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The hydrography of the United States

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TABLE OF ALTITUDES.

Name of Place.	Feet above Sea-Level.
Gulahek,	4656
Top of pass between Jaj Rud and Tehran basin,	6107
Bridge Jaj Rud,	5253
Galendavek,	5582
Narun Village,	5779
Village of Afcha,	6599
Plateau half way down on south side of Afcha pass,	8307
Top of Afcha pass,	9866
Ab-i-Safid at Lar side of Yalu pass, shown on Schindler's Map,	8438
Kulayek or Kulwek on Nur river, *vide* Lovett's Map,	6007
Junction of two waterways in gorge between Kuruk pass and Baladeh,	7125
Summit of Kuruk mountain,	9850
Summit of pass out of Kujur valley,	9456
Plateau going from pass to Varasun,	7716
Varasun in Kujur valley,	6173
Ruin in Kujur valley,	5073
Centre of valley below Kujur town,	4656
On road above Nao Rudbar,	3841
Ditto ditto,	3447
Nao Rudbar,	3168
At foot of precipice and on stream,	2068
Down stream at bridge,	1346
Mulla Kala,	615
Caspian Sea at Sarin Kala,	- 84

N.B.—Rud = River.
Kuh = Hill or mountain.
Kala and Deh = Village.

THE HYDROGRAPHY OF THE UNITED STATES.

By Frederick Haynes Newell,

Chief Hydrographer, U.S. Geological Survey.

(*Read at the Meeting of the British Association, Toronto,* 1897.)

(*With Maps.*)

In considering hydrography as a branch of geography, it may be claimed that the period of exploration has passed. The location of nearly every stream or source of water is fairly well known and represented on the ordinary maps of States and counties. The next stage of progress, that in which accurate information is obtained as to the

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volume and fluctuations of the water resources, may be said to be fairly entered upon. Of few localities, however, can it be held that there exists information concerning the waters sufficiently definite to suffice for ordinary engineering or civic requirements, excepting possibly in the case of some of the principal harbours and larger navigable streams.

THE FIELD OF INVESTIGATION.

The country to be studied in obtaining a knowledge of the hydrography of the United States is not only large, but also highly diversified in character. The problems encountered have great variety, not only in kind, but in magnitude of scope and in practical application. While in some respects intimately connected, the subjects of hydrographic study have a natural classification, based largely upon geographic divisions, the western or arid part of the country demanding investigations differing widely in purpose from those of the eastern or humid sections. In following out this classification, the rivers of the Atlantic slope, taken in order from north to south, come first; then the Mississippi river and its tributaries, from the Appalachians westwards to the Rocky mountains; then come the Texan or Gulf streams, including the Rio Grande; next to these the great Colorado river, flowing south-westerly into the Gulf of California; after these may be taken up the lost rivers, or the drainage of the vast interior basin of the continent from which no streams escape to the ocean; and, finally, the Columbia and other rivers flowing into the Pacific, the most notable of which are the Sacramento and its tributary, the San Joaquin.

THE PURPOSES OF INVESTIGATION.

The direct objects of the various investigations bearing upon the hydrography of the country are distinctly economic. Each has in view the accomplishment of some result which shall render available to a larger degree the natural resources adding to the wealth, comfort, or health of the people. Indirectly, however, facts of broad scientific interest are revealed, though the work may not have been planned for this larger end. It is well to keep in mind the object or motive of the various branches of work, in order to better comprehend the causes of the deficiencies or want of symmetry in the resulting body of facts.

The first in time, if not in importance, of the objects of hydrographic investigation are undoubtedly those pertaining to navigation. Since the period of the first discovery of the continent, explorations and the minute mapping of the shores, harbours, and navigable rivers have been almost continuously carried on. The body of facts thus accumulated is in what may be termed a complete form, requiring for the most part merely the continual revision and refinement necessitated by changing conditions and by the more exacting demands of commerce. The methods and results of the surveys of navigable waters are so well known, and have been so widely extended throughout the world, that comment here is not necessary.

Next to the demands of commerce for information concerning waters

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are those of the manufacturing industry. In the former case water furnishes the means of transporting the goods, and in the latter, through its momentum in the descent from higher to lower levels, it furnishes power to drive the complicated machinery which has replaced manual labour. It would be a comparatively trivial matter to ascertain the extent and value of available water-powers, if the streams continued with unvarying flow through seasons and years; but, with their constant fluctuations day by day, the problem becomes one requiring years of measurement to determine what may be considered as the available economic power to be realised. At certain seasons of the year the amount of water is vastly in excess of any possible utilisation, and then is a source of danger to structures and to population. At other times the quantity drops below the capacity of the water-wheels or other machinery, and storage of flood waters must be resorted to. In contemplating a new enterprise, it is necessary to know the range in the behaviour of a stream through many years, in order to determine the necessary dimensions and strength of structures to be erected, and to make suitable provisions for tiding over the times of deficient supply. The question of probable profit or loss may be determined by the record of a few days' low water in the past. In illustration may be cited the case of a great water-power enterprise for which capital had been raised and thorough examinations made. It was found, however, that no trustworthy records existed of the behaviour of the river in the past, but the assumptions of the engineers, based on incomplete data, seemed to show that a possible short period of low water might eat up the profits of the enterprise. The project was therefore abandoned. The phenomenally low water of subsequent years, however, never reached the minimum predicted, and it is now obvious that, had the works been erected, failure would not have resulted from this cause. The utilisation of the water-power of the country demands, therefore, the most careful examination conducted through many years, so that, on the one hand, costly experiments may be avoided and, on the other, that these natural resources may not be undervalued.

In the United States there has arisen a third demand for knowledge of the water resources which, in political and social importance, ranks even above the needs of navigation and manufacturing. This is through the extension and higher development of agriculture by the artificial application of water. The nation as a whole has been, and still is, a great landowner, having now in its possession, and at the disposal of Congress, one-third of its area, excluding Alaska. This one-third includes some of the richest and most fertile areas of the continent. It is for the most part open to settlement and private acquisition under what is known as the Homestead Act, but it is practically unavailable to the settler, usually a man of small means, because of the fact that the climate prevailing throughout the vast extent of public land is too arid to allow of the growth of ordinary farm crops. Irrigation must be practised, and, where employed, it has been notably successful and remunerative; but the supply of water is scanty, and in many cases, before an acre of the best land can be cultivated, enormous expenditure must be made in the construction of reservoirs, canals, and ditches, such as puts it beyond the power of farmers or groups of farmers to make even a beginning.

Throughout the greater part of the western half of the United States all land values are dependent upon the ability to secure perennial supplies of water. The fluid which in the east is in excess, and in many localities is literally free as air, becomes, as the supply diminishes, a valuable commodity. A spring of moderate capacity found within the arid region may be more highly prized than a mine of precious metal; it is a never-ending source of revenue. The limitation of the supply of moisture puts a premium upon careful farming; for, with the warm, cloudless days, and the application of a proper amount of water, combined with thorough cultivation, the largest results are obtained from the minimum acreage. Economy of effort and density of population are thus favoured by the employment of water in agriculture.

The utilisation of the vast extent of fertile public land is a question of great national importance, not only from the standpoint of the citizen as owner of the land, but from many other sides. The arid lands now desert are capable of furnishing homes for a population of millions, and if properly utilised will serve for many decades as an outlet for the congested population of the eastern cities, furnishing a possible solution for some of the most pressing social problems of the day. Before plans involving the utilisation of these lands can be made, it is necessary, however, to obtain accurate knowledge as to the available water supply both above and below ground, and of possibilities of conserving floods and of raising water by machinery from lower to higher levels. With the fluctuations which take place from year to year, it is obvious that such investigations must be continued for periods sufficiently great to show the ordinary range of conditions.

There is yet another series of investigations which, though individually of local concern, are yet found wherever civilisation progresses. These pertain to the supply of water for domestic and municipal use. The quantities to be secured are relatively small—almost insignificant in comparison with those required for navigation, water-power, or even for irrigation—the supply of water for a city of 10,000 people being not greater than that needed to irrigate a farm of 150 acres. But while the quantities are small, the quality is of prime importance, for upon it depend the life and health of communities. As a rule, each city or town, or, in the country, each family, makes its own investigation regarding sources of water; but as population increases the opportunities of enjoying an unpolluted source of supply rapidly decrease. Especially is this the case with cities which, from their location, are compelled to draw water from streams flowing for a considerable distance and possibly crossing State lines. Such streams, in our present state of civilisation, receive with the drainage of the country the sewage from towns and institutions, together with offscourings and refuse of all descriptions. The time is rapidly approaching when vigorous steps must be taken to prevent stream pollution, and in the meantime a thorough knowledge must be obtained of all possible sources of supply.

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Passing over many minor demands for hydrographic investigation, there may be taken up as of general interest the class of facts, geologic in character, which pertain to the eroding and transporting power of running water. These matters have interest, however, not only for the student of geology in tracing out the operations by which the present aspect of the earth has been produced, but also for the engineer, who is concerned with the stability of earth and rock, and the formation of bars or obstructions in rivers and harbours. Comparatively little observation has been directed specially to such matters, investigators being content with the derivation of a few somewhat empirical formulæ as to the ability of streams to carry material of certain form and weight.

The Investigations.

From the foregoing abstract of the objects of hydrographic investigations it is obvious that such work must be carried on by many men and by various methods. With the rapid development of the country, and the impossibility of predicting future needs, it has been impracticable to lay out broad lines of research, and field work has, in fact, been devoted to the purposes of the moment. In reviewing the results that have been attained, it may properly be claimed that the pioneer efforts are on the one hand traceable to the efforts of Thomas Jefferson in his advocacy of the establishment of scientific surveys, realised later in the operations of the Coast and Geodetic Survey. On the other hand, as regards the hydrography of the country at large, the foundations may be said to have been laid by the Smithsonian Institution. The history and operations of the Coast and Geodetic Survey have been so fully discussed by others that it is not necessary at this time and place to enter upon them, and the importance of the achievements of this organisation call for more space than can here be given.

Brief reference only can be made to the work of the Smithsonian Institution, the mother of many important governmental bureaus of investigation. It has apparently been the policy of the guiding spirits of this institution, in their attempts "to increase and diffuse knowledge among mankind," to inaugurate scientific work in all lines, and, when any one investigation attained a growth such that public interests ensured its continuation, to dismiss from the parent home this offspring as a separate bureau, usually attached to some one of the executive Departments. In this way the Fish Commission—an independent organisation—took its origin; also the Weather Bureau, now a part of the Department of Agriculture. Possibly the Geological Survey, one of the bureaus of the Department of the Interior, may also be traceable to the explorations fostered and encouraged by the Smithsonian funds. It is apparent that the first systematic studies of the water resources of the United States and the discussion of their possibilities and limitations is due to the stimulus afforded by this institution. Work of this character has, however, been almost entirely abandoned by the Smithsonian, because original research in this direction has been taken up systematically by younger organisations.

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The construction of public works for coast defence and for the improvement of navigation has been intrusted to the supervision of engineer officers of the army. The preliminary work of ascertaining physical conditions has necessitated the acquisition of a considerable body of facts in regard to the rivers and harbours, especially in the immediate locality of points where works of improvement are undertaken. The study of hydrography carried on under such conditions is of necessity fragmentary and incomplete, but it is yielding data which, when rounded out and supplemented, must be of inestimable value in the progress toward better knowledge. Each year is adding to the accumulation of data through the maintenance of tidal gauges and of observations of water levels in navigable streams, such, for example, as the Mississippi, Missouri, Ohio, and their principal tributaries, and the larger rivers entering the Atlantic and Pacific Oceans. Besides these operations and the surveys of the Mississippi and the Missouri rivers, various engineer officers are from time to time making special examinations of streams large and small, reporting upon the practicability or advisability of removing obstructions and of providing locks and dams for maintaining navigable stages during times of low water. The information thus obtained is for the most part published in the annual reports of the Chief of Engineers.

The work of the Weather Bureau, in many of its divisions, is of prime importance to the knowledge of the hydrography of the country. It lies at the root of the matter, in that through the records of precipitation facts are obtained as to the distribution of rainfall over the surface of the land. These observations are being carried on at many hundreds of localities, a few records being kept at stations provided with trained, salaried officers, but for the most part they are obtained through the co-operation of persons who voluntarily give their time to the measurement and recording of rainfall and also of changes of temperature. In addition to this, the Bureau maintains on a number of the more important streams a system of gauges under the charge of local paid observers, these being so placed as to give information concerning the rise and fall of the streams at points where the information will be of value in making flood predictions. The system of warnings based upon these observations has proved of great value, not only to commerce, but also to all the inhabitants within areas liable to inundation. Through the notices timely given it has been possible to save from destruction property valued at many thousands of dollars, and doubtless many lives. The observations are made, as a rule, only during the flood season and are discontinued throughout the winter, especially in the case of rivers covered with ice during a great part of this season.

The investigations of the Geological Survey through its Division of Hydrography are designed to give a general yet thorough knowledge of the distribution of water throughout the country, both above and below ground, its fluctuations in quantity from time to time, and the factors which govern its capability of contributing to the prosperity of the citizens. In view of the limited resources available for the purpose, it is not practicable to measure all streams or to carry on studies of under-

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ground waters in all places, but attempts are made to select the more important or typical localities, and to obtain facts which will be not merely of local value, but will have a broader application. There are two classes of work involved—one of a somewhat simple engineering character, consisting of measurements of the discharge of rivers at designated points, and computations of the daily flow; the other less direct, necessitating a thorough examination of geologic conditions and the bearing of these upon the occurrence of water and its motion underground.

The measurement of water in the river differs from the ordinary meteorological operations in that we are dealing with a constantly varying quantity, the natural streams fluctuating from moment to moment, often by perceptible amounts. Thus extreme accuracy is practically impossible, even if desirable, for the amount ascertained for one hour in the day on a given date may not again be equalled in a decade. A considerable number of measurements, whose errors, though relatively large, are not cumulative, must therefore be made, and at times and seasons when they are representative of prevailing conditions. The expense, however, of frequent measurements is usually prohibitory, and therefore a further method of approximation must be employed, consisting in maintaining continuous observations of the height of water of the stream, or daily or periodic records made at intervals so short that there can be no extreme variation between them. This is the course adopted, the assumption being that the quantity of water in a given stream in a general way follows the height upon a fixed gauge. That assumption, however, is in error wherever a stream is eroding or modifying its channel to a notable degree. Then the height of water means little or nothing, unless taken in connection with the shifting form of cross-section.

The operation of river measurement as now carried on consists in establishing a gauge at some point favourable for measurement and for observation. Readings of height of water are made, and records are transmitted to the local engineers or hydrographers; at intervals of a few weeks the hydrographer visits the stations under his charge, measures by means of a suitable apparatus—usually an electrically recording current meter—the velocity of the water, obtains by direct measurement the depth and width, and from these data computes the discharge for the height at which he happens to find the stream. The results thus obtained are collected, and from measurements made when the stream is at high and low stages and at intermediate points a graphic curve is constructed, representing what may be termed the average relation between height of water and quantity flowing. From the curve a table is constructed which gives the ordinary flow for each tenth of a foot at which the water stands on the gauge. This table is used in converting the daily record of height into a statement of discharges, from which may be learned the maximum, minimum, and average flow for any particular month or year. Such river stations are being maintained in about 150 localities, for the most part in the western half of the United States, where the question of water supply has an immediate bearing upon the utilisation of the arid public domain. Where the channel of the stream is of such an unstable character that these simple operations are not applicable, more frequent direct measurements of discharge must be made, as it is usually impracticable to attempt to improve or rectify the channel for the purpose of measurement.

A knowledge of underground waters is based upon a systematic examination of the materials which form the outer covering of the earth. In order to obtain facts concerning the quantity and quality of the contained water and of its probable hydrostatic pressure, it is essential to know not only the topographic structure, but also the position and character of the rocks for a considerable distance beneath the surface. Operations are being carried on mainly within the Great Plains region, where living streams are rare, and where the surface of the ground is so nearly level that it is impracticable to store water in reservoirs or tanks. Here wells must be depended upon to a large extent to furnish not only drinking water, but the supply necessary for cattle and for the cultivation of gardens and of the trees shading the homes of the people. In this country, characterised by uniformity, the rocks are continuous in character over great areas, and examinations extending over a considerable portion of the continent must be made before local conditions can be determined. The underground structure, however, is not as simple as might be inferred from the surface, for the older and deeper rocks have in many places been decidedly flexured or even faulted, especially at points near the foothills. Thus, while predictions can be made as to the thickness of the rocks over considerable areas and the depth to certain water-bearing strata, yet these statements must be carefully checked by a thorough search for interrupting causes.

The method of work consists in careful examination of the surface rocks of all places where outcrops may be expected, and the collecting and comparison of records of wells, especially those of notable depth. The exposure of the upturned edges of the Plains rock against the mountains affords opportunities of estimating its thickness, and this in turn is checked by the examination of outcrops in ravines and by measurements obtained from deep wells. The character of the water-bearing beds must be determined from these outcrops and from the borings, and in short every available fact and inference must be utilised in adding to the mass of information.

Results.

The results of the various branches of hydrographic investigation, when rounded out, give a complete history of the progress of the cycle of existence of water from the time it reaches the earth as rain until it is again returned to the air by evaporation, or fixed more or less permanently in the tissues of plants or the rocky crust of the earth. This life-history embraces not only the progress of the water from point to point, but also its quantity, distribution, extent, and depth in the rivers and lakes and on the navigable coasts. The progress of events in such a history can be discussed under several heads, the principal of which are the quantity and distribution of the rainfall, the amount of

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water which runs off the surface of the ground to form streams, commonly known as the runoff; next the portion which is early evaporated from the soil or from plants growing in it is considered; and, lastly, that which sinks underground, percolating for considerable distances to form relatively permanent ground-waters or to re-appear, in part at least, in springs and ordinary or artesian wells.

The great body of facts thus far acquired consists of measurements of rainfall made by the Weather Bureau, of records of river height kept by this organisation and by various officers of the army, together with occasional discharge measurements, made at irregular intervals. To these must be added the measurements and computations of daily and monthly discharge of various streams resulting from the field work of the Geological Survey, and a considerable body of facts relating to the

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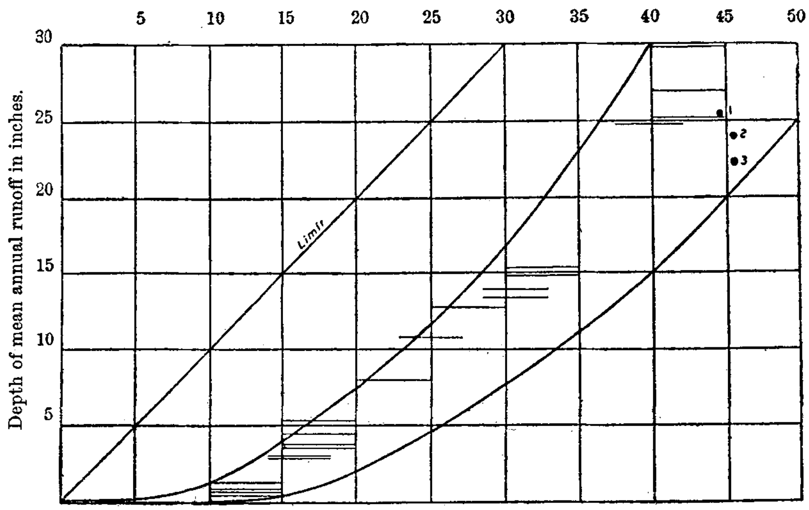

Relation of runoff to rainfall.

occurrence and movement of water underground resulting from the studies of various geologists. This somewhat heterogeneous mass of material is being digested as rapidly as possible by the Division of Hydrography of the Geological Survey, with the intention of preparing a systematic description of the hydrography of the United States.

One of the first results to be attained, but one for which many more facts are needed, is the relation existing between rainfall and runoff under various conditions of topography and culture. Tentative conclusions have been drawn and expressed in the form of simple diagrams. If all the rain that fell upon the surface flowed off in the streams as from a roof, then with, say, 40 inches of annual rainfall, there would be an equivalent depth of 40 inches of annual runoff; but, as a matter of fact, from the ordinary mountainous country only about 30 inches in depth of runoff may be expected, and from surfaces of less relief, as the rolling prairies and foothills, about 15 inches in depth of runoff per year. On

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the other hand, with 20 inches of rainfall, the amount running off from the mountainous country is approximately 7 inches, and from the prairies 2 inches. With half as much rainfall, or 10 inches in depth, only about 2 inches per year can be expected from the mountains and practically nothing from the plains. In other words, with a mean annual rainfall of less than 10 inches, or from 10 to 15 inches, no living streams can be expected outside of the mountains, and, as shown by the map of the United States, rivers rising in regions of such aridity disappear upon reaching the lowlands, so that the great arid region of the west is characterised by its lost streams.

Another set of results that are being obtained regards the average discharge of the rivers of the country. It is recognised that, with the great seasonal and climatic oscillations that take place, the streams have great range and may never flow for any considerable length of time at their average rate, but nevertheless, even with these wide and irregular variations, it is a matter of considerable moment to know what has been for a period of ten years or more the average discharge of the streams at certain points. This average discharge, when represented diagrammatically on a map, enables the student to see at a glance the relative importance of various rivers, as well as their length and position.

The average quantity of water carried by rivers at various portions of their course being ascertained approximately, it becomes practicable, upon this basis, to study the variations from the mean, and to fix a standard by which to express the relative excess of floods or the relative deficiency of droughts. The intensity and duration of these are matters of great importance, both in their practical and scientific application, and can only be satisfactorily discussed when results have been obtained covering a considerable range of time. When such data have been assembled and arranged for convenience of reference, it will be possible for individuals—officials, engineers, or promoters—to discuss the practicability of enterprises designed to promote the health, comfort, or wealth of the people.

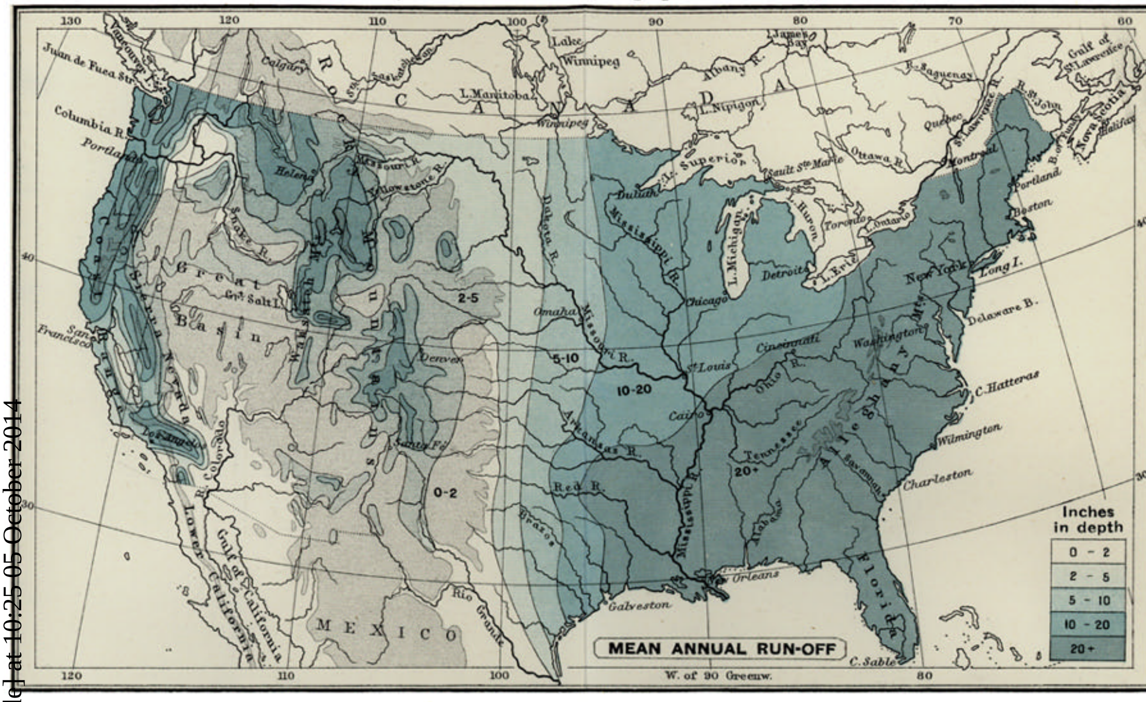
PRIMARY CONDITIONS OF TROPICAL PRODUCTION.

BEING AN INTRODUCTION TO ECONOMIC BOTANY.

By G. F. Scott Elliot, M.A.

The idea of studying this subject arose from my own experience in Africa and Madagascar. I have very often seen both serious financial loss and waste of valuable life through a misunderstanding of the most obvious rudimentary laws of plantation. To our own country the subject is of increasing importance. Against our imports last year of £441,808,904 we can only place a poor export of £296,379,214. This leaves a balance paid away of over £140,000,000. It is not necessary to go into the political economy of the subject, but there can be no doubt that this money for the main part passes over to support American and German

MAPS ILLUSTRATING THE HYDROGRAPHY OF THE UNITED STATES
by Frederick Haynes Newell, Chief Hydrographer U.S. Geological Survey.



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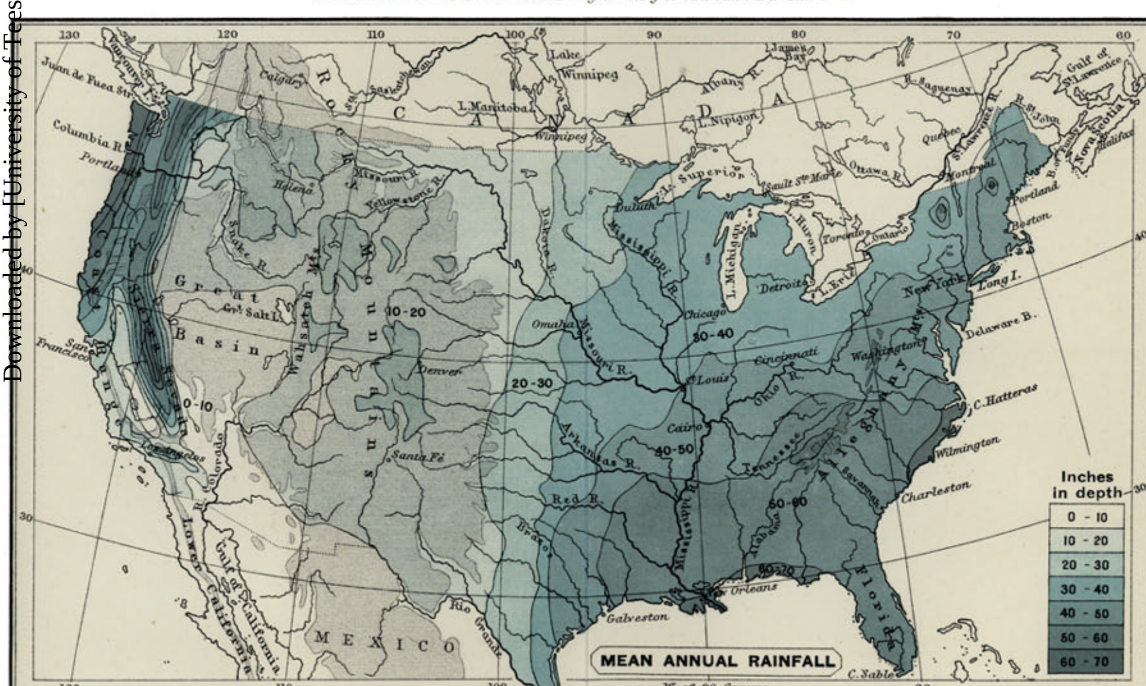

The Edinburgh Geographical Institute

J.G.Bartholomew.

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