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PAPERS ON THE RELATION OF THE ATMOSPHERE TO HUMAN COMFORT

551.5 : 613.1

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In a manner much to be commended Dr. C. F. Brooks has published in the MONTHLY WEATHER REVIEW, October, 1925, **53**: 423–437, a paper under this heading having as its object the characterization of the climate of a given place by the relations of the total influences upon man's feeling of certain weather types prevalent at that place.

Meteorology has achieved much in recent decades in the service of agriculture, shipping, and air travel; on the other hand, it has not many successes to record in its direct relationship to man in health and disease, to his feeling, and to hygiene. The explanation lies in the difficulty involved in the task, for, in addition to the great variety of climates, depending chiefly on geographic latitude, altitude above sea level, soil covering, and the complexity of each resulting from the many weather elements superposed in their effects, the influence of the ecological factor is effective to a far greater degree in man than in plants (agriculture), in that with the progress of civilization man has been able more and more to withdraw himself from the direct influences of the weather by means of housing and clothing—through the influence; that is, of the "private climate" which he can create and which is considerably at variance with the local climate as measured by meteorology. Racial peculiarities present further difficulties and the problem which Doctor Brooks has set is, to be sure, rendered most complicated by the circumstance that with man, in contrast to the method most generally employed in botany, we must individualize according to constitution, antecedents, etc. Neither in legal practice nor in intellectual theory has it been possible to construct a "normal human being," and even fundamental laws which appear to establish relationships to normal man, such as, *e. g.*, Rubner's law of surface (i. e., basal metabolism proportional to human body surface, or indeed to surface of all warm-blooded animals) have probably never proved more than roughly approximate values which in certain conditions are found to be not applicable (*1*).

Shall we, then, in view of the knowledge of these great difficulties, abandon the attempt to create a science of climate in its relation to human comfort, or, as I have termed it, a "specifically medical climatology?" (2). (Still better, perhaps, would be, "physiological climatology.") Nothing were more absurd, for no climatology assumes a simpler form than one brought into reference to warm-blooded animals with their constant temperature. If to this end we employ our present meteorological tables in their usual form, as George F. Howe and E. S. Nichols and J. Elmer Switzer (*loc. cit.*) have ingeniously done, unanimously stressing the importance of the frequency data for characteristic weather types, then we do not calculate, we merely estimate, on the basis of the experiences gained from our environment, and the conclusions derived vary accordingly.[1]

In this respect the Davos Climatological Congress was quite instructive (the programme appeared in the MONTHLY WEATHER REVIEW, Volume 53, No. 7, 1925, pages 312–313, and the papers read are just being published), for it reflected as in a mirror in the most varied manner the views upon climatic characteristics and climatic effects held by the representatives of climatological science—kaleidoscopically varied biological and medical scientists from the most northern and southern continental and littoral, plain and Alpine regions. The sun is a friend to one, to the other an enemy; one prefers

[1] We may perhaps here refer to the table of factors for the determination of the index of comfortableness of the weather (a conception first introduced by Cleveland Abbe) compiled by Z. von Dalmady, of Budapest,* as a result of medical experience with middle-European patients needing a protective climate:

I Temperature		III Wind (empir. degrees)		IV Cloudiness 1/10	t°<19°C.	t°>19°C.	V Difference of insolation °C.	
−3.1− 0.0	−5	0	+2	0, 1, 2	+2	0	10	+1
0.1− 6.0	−4	1	+1	3, 4	+1	0	20	+2
6.1−11.0	−3	2	0	5, 6	0	0	30	+3
11.1−15.0	−2	3	−1	7, 8	−1	0	40	+4
15.1−19.0	−1	4	−2	9, 10	−2	−1	50	+5
19.1−22.0	0	5	−3					
22.1−26.0	+1							
26.1−30.0	+2							
30.1−35.0	+3							
35.1−40.0	+4							

II Atmospheric humidity

%	6°C.	6.1−11.0°C.	11.1−15.0°C.	15.1−19.0°C.	19.1−22.0°C.	22.1−26.0°C.	26.1−30.0°C.	30.1 °C.
− 45	+2	+1	+2	+1	0	0	0	0
46− 65	0	0	+1	0	0	0	+1	+1
66− 85	−1	−1	0	0	0	+1	+2	+3
86−100	−2	−2	−1	0	+1	+2	+4	+6

The addition of the factors gives the index. The zero-value corresponds to pleasant, indifferently-tempered weather at wind-velocity Beaufort 2.

Index >0 signifies favorable weather.

Index −1 to −4 signifies less pleasant weather.

Index <−4 signifies unserviceable.

This scale also fails when applied to the calm Alpine valley of middle geographic latitude, as has been shown by reckoning (similarly to that mentioned above). The effect of the cold is greatly over estimated, that of the solar radiation and the dryness of the air underestimated.

* Zeitschrift für die gesamte physikalische Therapie, Vol. 30, No. 5, 1925, p. 223.

wind, the other avoids it, etc., each according to the effect upon the human species which he has observed in the conditions of his environment.

If we wish to pass from "estimation" to "calculation," then we must refer uniformly to income and loss at 36.5° C. our body temperature, as is done by C. F. Brooks (*loc. cit.*, p. 424), and also to the income and discharge of moisture. Heat and water constitute the basis of all life. This might be attempted with a certain degree of success by calculation from the meteorological tables at present in use. These while of course primarily and universally serviceable for the purpose of meteorological science *par excellence*, are by no means yet employable for a physiological climatology, for they only place the different elements side by side and with reference to very different standards. Thus atmospheric temperature and atmospheric humidity both set out from the zero-point given by the change in the aggregate states of water, a fundamental meteorological value, and in the measurement most frequently undertaken, viz., that of the relative humidity, the latter is referred to the former; but in the case of wind the standard which serves is the velocity of its propagation, which in no way expresses anything with reference to its cooling effect,

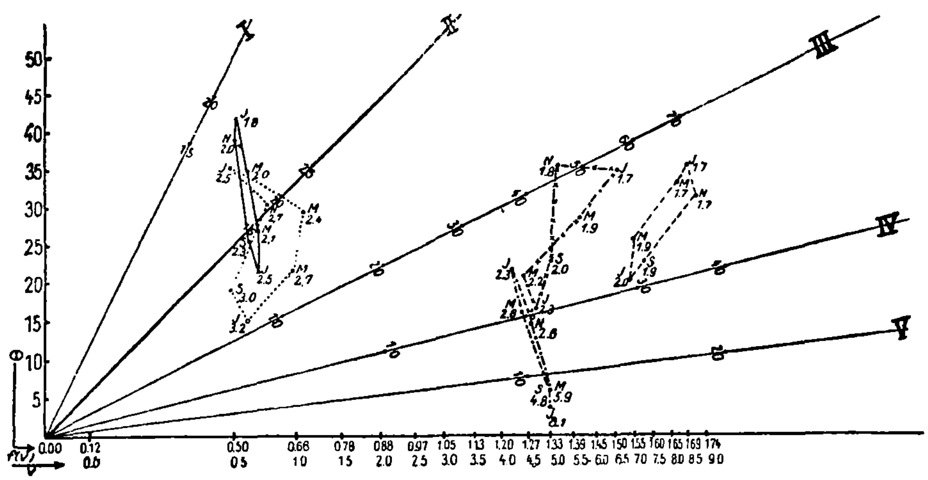

FIG. 1.—Specifical-physiological climogram

i. e., its relation to temperature and humidity. Radiation absorbed and emitted are denoted by the heat absorbed and emitted by an absolutely black, totally absorbing surface, which in nature is nonexistent—and here again the radiation is made referable to the atmospheric temperature.

When we wish to make climatologically correct use of these data for the determination of income and outgo of heat and moisture, whether in the organic or inorganic world, cross-calculations to the temperature of the body under observation are inevitably necessary, which can be very different from that of the atmosphere, either from heat-production as in warm-blooded animals or from the influences of radiation and conduction. Thus, for example, a relative humidity of 100 per cent for 0° C. atmospheric temperature is equivalent to 50 per cent in the case of a wall heated by radiation to 10° C. at the same time, and to only 10 per cent for the human subject with his body temperature of 36.5° C., and an emitted radiation of 0.200 calorie at 0° atmospheric temperature is in the instances under consideration equivalent to 0.265 or 0.488 calorie; and in the same manner evaporation (loss of humidity) and cooling (heat loss) assume quite enormously different values. The great advantage, however, gained for physiological climatology in these cross-calculations is that the point of reference continually remains the same, while for the instance of a wall subject to radiation (or, substitute a plant or cold-blooded animal) it continually fluctuates. If, in the tables to be compiled for a "physiological climatology" we uniformly substitute 0° *phys.* (similar to the common abbreviation *abs.*) for 36.5° C., and then for temperature, relative humidity, and loss by radiation refer uniformly to this zero point, the tables will become much more serviceable and impressive. One need but compare in the case of Davos the statement for humidity and emitted radiation, as is at present customary, with the corresponding "physiological" values, viz: annual mean relative humidity over 54 years 77 per cent (at 2.6° C. atmospheric temperature), corresponding to a physiological humidity of 9 per cent only; mean emitted radiation of the black surface during winter nights at atmospheric temperature of −6° C., 0.219 calorie, as against a physiological radiation of 0.543 calorie.[2] These physiological figures show at once the climatic nature of the dry, cool, calm Alpine valley with its pure, light atmospheric mantle. As I demonstrated in 1920 (*3*), instead of the figures for the physiological humidity, impressive as they are, it is, perhaps, more advantageous to substitute the "physiological saturation-deficit," for this directly expresses the amount of water in grams that each cubic meter of respired air is capable of removing from the body.

Except in extreme cases of very high atmospheric temperature, when we wish to deduce by calculation from its velocity the cooling and drying effect of the wind upon a body at 36.5° C., special assumptions, particularly with regard to the size and surface-nature of the body, become necessary, also somewhat intricate formulæ which need not here be discussed. It is obviously possible, however, to derive by calculation from the present tables the physiological heat income and loss and the physiological humidity income and loss referred to a uniform standard, but it is certainly very troublesome.

And here our medical brethren have indicated to us the road, as we are bound to acknowledge, for their endeavours to formulate the sum of climatic influences according to a uniform standard of "cooling power" dates back a century, and the subject has concerned the medical profession in almost every civilized country. Leonard Hill taught us about eight years ago, it will be remembered, how to obtain this quantity very simply, by means of his kata thermometer, whose revolutionary effect was due precisely to its simplicity. He also provided us with the formulæ according to which the cooling power measured in the shade is dependent upon atmospheric temperature, humidity, and wind, from which, conversely, we may calculate the cooling power from these three quantities; as an anemometer, indeed, the kata thermometer even surpasses all known wind-measuring instruments for delicate air-currents approach-

[2] Radiation for −6° following Stefan's law	0.386
—effective radiation	0.219
Radiation of the atmosphere	0.167
Radiation for 36.5° following Stefan's law	0.710
Radiation of man	0.543

ing 0.25 meter per second (Rubner's "sensiblen Luftströme"), to which our cutaneous nerves are sensitive to a distinct and unpleasant degree. This achievement alone assures the instrument a permanent existence. Recently Paul Weiss (*4*), employing the old empirical formula of the technician for ascertaining the coefficient of thermal conductivity, has made very careful investigations resulting in Leonard Hill's formulæ for the dry kata thermometer being confirmed.

If we plot this readily obtained quantity of the cooling power in a system of coordinates in which the ordinate is the difference between body temperature and atmospheric temperature, and the abscissa the function of the wind velocity (according to Hill's formula)—as was done by me in 1922 for five very different climates (*5*)—we obtain clear pictures not only of the total effect of the meteorological factors, but also of the single effects of the principal factors, viz, temperature, wind, humidity—the last from the quotients of the wet and dry cooling power adjoining the month initials. The product of the co-ordinates of each point represents the cooling power; all the values along the thicker middle line are influenced by wind and temperature in the same manner, in the values lying above the middle line the influence of temperature predominates, in those below it that of the wind; ratio $\frac{\text{influence of wind}}{\text{influence of temperature}}$ along line I is ½, on line II it is 1 : 1, on line III, 2 : 1, on line IV, 4 : 1, on line V, 8 : 1.

It is clear at first glance that from their position with regard to the middle lines, Lugano and Davos are protected from the wind, the other places exposed to it, and that the wind influence increases from winter to summer at Lugano, Davos, and Assouan, while on the other hand it diminishes at Borkum and Potsdam. From the position relative to the neighboring figures for the cooling power, it is seen that Potsdam and Borkum are for human beings much "colder" than the other places—colder in the true sense of the word, for this is expressed alone by the cooling power and not by the atmospheric temperature, which is but one among several factors in the cooling—and that protected Lugano does not differ very markedly from Davos with the latter's very low atmospheric temperature. A somewhat closer inspection shows that the annual amplitudes for Davos and Lugano are small and differ little from one another, but that those of Potsdam and Borkum are large, while at Assouan, which passed beyond line *V* notwithstanding the strong wind, in July the cooling power only attains 4.7, while in January it reaches the same values as at Davos.

The figures attached to the month initials indicate that, in all places without exception and in spite of their great climatic differences, the ratio $\frac{\text{cooling wet}}{\text{cooling dry}}$ increases with increasing temperature from winter to summer; that is the reason why God has endowed us with sweat glands. It is of importance to note that the increase of this ratio takes place contrary to the increase of atmospheric humidity, contrary to the decrease, therefore, of the physiological saturation-deficit. Here again the decisive climatic factor is not the amount of humidity in the atmosphere, but the wind, and it more than compensates for the influence of humidity, not merely when its strength increases, but as the examples of Potsdam and Borkum show, when it loses in strength from winter to summer. The annual amplitudes of the ratio $\frac{\text{cooling wet}}{\text{cooling dry}}$ resemble each other at every place, unless extreme aridity is associated with great increase of temperature as in a desert climate; *thus only in extreme conditions is the humidity of the atmosphere decisive as a climatic factor.* The absolute value of the ratio $\frac{\text{cooling wet}}{\text{cooling dry}}$ is lowest, of course, at the seashore and it gradually increases inland and toward high altitudes with cold atmosphere, and more rapidly toward the warm air of the south.

The diagram shows at the same time in a quite general form that with low atmospheric temperatures (quantity Θ) an increase of wind velocity gives rise to a far greater cooling than with high atmospheric temperature, and that when the air is slightly in motion a small increase of wind increases the cooling to a far greater extent than in a strong wind.

Just as here the annual course at different places is represented comparatively in a climogram, so it would be possible to combine the daily course over the various months at one place into a climogram, and thus supply in diagrammatic form an answer to almost any question which might arise as to the climate of a particular place.

All values refer to temperatures in the shade; data with regard to radiation had to be given in an extra table.

Let us acknowledge the immense advance which the simple determination of the cooling power has represented for a "physiological climatology"—toward which we must by all means strive—and thoroughly utilize it. By far the most important value is the cooling power as indicated by the dry kata thermometer. From the measurements (*6*) carried out at Davos in 1921–1922 on the basis of systematic thrice-daily determinations of both rate of cooling and temperature of the skin of the cheek, there emerges a far-reaching proportionality between the difference, 36.5° C. minus the temperature of skin of cheek (i. e., the cooling of the skin of cheek) and the cooling power shown by the dry kata, viz: the cooling value for the cheek is obtainable in ° C. by halving the cooling power shown by the kata thermometer. This proportionality is found both in the average and in the single measurements at all times of day and year. This may be taken to indicate that the skin temperature well expresses the combined thermal effect of the single weather factors upon the organism, and this need not appear astonishing, for most probably there is a parallelism between the feeling of temperature and the functions of the nervous regulating-mechanism. The same nerves, which transmit stimuli for the feeling of temperature may be concerned, also at least partly reflex, in providing the vaso-motor regulating influence, thus regulating the amount of blood in the skin and the loss of heat therefrom.

On continuing the measurements of the skin surface (*7*) it was found that precisely the skin of the cheek, which Leonard Hill had also selected, delivers the most suitable temperature for comparison, better than the skin of the forehead as frequently employed. The skin temperature is, of course, not by any means a universally valid measure of the total loss of heat, being merely an indication like the kata index which is proportional to it. This indication, however, is of the utmost importance to "physiological climatology" and "human comfort" in that it largely corresponds with personal feeling. This has been demonstrated by Leonard Hill and his collaborators as well as by Weiss (*loc. cit*) and still earlier by Reichenbach and Heymann (*Zeitschrift für Hygiene*) by exact experiments in closed rooms, and it agrees with the Davos and other findings in the open air. So far as hitherto known the temperature of the cheek and the kata index (including the wet) fail us only in extremes of humidity, particularly in the combination of very high temperature with very great humidity; through sweat-ing an entirely new mechanism comes into function which is decisive for the heat discharge, and no further conclusions as to feeling can then be drawn from the measurements of heat quantities.

To me it would seem that "physiological climatology" should find its most important field in the accumulation of the "dry kata" values, in checking up the extent to which these run parallel with the temperatures of the cheek and hence with feeling, clothing being adequate and external conditions as varied as possible (including those meteorological elements against which it is possible to afford protection, such as wind and radiation), and in fixing the laws of deviation if such laws exist. Should the existence of a most far reaching parallelism, except in extreme conditions, between the physical instrument and the physiological cooling indicated by the skin be confirmed, as may be hoped, then the mean and extreme values, the daily and annual course, the frequency, and the hourly, daily and annual sums of the cooling power indicated by the dry kata, should constitute the basis of "physiological climatology." To these values corresponds very largely the tax levied by a climate upon body heat production, which ultimately must be met by the heart's work. The very important therapeutical conceptions of the stimulative and the protective climates, with all their subdivisions, would then be defined by this single numerical category. In truth, the determination of human comfort is not the sole, nor even the chief, end of "physiological climatology."

Manifestly the same degree of cooling power can result in manifold ways from the cooperation of the various meteorological elements, and it is not by any means unimportant whether it is produced, for example, by cool, dry air in combination with a calm, or by warm, damp air associated with wind. In this respect, however, the tables in use to-day, as they stand, provide definite information, but their full value is realized only when they are considered in combination, in terms of a fundamental unit.[3] They then serve for an analysis which is quite simple in comparison with the very complicated synthesis on p. 39. It could be considered, perhaps, whether the tables of the cooling power should be supplemented by indices showing the wind velocity; by these indices the second important quantity, atmospheric temperature, would then be shown indirectly with sufficient clearness.

The task of meteorology within its own field in relation to physiology and hygiene would thus, I think, have been fully accomplished; for special studies of basal metabolism and its increase by the agencies of nourishment, clothing, and work, belong exclusively to the realm of physiology and hygiene.

Lefévre's formula for the determination of human comfort, as employed by Doctor Brooks and by Donnelly, fails under such conditions of calm—as obtain here in Davos chiefly during the winter for many days in succession; and it gives quite inadequate consideration to the solar radiation. The physiological effect of this, indeed, is not exhausted by setting down an average number of calories. Apart from the great fluctuation of intensity in the daily and annual course, according to altitude above sea level, water vapor content, and dust content of the atmosphere, the solar radiation is effective to very different depths in the body (*a*), varying with its spectral composition, while temperatures at the skin surface and deeper parts run by no means parallel—the latter again, being very rarely dependent on the wind velocity. The annual variation in the spectral composition of the Davos sun has, moreover, been shown to coincide with the variations of temperature at about a depth of 2.5 centimeters under the skin (which, moreover, reaches a maximum of 40° C, with essentially lower skin temperature) in that the spring sunshine, richest in deeply-penetrating infra-red rays, exercises the most powerful deep-seated effects. Much was said at the Davos congress[4] on the subject of the physiological and therapeutical deep-seated effects of radiation in its relationship to the wave-length.

In conclusion, the question may be briefly discussed as to whether any improvement is possible and necessary in the methods of measurement employed at the present day, particularly by Leonard Hill and his coworkers.

A. *The kata thermometer*

(1) In the nonhomogeneous alcohol thermometer the adjustment between vessel-wall and liquid is necessarily delayed owing to the difference of conductivity, and convection currents then give rise to inequalities. A homogeneous substance would be preferable. (2) The exchange of heat by conduction with the air is also retarded owing to the poor conductivity of the glass. (3) The cylindrical form possesses disadvantages by comparison with the spherical, as in the latter all points at the surface are equidistant from the center of mass and are equally oriented against the factors of heat withdrawal which are effective on all sides. (4) An increase in the size of the measuring body is desirable in that it would more resemble the dimensions to which it is intended to be applied viz, the human body. (5) As the single elements governing the cooling power are as a rule each separately subject to continual fluctuation, as is therefore the cooling power also, it would appear to be most desirable to be able to make a registration which would supplement these individual values.

The Davos Frigorimeter (*9*) answers all these requirements.

A black, nearly solid copper ball 7.5 centimeters in diameter, into which is fitted a small control-thermometer, is mounted on a metal plate by means of a metal tube about 1 centimeter in diameter and 8 centimeters high, and provided with a conducting cable and a contact plug. Separately from these a powerful clock about 12 centimeters in diameter and 11 centimeters high is mounted on a wooden board together with a contact plug and a relay and two resistance coils. Another cable is linked to the electric supply by a contact plug and joined to the relay and the clock. The ratio between the time read off at the clock and the time which has elapsed during the intervals between the readings, multiplied by the factor provided with the instrument, gives the cooling power in thousandths of gram calories per square centimeter per second. A triple range of measurement which suffices for all requirements is provided for and rendered available by a switch system. Repeated, mutually checking,

[3] The value of the cooling power is again very instructively shown under the extreme conditions of a wind-protected Alpine valley in middle geographic latitudes. What physician can send a patient to Davos on the strength of the individual values presented in the meteorologcial tables?

The wintry cold, the large fluctuations of temperature, the high relative humidity, would appear to exclude the idea entirely, yet these are in strong contrast to the therapeutic experience of 65 years and to the conclusive measurement of the cooling power. Notwithstanding the low temperatures the cooling power is found to be probably less than at any place north of the Alps and not much greater than in the protected health resorts of the Swiss and north Italian lakes, and in spite of the considerable fluctuations of temperature it is more uniform in its daily and yearly course than perhaps in any place not subtropical or tropical. This is due to the extremely little motion of the air and to its really extraordinary dryness together with the powerful insolation (which in the method of measurement of the cooling power after Leonard Hill in use hitherto, has not been determined, because owing to the short duration of the period of observation the effect of radiation in the instrument can not attain full expression, the measurement being undertaken therefore only in the shade.).

[4] The congress books are published by Messers, Benno Schwabe & Co., Bale, Switzer land.

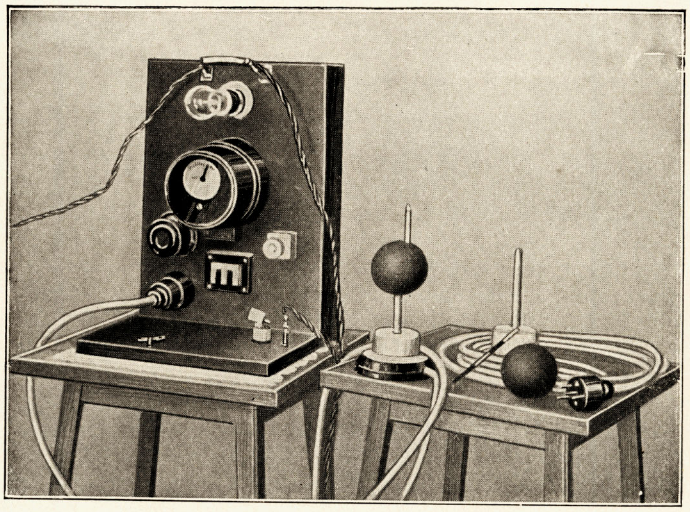

FIG. 2.—The Davos Frigorimeter

single measurements can be made within two or three minutes; summation for longer periods, such as, morning, afternoon and night, is obtainable by a single reading of the clock and a simple multiplication.

B. *The skin thermometer*

This never gives such precise values as those obtained by the thermo-electric method, and in a powerful wind it is unreliable. A thermo-element has been employed at Davos consisting of copper and constantan of which one soldered joint is immersed in a thermos bottle filled with oil (air is also sufficient, but not water) and is in direct connection with the mercury bulb of a sensitive thermometer, which projects from the mouth of the bottle and may be read off there, while the other soldered joint is movable and can be transferred to the surface of the body to be measured. A simple but important provision is that this second narrow and thin soldered joint is extended over a tiny, narrow piece of cork, which hinders radiation and owing to its low conductivity does not remove any heat. Mounted on the same board and in connection with the thermos bottle is a galvanometer with a resistance of 1 Ohm only and a sensitiveness of 10^5, rendering the whole very transportable. With this outfit it is possible to measure on an average to a tenth of a degree centigrade with precision.

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SIXTEEN YEARS OF SNOW-SURVEYING IN THE CENTRAL SIERRA AND ITS RESULTS

551.578.46 (57)

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Snow-surveying under the percentage system as conducted by the Mount Rose Observatory is based upon two fundamental facts: (1) The approximate uniformity of the snow cover over wide areas and (2) the intimate relationship in the western mountains between winter snow fall and the spring-summer flow.

During the 16 years of field work, only two disturbing factors of major importance have been found, viz, (1) premature melting of the snow cover at lower levels and (2) deficiency in normal precipitation during April–July. The former can be determined and measured by means of low level snow courses at the time of the annual snow survey April 1. The probability of the latter and its results can usually be determined by May 1 or at the latest by May 15.

The maximum shrinkage in stream flow due to lack of April–July precipitation is 25 per cent of normal for rivers and 50 per cent for Lake Tahoe. However, the usual revision for precipitation has not exceeded 10 per cent for streams and 20 per cent for Tahoe. A few revisions have been made after the season was over. However, these were based upon principles noticed then for the first time but applicable at the beginning of the season. These revisions are distinguished from those for April–July precipitation by being placed in parentheses.

Six basins are included in the series and are situated on both sides of the range. One of these, the Tahoe, consisting mainly of a lake, is greatly affected by precipitation upon its surface. Another, the Carson, has large diversions above its point of gaging. A third, the Mokelumne, possesses only crest snow survey stations and depends for its outpost estimates upon measurements in the South Yuba Basin, which is separated from it by the wide American Basin. Yet out of 54 forecasts for the entire six basins, 29 forecasts were within 10 per cent of the actual run-off while 14 were within 20 per cent. In the remaining 11, the maximum divergence between snow cover and run-off was only 30.4 per cent.

The following table on comparison of snow cover and run-off will give details and serve as a record of seasonal net snow cover and run-off in the Central Sierra since the snow surveys were established in 1909–10: