TOWARD A GLOBAL HYDROLOGICAL TYPOLOGY

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ABSTRACT

To provide an elementary hydrological typology, 7 basic components are varied on an all-or-nothing basis; this results in 48 hydrological units. These units, presented in tabular form, are briefly discussed in terms of constancy, seasonality and spatial interaction. Global maps of the individual hydrological units are shown to vary from the world climate pattern because of irregularities in topography and permeability of the parent material.

INTRODUCTION

It would seem that attaining a global perspective of the many variations of the hydrological cycle would be one of the goals of hydrology, yet texts in this field refer only to a highly generalized cycle, and discuss this generalized version in great detail. It is then left to the imagination of the reader to apply this detailed information to the many various subcycles that actually occur.

For example, in outlining the hydrological cycle, Linsley *et al.* (1949) refer only to the following factors: potential evapotranspiration (amount and time); evaporation; precipitation (amount, time, form); interception; runoff; interflow; soil storage; percolation; groundwater storage. Wisler and Brater (1959) include such additional factors as: area of basin; shape of basin; slope; drainage network type; vegetation (use rate, density).

The existence of many various hydrological cycles is only briefly referred to by Bruce and Clark (1966, p. 50) when they state "There are a great variety of hydrological regimes on rivers of the world. Even within a single country tremendous variations can occur". They then go on to briefly describe and present typical annual hydrographs for several Canadian regions, such as the Canadian Shield, the Appalachian area, the St Lawrence lowlands, the Great Plains and the Cordilleran area.

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A review of current research in hydrology reveals an occasional paper dealing with the delineation of hydrological regions (Kuzin, 1960; Toebes and Palmer, 1969). For the most part, however, the review will reveal a great wealth of regional studies such as "the hydrology of a karst area in east central West Viriginia" or "hydrological characteristics of alluvial fans near Salinas, Puerto Rico". There remain, however, an outstanding number of gaps in this approach to attaining a global hydrological overview, because these regional studies deal only with a very small percentage of the possible types of hydrological subcycles, and most of these in the temperate climates of the northern hemisphere.

Recent investigators dealing specifically with the hydrological cycle are of the opinion that before models of any given cycle can be successful, more knowledge concerning factors involved as well as the degree of interrelatedness of factors is necessary. Mustonen, for example, used basic climatological and basin characteristics affecting annual runoff in Finland to develop a reliable prediction equation by means of a simple linear multiple regression approach. However, he states that until the basic physical relationships are better understood, no statistical procedure can uncover the underlying laws governing runoff (Mustonen, 1967, p. 123). Diaz *et al.* (1968, p. 305) conclude that thorough physical characterization of watershed variables is necessary for gaining insight into identifying and determining the effects of various factors on water yields.

Wallis (1968, p. 523), in outlining the tentative procedure for building watershed models based on principal components analysis and varimax rotation of the factor weight matrix, heads his list with the statement "Know as much as possible about the system being investigated". Huggins and Monke (1968, p. 531), in discussing mathematical models to simulate surface runoff from watersheds, state that "obviously the overall accuracy of the model depends upon the ability of the functional relationships of hydrological components to describe their respective phenomena. Unfortunately, hydrological research has not yet produced reliable, quantitative descriptions of several of the hydrological components needed for a comprehensive watershed model".

Thus, before hydrological systems can be meaningfully studied in great detail, they must be described in general, with the basic interrelationships between individual cycle components understood. This would first seem to require the derivation, classification and location of all major hydrological cycles. Location would seem to be of extreme importance in terms of regional and international water transfer projects.

DERIVATION OF HYDROLOGICAL UNITS

The first step in the derivation of possible subcycles is the selection of those cycle components to be considered. Secondly, the factors and variables under each of these basic cycle components must be selected. The more components and component variables chosen, the closer the derived list of subcycles approaches the real world.

In this paper, an elementary hydrological typology is realized by selecting seven cycle components (precipitation, vegetation, soil, potential evaporation, slope, permeability, and surface runoff) and varying them on an all-or-nothing basis (except for potential evaporation, which is varied in terms of low or high).

The criteria used in determining the situation for each of the seven cycle components are presented below. It should be kept in mind that at the global scale of analysis, information concerning these components is highly generalized, and for the components of vegetation, soils, slope, and permeability the information is qualitative. In addition, the components of precipitation, potential evaporation and surface runoff have been quantified with reference to determining the hydrological subcycle for a given month.

Precipitation The division between no significant precipitation and some precipitation was selected at 1 inch for any given month.

Vegetation An area was considered to have no vegetation where an actual absence of vegetation was indicated on global vegetation maps, where an absence of soil was indicated on global soil maps, where the average annual precipitation was less than 10 inches, or where the vegetation was dormant owing either to no precipitation for the month in question or to the mean temperature falling below 50°F for the month in question.

Soil The absence or presence of soil was determined directly from global soil maps. Mountain areas of high elevation which were mapped as 'complex regions of no soil and some soil' were considered as no-soil areas.

Potential Evaporation The mean temperature of 60°F for the month in question was used in determining whether an area had a high or low potential evaporation rate.

Slope Areas classified on global land-surface form maps as flat plains were considered to have no slope. All other land-surface forms were considered as having some degree of slope.

Permeability Areas on global lithological region maps were considered to have permeable parent material if they were classified as weakly consolidated or unconsolidated sedimentary rock, complex folds and faults, and recent alluvium. All other lithological regions were considered impermeable. In addition, all areas with continuous permafrost for the month in question were considered impermeable.

Surface Runoff It should be noted that there is a distinction made here between surface runoff and stream flow. This particular typology deals with point locations for a specific time, whereas stream flow results when excess precipitation (greater than 1 inch per month with a low evaporation rate or greater than 8 inches per month with a high evaporation rate) reaches the stream channel by direct surface runoff (where no soil is present and the parent material is impermeable) or by groundwater seepage (where soils are present and the parent material is permeable). No runoff of any kind occurs in the cases where there is no precipitation, or where there is precipitation and the mean monthly temperature is below 32°F.

Thus where there is an excess of precipitation, and no surface runoff, this indicates the water is participating in the hydrological subcycle either as soil interflow or percolation down to the groundwater table.

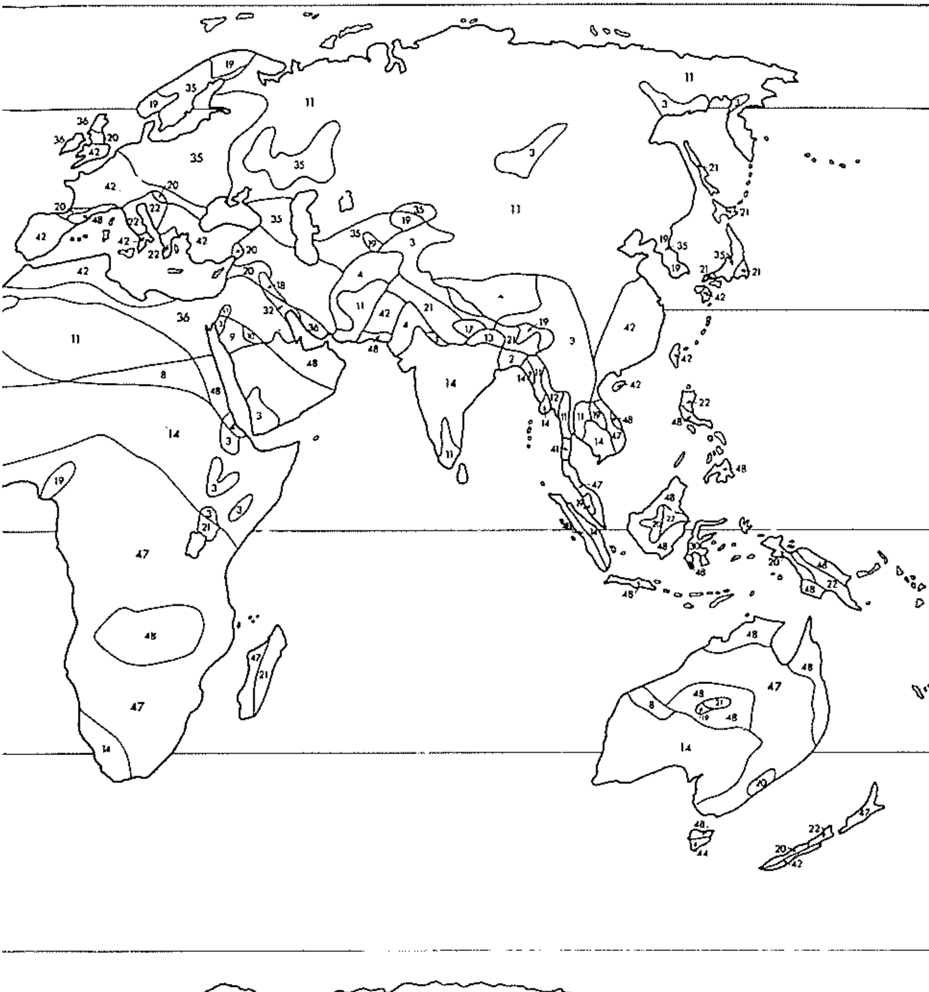
Of the resulting hydrological units, 48 are accepted as possible (see Table 1), with the following five groupings being considered impossible: runoff and no precipitation; no precipitation and vegetation; no soil and vegetation; soil, slope, and impermeable parent material; and precipitation, no vegetation, soil, and high potential evaporation rate.

LOCATION OF HYDROLOGICAL UNITS

Global maps of each of the seven cycle components were prepared and superimposed in order to locate the individual units. This was done for the months of January and July (see Figs 1, 2).

The global maps resulting from the superimposition of the first four components (precipitation, vegetation, soils and potential evaporation) were found to be highly similar to global climate maps. The complexity of the final hydrological unit maps is compounded by the apparently random occurrences of both slope and permeability. That is, whereas the superimposition of maps of precipitation, vegetation, soils and potential evaporation results in a display of some latitudinal patterns owing to their high correla-

FIG. 1 — Location of hyd



ydrological units; January.

ydrological units; July.

FIG. 2 — Location of hydr

TABLE 1 — Hydrological units obtained by varying seven basic components on an all-or-nothing basis.

Map unit	Precip-itation		Vege-tation		Soils		Evapo-ration		Slope		Permea-bility		Runoff		Comments
	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	
1		x		x		x		x		x		x		x	Polar
2		x		x		x		x		x	x			x	
3		x		x		x		x	x			x		x	
4		x		x		x		x	x		x			x	
5		x		x		x	x			x		x		x	Rocky, hot desert
6		x		x		x	x			x	x			x	
7		x		x		x	x		x			x		x	
8		x		x		x	x		x		x			x	
9		x		x	x			x		x		x		x	Cold, dry winter, vegetation dormant
10		x		x	x			x		x	x			x	
11		x		x	x			x	x		x			x	
12		x		x	x		x			x		x		x	Dry, hot summer, vegetation dormant
13		x		x	x		x			x	x			x	
14		x		x	x		x		x		x			x	
15	x			x		x		x		x		x		x	Rare, lack of soil owing to glaciation, erosion, vulcanism,........
16	x			x		x		x		x		x	x		
17	x			x		x		x		x	x			x	
18.	x			x		x		x		x	x		x		
19	x			x		x		x	x			x		x	
20	x			x		x		x	x			x	x		
21	x			x		x		x	x		x			x	
22	x			x		x		x	x		x		x		
23	x			x		x	x			x		x		x	
24	x			x		x	x			x		x	x		
25	x			x		x	x			x	x			x	
26	x			x		x	x			x	x		x		
27	x			x		x	x		x			x		x	
28	x			x		x	x		x			x	x		
29	x			x		x	x		x		x			x	
30	x			x		x	x		x		x		x		
31	x			x	x			x		x		x		x	Cold, wet winter, vegetation dormant
32	x			x	x			x		x		x	x		
33	x			x	x			x		x	x			x	
34	x			x	x			x		x	x		x		
35	x			x	x			x	x		x			x	
36	x			x	x			x	x		x		x		
37	x		x		x			x		x		x		x	Cool, wet
38	x		x		x			x		x		x	x		
39	x		x		x			x		x	x			x	
40	x		x		x			x		x	x		x		
41	x		x		x			x	x		x			x	
42	x		x		x			x	x		x		x		
43	x		x		x		x			x		x		x	Hot, wet
44	x		x		x		x			x		x	x		
45	x		x		x		x			x	x			x	
46	x		x		x		x			x	x		x		
47	x		x		x		x		x		x			x	
48	x		x		x		x		x		x		x		

tion with the global climate pattern, the distribution of slope and permeability seem to have no latitudinal basis whatsoever, and thus show global hydrology to be a much more complicated and thus less predictable phenomenon than climate.

The degree of generalization in this typology is necessarily high and is due to selecting only seven components and varying them on an all-or-nothing basis. As the number of components is increased, and the variation quantified, the degree of generalization will be correspondingly lowered.

DISCUSSION

The elementary typology presented here is an initial attempt to derive and locate a very complex set of phenomena (i.e. global hydrological subcycles). The typology is comprehensive in that every real-world subcycle will only be a more complicated version of one of these basic 48 possibilities, which is approaching the limit for the amount of detail that can be cartographically represented at the global scale. As more advanced classification schemes are developed for application to regional and even local studies, they will be an expansion of this elementary typology, where more cycle components are reviewed in terms of greater component variation for as many time increments of the year as it takes to describe adequately the area's hydrology (Haley, 1970). The degree of sophistication attainable in these more advanced typologies, especially in terms of quantifying the component variables, will result in a hydrological classification scheme that will allow the numerous local hydrological studies presently available to be organized into a much more meaningful framework than is possible now.

Concerning this elementary typology, it should be kept in mind that any given location may have one or several subcycles throughout the year. This is because several of the cycle components are not constant in time, these being precipitation, vegetation, potential evaporation, and runoff. Areas with a relatively constant hydrology throughout the year will cover less than one-fourth of the earth's land surface, namely the polar areas, the centres of large desert areas, and the centres of tropical rain-forest areas.

In addition to seasonal variation, annual variation will also occur in any area's hydrology. For example, an area may have an occasional drought year or an occasional winter with snow.

Where more than one subcycle occurs throughout the year for a given location, these subcycles will interact. Examples here would be delayed snowmelt and soil moisture storage.

In addition, the individual subcycles will interact spatially, with examples being the occasional flooding of an arid area by an area with excess precipitation, or the movement of groundwater from one cycle region to another.

CONCLUSION

Detailed investigations of relatively small areas is one trend in physical hydrology, and will not in itself resolve the present lack of comprehensive understanding of the hydrological cycle. This is because these detailed studies will not necessarily include all major cycles, and moreover, remain unclassified once they are completed owing to the lack of any hydrological typology.

The purpose of this paper is to realize a more comprehensive understanding of the hydrological cycle by presenting an elementary global typology. As more cycle components are added, and more component factors and variables are added, the resulting subcycles will become increasingly similar to the individual cycles encountered in the field.

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