spatial distribution of the biota and of the physical and chemical conditions within the "sphere of influence" of the biota is important.

Mechanics of Estuarine Flows

Estuarine flow occurs in tidal reaches of rivers that discharge fresh water to the sea. The chief factors which set estuarine flow apart from what could otherwise be termed "ordinary, open-channel flow" are the presence of long, translatory-type waves which have propagated inland from the ocean and the intrusion of sea water, of greater density. In addition, differences in temperature between the fresh water and the sea water occasionally are sufficient to contribute to variation in density. It is the interaction between the wave motion, the variation in water density, and the relatively steady outflow of fresh water that creates estuarine flow. Because the influence of each of these factors fluctuates appreciably both with space and with time, the character and mechanics of estuarine flow become exceedingly complex.

Present-day comprehension of the mechanics of estuarine flows can be described as cursory and rather disconnected at best. However, we need to understand fully the mechanics, and thereby thoroughly perceive the processes, of estuarine flow. Such flows are of considerable importance, from the standpoint of agriculture, industry, and navigation, to the present and future economic welfare of the United States. Moreover, from the technical viewpoint, comprehension of the mechanics of estuarine flows is the keystone, so to speak, in research on the dispersal of solids and solutes in estuaries.

Estuarine flow is unsteady open-channel flow created through translatory-type wave motion. Such wave motion is a composite product of tides and other long waves of lesser importance, all of which have propagated into an estuary from the ocean. However, translatory wave motion is inherently of unstable form. The crests of such waves travel faster than any other portion, with the result that the wave fronts become increasingly steep while the trailing profiles tend to flatten. Will such a wave profile become so asymmetric, with propagation, as to degenerate into a tidal bore, or will it remain stable until its energy is totally dissipated? What factors influence its stability? These are just two of the questions pertaining to propagation of translatory waves for which answers must be sought.

Several other problems regarding wave action require attention. For example, the variation in channel geometry and its effect upon wave propagation is only partially understood. In stratified flow, wave motion can occur not only at the free surface but also at an interface between the fresh water and the more dense salt water. How do these interfacial waves propagate? What factors govern their stability? These again are unknowns which require answers.

By virtue of its greater density, salt water from the ocean penetrates and tends to flow inland beneath the fresh-water outflow of coastal rivers and waterways. The strength of this tendency apparently depends in large measure upon the width of the channel and upon the rate of fresh-water drainage, by volume. However, the character of stratified flow varies widely from one estuary to another. By way of illustration, the salt-water intrusion in some estuaries assumes a distinct wedge-shaped profile. Moreover, the salt water tends to flow inland along the channel bottom toward the apex of the wedge; it then swings upward and flows back to sea just below the interface between the fresh and the salt water.

The estuaries of the Mississippi River and the Rhone River are examples of this type of flow. In each of these estuaries the impressed wave action propagating from the sea has a minimum range. At the other extreme are the estuaries of the Delaware and Sacramento rivers, in which a distinct interface seldom forms. In these streams the particular conditions are such that extensive mixing occurs. Consequently, the density of the water varies gradually throughout the reach, with little or no distinct stratification.

But what are the various mechanisms that cause the breakdown of stratified flow? Certainly wave motion, particularly at the interface, must contribute to mixing. Turbulence due to dissipation of energy must also be a factor in the mixing process. The exchange of water from shoal areas is certainly another, perhaps major, factor. And, of course, diffusion and convection must finally prevail. Just exactly how and to what degree these various factors combine to bring about the mixing of stratified flow is not known.

Effects of Changes in Land Use

The physical characteristics of drainage basins are continually modified by changes in land use, such as the removal of timber, the building of cities, the construction of reservoirs, and the application of improved agricultural practices. The effect of these changes on the storage, movement, and quality of water must be evaluated (i) for proper interpretation of the data now being collected and (ii) as an aid in planning for optimum development of land and water resources. Because of our inadequate knowledge of the details of the physical processes involved, change in hydrologic regime is commonly evaluated by statistical methods.

The type of statistical analysis used depends primarily on whether the change in basin characteristics occurs abruptly or over a long period of time. Covariance analysis is suitable for assessing the effect of an abrupt change, such as the deforestation of a basin in one year. The data required for this analysis may consist of records of rainfall and runoff for several years before and after the change, or records of runoff for a treated basin and for a control basin whose physical characteristics will not change.

More commonly, the change in land use on a river basin occurs gradually. For assessing this condition regression analysis may be an appropriate tool. Regression analysis has been used (*10*) to evaluate the progressive change with time in seasonal runoff from a reforested watershed, through two hydrologic approaches. In one, seasonal runoff from the reforested basin was related to precipitation and to time during the period for which data were available. The second approach related seasonal runoff from the reforested basin to the corresponding seasonal runoff from a control basin and to the time factor. In both of these regressions it is assumed that the effect of the increasing size of the trees on the seasonal runoff is represented by the time factor. The regression coefficient of the time factor in both regression equations was found to be statistically significant. Thus, both analyses indicate that the progressive change with time is real, and both provide estimates of its magnitude.

The characteristics of hydrologic events and the small number of data available severely limit the use of the regression method. Streamflow, precipitation, and temperature observations constitute time series. The variation in each of those characteristics is a combination of random variation and a within-year cyclic variation. As a consequence, the particular values for streamflow, for example, which may be used in regression analysis must be so selected that they are substantially independent of each other. This usually restricts the values to one per year—for example, one monthly mean, one seasonal mean, or one flood or drought event.

Another deficiency of standard multiple-regression methods arises from the fact that the so-called independent variables to which streamflow is being related are in reality interdependent and thus the regression coefficients do not reflect the specific effect of each variable. This is a handicap where the objective of research is the establishment of hydrologic relationships rather than the delineation of a predicting equation. Other techniques of statistical analysis are available under the broad classification of multivariate analysis; these are factor analysis, component analysis, canonical analysis, and the use of discriminant functions of Taylor series expansions. Investigation of the suitability of each of these techniques for the analysis of hydrologic data is needed.

Further difficulty in delineating the effects of changes in land use on streamflow arises from the fact that the effects are often small with respect to the unexplained variation in regression. Although it may not be of practical use to know the magnitude of a minor effect in a particular basin, it is desirable to know whether that effect is positive or negative. The conclusion that an effect was real and positive might be reached if many regressions based on data from different areas showed positive effects, even though these effects were statistically significant only at low probability levels.

A problem of great interest at the present time is that of determining the amount of water that could be salvaged by removing vegetation from the flood plains of rivers in the southwestern United States. One approach has been to determine the amount of water used by similar vegetation in lysimeters, but it is extremely difficult to simulate water availability and the growth pattern of vegetation under controlled conditions. Another approach is to determine the loss through evapotranspiration in a reach of river channel by measuring the inflow, outflow, and change in storage. After the loss through evapotranspiration has been determined from the water-budget equation, the vegetation is removed, and the change in evapotranspiration represents the amount of water that could be salvaged. The water-budget method is useful only for delineating an effect which is almost constant from year to year. It also requires removal of the vegetation and accurate measurement of streamflow and storage. In many reaches the water salvaged by removing vegetation is a small item in the total water budget and thus cannot be determined accurately as a residual. Furthermore, the loss through transpiration may vary greatly from year to year, and accurate measurement of the factors in the water-budget equation is usually difficult.

Given adequate data for many years before and after the removal of the vegetation, a regression analysis might provide a conclusive answer. It seems reasonable, however, to expect quite different answers for different reaches, and therefore it is not possible to generalize.

The statistical approach to the water-salvage problem has not been encouraging, and the ultimate solution may depend upon the direct measurement of transpiration, which is a current subject of research (*11*).

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