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LUTHER H. HODGES, Secretary

U.S. WEATHER BUREAU
F. W. REICHELDERFER, Chief

WEATHER A FACTOR IN PLANT LOCATION

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CONTENTS

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WEATHER . . . *its effect on plant location*

By Dr. H. E. Landsberg

CLIMATE is one of the most important factors in industrial development. In many areas it is a distinct asset for a community and the location of a plant. In some localities it has been treated—and rightly so—as a natural resource. This is particularly true where the climate favors outdoor activities and recreation.

However, no industrial establishment should be planned without taking climate into consideration. Its favorable and its unfavorable aspects alike should be fully considered and given equal weight with other factors such as availability of labor, access to markets or raw materials, and taxes.

Dr. Helmut E. Landsberg is director of the Office of Climatology of the United States Weather Bureau. He also serves as Weather Bureau representative or U. S. representative on national and international committees and is chairman of the Earth Science Advisory panel of the National Science Foundation. He is editor of "Advances in Geophysics." Dr. Landsberg was born in Frankfurt, Germany, in 1906. He attended school there and took his Ph.D. at the University of Frankfurt. With wide experience gained in various positions in universities, observatories, laboratories and in military work, Dr. Landsberg in his scientific work has been mainly concerned with problems of climatology, micro-climatology, cloud physics and siesmology. He has published two books and 140 research papers, and has acted in a consultant capacity to a number of industrial concerns.

Climate governs many important facets of modern industrial location policy. In some instances this influence is an indirect but still potent one. Think in this connection just of the availability of water. This is primarily geared to rainfall which replenishes the natural water supplies.

Climate influences both capital investment and operation costs. It determines the size of heating facilities and of air-conditioning plants. It affects the efficiency of outdoor operations. It is a facet in the production, storage, and shipping of many products. Intelligent assessment of the climatic factor in industrial operations can save money and. in particular, managerial headaches.

The latter are usually connected with climatic hazards. These are not the same as the continuing effects of temperature, humidity, rainfall and wind which affect normal operations. The climatic risks of an area are usually governed by extreme events. These can cause major damage to capital investment, such as plant installations, and also disrupt operations.

In this category are high winds as produced by hurricanes or tornadoes, other severe storms which affect power lines and communications, snow and ice storms which interfere with transportation, and also extremely low or extremely high temperatures which have disruptive effects. Excessive rainfall leading to floods will, of course, interfere with poorly sited plants.

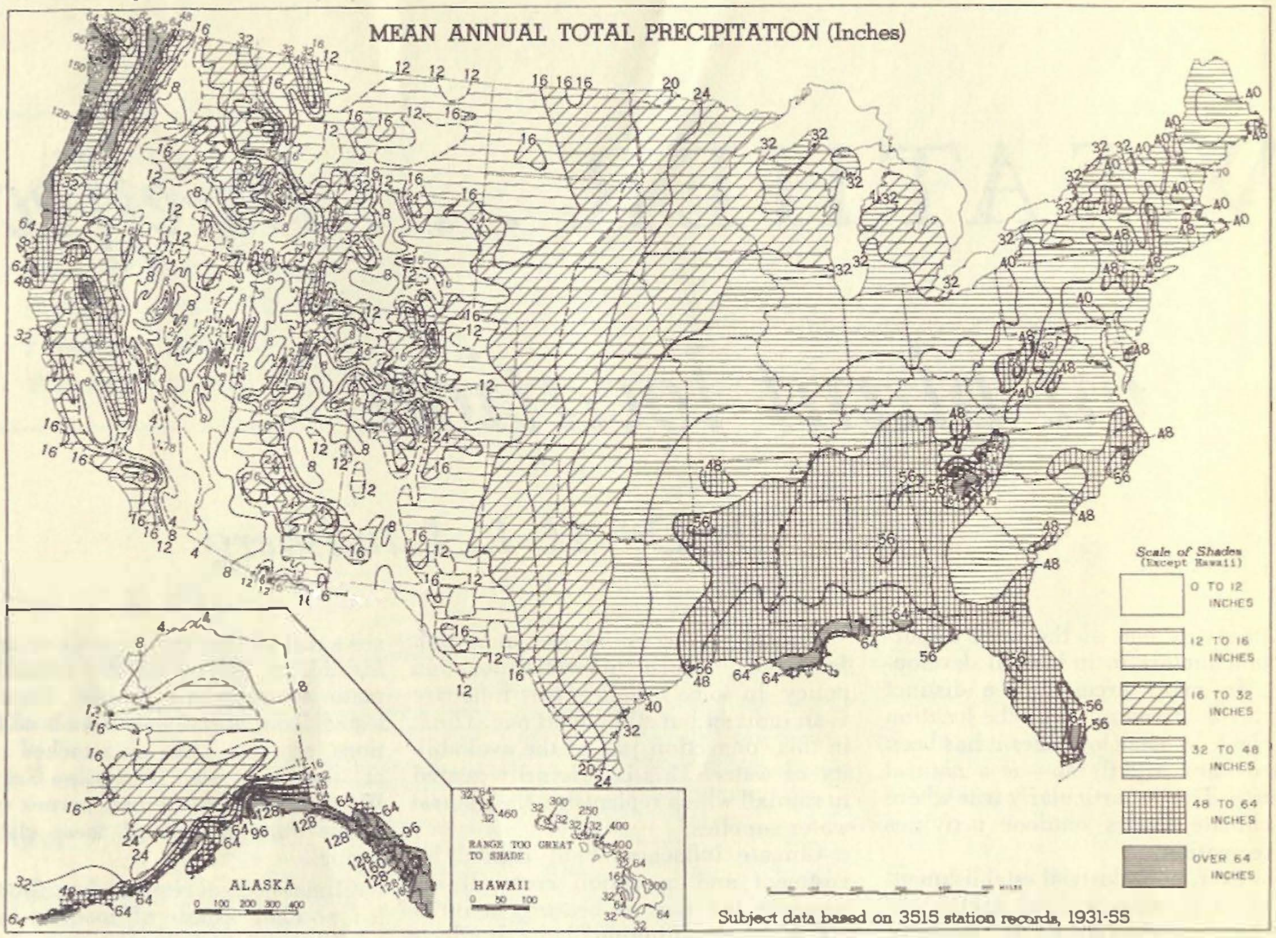
Climatic statistics permit the assessment of frequency and extent of such risks just as they can provide estimatesa for design factors of the normal climatic elements at a locality. Data collected from literally thousands of locations, now available on punched cards at the Weather Bureau's National Weather Records Center, permit quick access and analysis of these climatic factors.

Climatological research has also tackled another aspect of modern industrialization which has become of vital importance to many communities. This is the control of plant effluents and pollution. The general and local climate of an area dictate the vulnerability of a site to air pollution. The wind currents and stratification of the air will determine whether pollutants brought into the air are dissipated rapidly or will hang around to plague the neighborhood.

One need not wait until a pollution situation fully develops to have an estimate of the risk at a particular location. This can be determined by reference to the topographic and climatic environment which conrtol the air pollution potential.

The Weather Bureau with its vast climatic archives and through its regular climatological publications furnishes the basic background information for climatological analysis. Through its field organization of Area and State Climatologists, it makes this information available to public bodies and for general industrial and commercial use. It does not furnish, of course, individual service to industrial firms but supplies climatic statistics at cost of compilation.

The interpretation of such raw material is left to private meteorological consulting firms or to meteorologists who are in the employ of various corporations. In furnishing the generalized information the Weather Bureau cooperates with many local Chambers of Commerce who often bear the cost of printing authoritative climatological summaries for their communities.



MEAN ANNUAL TOTAL PRECIPITATION (Inches)

Subject data based on 3515 station records, 1931-55

WEATHER PATTERNS IN THE NORTHEAST

By Dr. James K. McGuire

How can climatological information be profitably applied to the problem of selecting a plant site in the Northeastern United States?

Both the writer and the reader of this article can get down to the business of answering this question if we can agree on two simplifying assumptions.

(A). No article can give all the answers, and no business man would want to read all the explanations and qualifications required for a comprehensive scientific discussion. On the other hand, it may be agreed that the reader is entitled to a summary of the technical aspects of the subject and to references for further investigation of them, if he be so inclined.

(B). The article ought to give the most important answers, outline the rest, and once again supply references for further reading. If we agree on the truism that water is the life-blood of industry, then obviously the main concern of this article should be with precipitation conditions (rain, snow, etc.) over the Northeast as they affect water supplies and other factory problems.

The effects of temperature and humidity should come next in importance; then winds and atmospheric relations to air pollution; next such weather hazards as hurricanes or floods; and finally, something on the region's climate as a factor in working efficiency and employee living-comfort.

Dr. James K. McGuire was born and reared in Manhattan and the Bronx. He attended Fordham and New York Universities, receiving his Ph.D. at the former institution. He entered the research service of the United States Weather Bureau shortly before World War II duty with the Office of Naval Intelligence. He returned to the U. S. Weather Bureau's Office of Climatology and has served as Metropolitan climatologist for New York City, as state climatologist for New England, and as northeast area climatologist.

Principal Climatic Features

1. The region lies in latitudes where the duration of sunlight ranges from some 15-16 hours in late June to about 9 hours in late December. The long Summer days are warm, sometimes tropically hot; the long Winter nights tend toward Arctic-like cold. In comparison to some other areas in the same latitudinal belt, however, these seasonal

extremes are comparatively moderate.

II. Cloudiness reduces the length of the sunlight hours throughout the year as a whole.. Speaking broadly, the Northeast receives only 30-50 per cent of possible sunshine in Winter, about 40-60 per cent in Spring and Fall, anda about 50-70 per cent in Summer.a

III.a These day-to-day fluctuations.a along with changes in temperature, humidity, wind, and the occurrences of precipitation are linked with the atmospheric circulation patterns. The Northeast is dominated by west-to-east air movements (the so-called "prevailing westerlies"), interrupted by northward and southward surges of the atmosphere.

The large-scale streams or masses of air involved in these movements differ (often markedly) in the surface weather conditions they bring. Their fairly steady procession, occasional stagnation and constant interaction are accompanied by similar behavior of the atmospheric high- and low-pressure systems (the latter with their associated weather fronts). Thus the Northeast is subject to the state of affairs honored in the traditional New England jest, "If you don't like our present weather, just wait a minute!"

IV.aThe Atlantic Ocean and the Appalachian Mountains exercise a much smaller influence on the region's climate than might be supposed. The Appalachians are not high enough, for example, to establish separate climatic zones on their western and eastern sides. They do have, especially in their more elevated portions, a "mountain climate," that is distinguished from the climate of the rest of the region mainly by more severe Winters (with respect to both cold and snowfall) and by cooler Summer nights but more abundant Summer rainfall.

Since the prevailing atmospheric flow is from a westerly direction, the Atlantic represents a modifying rather than a controlling climatic factor. Its influence is most felt along a narrow coastal strip that enjoys cooler Summer afternoon temperatures than inland locations, due to the onshore "sea breeze"; but the coastal belt is subject to more fog and generally damp conditions than the interior.

The presence of the Atlantic Ocean is very important, however, as a source of moisture for rainfall. Perhaps most noticeable is its function in fostering the development of coastal storms or "northeasters", that typically form off Cape Hatteras and move up the coast toward Newfoundland. These can be very severe along the shore and their effects may occasionally extend over the entire Northeast.

The Ocean also serves as a passageway for West Indian hurricanes, about which more will be said in due course. Surprisingly enough, the Great Lakes (Erie and Ontario) do affect significantly their eastern and southern shores; for example, the lake fronts have cooler and later Springs as well as windier and snowier Winters than they would if the lakes were not there. River valleys, too, have local climates that may differ appreciably from those of the adjacent higher land.

Precipitation

During the colder half-year (October-March) the Northeast receives its rain and snow from the general low-pressure systems that sweep across the continent or swing up the coast. During the warmer half-year (April-September), this large-scale activity decreases but its rain-producing effect is replaced by local showers and thunderstorms. Thus the Northeast usually has an adequate and dependable source of water the year around. Moreover, precipitation is usually distributed evenly over the year, with no pronounced wet or dry seasons.

The annual amount of precipitation averages about 40 inches at most places in the Northeast: over a ten-acre site, this represents nearly eleven million gallons of water per year! The mountains, especially in West Virginia, New York and New Hampshire, have average annual amounts of 50 inches or more.

An interior belt (extending from western Pennsylvania through western and extreme northern New York into the northern portions of Vermont, New Hampsihre and Maine) averages 30-40 inches. The coastal zone east of the mountains averages 40-50 inches. Of course, this general outline does not exclude local variations, which may be sizeable.

An authority on water resources has stated that "factories have been built without prior studies to determine whether water would be available to operate the factory and to provide for the communities around them." Such studies might seem unnecessary in thea Northeast in view of what has just been said about its plentiful and dependable rainfall. This is not the case. Water is needed by more and more people for more and more reasons, and the business-man thinking to build a new plant should carefully evaluate against future as well as present requirements not only the available water-distributing facilities but also the relevant precipitation records.

The U. S. Weather Bureau maintains and publishes these records for over 2,000 locations in the Northeastern States.

The foregoing applies to precipitation on a monthly, seasonal or annual basis, for planning industrial operations dependent upon the water supply. The intensity of short-period rainfall, that which falls in a matter of a few hours, is also important. Reasonable design-values for storm sewers, for instance, may be obtained from Weather Bureau records and statistical studies.

Snow presents at least two important problems to industry. First of all, it must be cleared away from highways and factory roads, parking lots, loading and unloading sites, etc. A knowledge of the expected snowfall in a locality may be used to determine the most economical and efficient types and quantities of snow removal equipment. Secondly, the sheer weight of snow on a roof, especially a flat roof, may be very heavy. Unless the structure has been properly designed for a reasonable snow load, damage and possible collapse can result.

Closely related to rain and snow is that "in-between" form of precipitation known as glaze or freezing rain, often miscalled sleet. In a few minutes, this can convert a surface into a slick and slippery sheet of ice. Vehicles will skid, pedestrians will fall: accidents will happen. To reduce this hazard, attention should be paid to the glaze potentiality of a factory site, and its approaches. A professional climatologist can size up aa factory site from this point of view and offer helpful recommendations.

Finally, if lightning represents a danger in the type of industrial operation being planned, the statistics should be consulted on the frequency of thunderstorms in the area.

Temperature and Humidity

Heating degree-days give a useful index to winter cold and consequently to what may be expected in the way of fuel consumption for heating purposes. Whenever a day's average temperature drops below 65° F., its value is subtracted from this base and the difference is termed so many heating degree-days. A cold day or winter will therefore havea more degree-days than relatively mild ones; and a place that has less rigorous winter temperatures than another will have fewer degree-days.

In the Northeastern States, the normal accumulation of degree-days for the heating season (usually taken as the period from September through May) shows a considerable variation. In the Delaware-Eastern Maryland region, it is about 4,000. From this minimum point, the normal accumulation increases northward to about 6,000 in central Pennsylvania and Southern New England, to over 9,000 in northern Maine.

In West Virginia, the accumulation normally exceeds 5,000 in the mountains but is under this figure in the western part of the State.

The most popular measure of atmospheric moisture, the relative humidity, is actually among the poorest indicators from the scientific viewpoint. A good technical measure, the "effective temperature" suffers from the drawback of being sufficiently complicated to make it hard for the layman to understand and for the climatologist to apply to large amounts of weather data. A promising substitute for the effective temperatures is the "discomfort index," which is the average of a pair of simultaneous dry- and wet-bulb temperature readings.

It has been found that most people will become uncomfortable when the D.I. or discomfort index approaches 70 and will experience increasing discomfort as the D.I. exceeds this mark. If 65° is used as a base, and the difference between it and a higher D.I. value is taken, the difference may be called "cooling degree-days" and accumulated in a manner analagous to heating degree-days. In this case, however, the purpose is to measure Summer discomfort, and the greater the cooling degree-day total the more uncomfortablee is the temperature-moisture condition.e

Eight-year monthly averages of such cooling degree-days have been computed for New York City. They showe that discomfort is highest in July, almost asehigh in August, and appreciably high in June and September. Of course, this conforms to common experience, but the point is that a numerical value may be assigned to the sensation of discomfort, and related to price figures when the problem is studied whether or not to air-condition office or factory space, and to estimate the likely operating costs. It may also be used to compare one locality against another, for the same purpose.

This concept is still in the development stage, and is introduced here to show that research is underway to improve theeapplicability of temperature and humidity data to such practical matters as choosing a plant site and designing buildings against Summertime conditions.

Wind and Stability

In order to effect economy in operations and to improve community relations, more and more businessmen are endeavoring to minimize any air pollution problem connected with a factory. The best way to do this is obviously to anticipate the problem and design chimneys, waste outlets, etc. to reduce the contamination to an unobnoxious level.

For example, a major public utility is constructing a reactor to generate 275,000 kilowatts of electricity at a site in the Hudson Valley. As part of the preliminary construction work, a 300-foot tower has been erected and instrumented to measure the wind flow and vertical temperature structure of the lower atmosphere. The information thus obtained, plus data from wind tunnel studies, will be used in the final determination of stack height and design.

The average industrial plant does not have as crucial an air pollution problem as a nuclear reactor. In all cases, however, the waste gases and smoke are harmlessly dispelled or concentrated in the atmosphere depending upon the speed of the wind (also its direction in certain instances) and upon the atmospheric stability or instability.

There is sufficient information available (some of it is cited in the References) to permit an intelligent evaluation of the likely wind and stability conditions at a proposed plant site to be made in advance of any decision to build and before, not after, costly construction features pertinent to the problem have been adopted. In general terms, the Northeastern United States are not as air pollution-prone as other parts of the world and even other sections of the country. Especially along the coasts, of the Atlantic and the Great Lakes, wind movement is usually sufficiently high to make the risk of severe atmospheric contamination comparatively minor.

Sheltered valleys, however, are very subject to stagnation of the air, the development of exceptionally stable conditions, and the consequent entrapment of pollutants. In the fall of the year especially, the large-scale atmospheric patterns are frequently such that irritating "smog" situations are established in and around every large population center or factory town.

These large-scale weather factors cannot be entirely allowed for, and it may notealways prove practicable to selecte a site that has the minimum "pollution potential." The wise use of climatological data and knowledge will nevertheless pay dividends in the form of improved employee comfort and optimum community relations.

The three most serious weather hazards encountered in the Northeast are floods, hurricanes and tornadoes. More common but much less dangerous are blizzards and hailstorms, and they may be discussed first.

True blizzards, that is, the combination ofe near-zero temperatures, gale force winds, and falling or blowing snow that blinds the vision and piles up in huge drifts, are rare in this portion of the country. They are most apt to occur along Lakes Erie and Ontario.

Hailstorms are unusually severe thunderstorms. Because of their localized and spotty nature, it is difficult to compile accurate statistics on their occurrence.

Like hailstorms, tornadoes are associated with severe thunderstorms, but there the resemblance ends. Large-sized hailstones will break windows, skylights, puncture car tops, damage certain types of material left exposed on open platforms or in the yard. A tornado will destroy, injure and kill. It bringsenot only a ring of rapidly-whirling winds, 200 m.p.h. or more, but a sharp reduction in the atmospheric pressure inside its funnel that can cause buildings literally to explode.

On June 9, 1953, for example, a tornado devastated central Massachusetts and struck several modern apartment buildings and factories in the city of Worcester, along with hundreds of frame dwellings in the suburban and rural areas along its course. Most of the latter were reduced to kindling wood where the tornado struck full force; the steel and concrete structures sustained comparatively small damage.

It was concluded by a team of engineers that factory structures designed in accordance with accepted modern standards are relatively tornado proof, although the different types of construction had varying resistances and severe damage must be expected to glass, roofs and lightweight sidings when even a modern building receives the full impact of a tornado.

The probability is small, however, that any given area, such as a plant site,e will be struck by a tornado. But it should not be overlooked, that no spot carries with it a guarantee against tornadoes, and they should be reckoned with in planning factory structures. There is abundant climatological information on which to base such plans.

Hurricanes, while their violent winds do considerable damage, are most dangerous to shore installations. They produce a "storm surge" that may raise the water level suddenly to several feet above mean water; the resultant flooding, unless the building has been protected against it, will damage machinery, supplies, etc. in cellars and ground floors. No factory should be buil't on the shore, whether of the open sea, bay or tidal estuary, and no docking facilities should be erected, without considering the possibility of this kind of hurricane damage.

In cases where plant sites are located along rivers and streams—as they often are for water access—the heavy rains associated with hurricanes will cause quick rises and similar flooding. In the New England hurricanes of 1955, for example, severe water damage was suffered in the "mill towns" built along the usually peaceful river banks.

The lesson is that stream flow, rainfall and hurricanes records should be consulted when contemplating a plant or factory near the water. The centers of a good many hurricanes and less intense tropical storms have passed over the Northeast area. In the period 1901-55, 23 have passed over Maryland and Delaware, 13 over New Jersey, 12 over Pennsylvania, 9 over New York, 21 over the southern New England States, 6 over New Hampshire and 7 over Maine, no hurricane "eye" went directly over West Virginia and Vermont during these fifty-five years. In analyzing these figures, it should be remembered that the same storm may have passed over several States; in other words, that the total of these individual figures is not necessarily the true over-all total for the area.

Balancing this, parts of the area (especially the coastal belt) have been affected by additional hurricanes whose centers did not happen to pass over one or more of the States listed. There is no persistent pattern or sequence by which various sections of the Northeast have been affected; hurricanes are facts in the area's climatological history and should be respected as such in any building plans.

With regard to floods, enough has been said for the purpose of this article in connection with those due to hurricanes. They have also resulted from other types of storms, either major low-pressure areas or small-scale storms (or "cloudbursts"). All these kinds of storms have produced floods, their effects depending upon the intensity of the rainfall and the size of the area affected. They are most frequent during Summer and Autumn.

Another kind of flood, typical of Spring but occasionally experienced in Winter, is that due to the thawing of snow, when the melted water runs off the frozen ground and eventually pours into the streams.

Methods have been devised to estimate the frequency of floods of specified heights on most of the important rivers in the country; it is therefore possible to take precautions (levees, spillways, etc.) where conditions warrant, without exaggerating the danger

As a final item, the writer wishes to deliver restrained praise of the climatic advantages of the Northeast from the viewpoint of human enjoyment. In Summer, the coolness of the mountains and the seashore adds to the pleasures of vacation. In Winter, the bracing air and snowy slopes beckon to ski enthusiasts. In Autumn, week-end trips to view the flaming foliage are enhanced by the beauty of the sky and the clarity of the atmosphere. And in Spring, the invigorating sight of budding vegetation is made more attractive by the equable temperatures.

In more sober terms, the Northeastern States offers a climate that is good for business and, equally important, is good to work in and enjoy.

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WEATHER PATTERNS IN THE SOUTHEAST

By C. K. Vestal

UNLIKE any other animal, the human possesses the ability to live and work in any of the world's climates. One of the reasons for this is that the human body has a very good natural heating and cooling system which gives it the capacity to adapt readily to wide ranges of climate or to rapid weather changes. More important, however, are the various artificial means man uses, such as clothing, shelter, and air conditioning, to extend his comfort range or his ability to live under the most rigorous weather conditions.

However, there is no concern here with man's ability to survive in extreme climates. Instead, the discussion surrounds the important fact that he can work efficiently only within his much narrower comfort zone. This applies either to indoor or outdoor work, although the comfort ranges will differ for each type of activity. In these days of rising labor and material costs, this fact has become increasingly important to plant managers, executives, and others concerned with efficient production. Also, those state and municipal agencies whose job it is to attract new industry to their areas have come to recognize climate as a salable commodity. In a recent issue of INDUSTRIAL DEVELOPMENT, about one out of every seven of the larger advertisements concerning plant sites made some mention of the local climate as an inducement for choosing an area in which to locate. Added to this is the belief of many that continued profits and maintenance of our high standard of living depend largely on increased output per man hour of work. It would appear, therefore, that no one can afford to overlook any factor which can operate to either raise or lower efficiency. Climate is one of these factors.

Mr. Vestal is a native of North Carolina and has held numerous positions in the U. S. Weather Bureau over the past 20 years, except for a two year period when he was loaned to the State Department for an assignment in Africa. He was graduated from Guilford College in North Carolina and has done graduate work at Maryland University and at Florida State University. At present he is Area Climatologist for the Southeastern States and acting Area Climatologist for the Southwestern States; he is located, for this dual assignment, at the Weather Bureau Regional Office in Fort Worth, Texas. His hobbies are golf, hunting, music, bridge, and reading.

Climate has its effects on a great many mechanical operations as well. Frequently, transportation or storage of materials, electric power generation and transmission, and functioning of much of the equipment of modern industrial operations are governed by climatic considerations. As a matter of fact, it is difficult to find an operation that is not affected by climate or weather to some degree, even though the effect is not necessarily of paramount importance.

In its essentials, then, the problem discussed here becomes one of evaluating the importance of climate in a particular operation. It may turn out to be a highly important factor that cannot be ignored, and preventive or compensatory measures must be taken once this fact is realized. On the other hand, one may discover that the climate factor is entirely secondary to other much more important items and, consequently, may be rejected as an influence on further considerations. However, in either case, the process has been one of examining the climate factor and determining its proper rank in the entire operational process, rather than the less wise procedure of ignoring its influence or deciding arbitrarily that climate or weather risks are not important.

In choosing the plant site, therefore, one should have some knowledge of the climate of the region and be able to evaluate the effect that various weather extremes will have on the plant's construction, operation, and maintenance. Of course, this appraisal should be carried on concurrently with that of the labor market and raw material supply; transportation and distance to markets for finished products; availability of land for purchase or lease; the state, county, and municipal tax structure; availability of power and fuel; regulations covering gas or liquid waste discharges; and the many other considerations that always enter into such decisions.

After a brief description of the climate of the southeastern states, the discussion following will cover many effects of the weather phenomena that are found in this part of the country. The discussion, of course, is designed to be of help in selecting and planning for a plant site in these regions.

Climate of the Southeastern States

Actually, there are many different climates within this area. There are, however, enough general similarities to make it easier, for the purpose at hand, to discuss the climate of this region as a whole rather than get into an involved story on the many climatic variations one will find here if he searches long enough. In line with this, there are several major geographical features which determine the climate of this region (and, indeed, of any region). Once the roles of these features are understood, it becomes somewhat easier to judge how various weather factors may interplay to produce the sum total of the weather, or what is more usually called the climate. These geographical features can be listed quickly:

1. The huge land mass to the west and northward.
2. The Appalachian mountain range.
3. The Atlantic Ocean and the Gulf of Mexico.
4. The latitude or distance from the equator.

In the winter, the great land area to the northwest, extending far into Canada, is covered with snow. This area becomes a source region for the very cold air which frequently slides down into the U. S. southeastward through the Midwest and causes our cold waves. Usually these cold waves have moderated considerably by the time they reach our area, and the southeastern cities do not get the very low temperatures of such cities as Chicago, Minneapolis, and Kansas City, nor do the cold spells last as long. Also, frequently the Appalachian mountains, which run

Southeastern City	Normal Heating Degree Days	Average Relative Humidity Near Noon	Average Number of Days Each Year						
			High Temperature Over 90°	Low Temperature Under 32°	Low Temperature Under 0°	Snow or Sleet	Thunderstorms	Measurable Precipitation	Precipitation 1 Inch or More
Birmingham, Alabama	2780	54%	60	38	†	†	65	118	15
Little Rock, Arkansas	2982	57%	75	46	†	1	59	103	16
Miami, Florida	173	60%	7	†	0	0	71	130	16
Atlanta, Georgia	2826	56%	34	38	†	†	51	122	12
Louisville, Kentucky	4439	57%	34	76	1	4	46	122	10
New Orleans, Louisiana	1175	62%	57	4	0	†	73	120	15
Jackson, Mississippi	2202	54%	99	36	†	†	62	107	11
Charlotte, North Carolina ..	3205	54%	40	46	†n	2	46	120	9
Charleston, South Carolina ..	1769	56%	27	9	0	†	59	110	12
Nashville, Tennessee	3513	56%	42	62	†n	3	52	120	12
Richmond, Virginia	3955	53%	45	83	1	2	37	115	9
New York, New York	5050	59%	7	92	†	8	31	124	12
Chicago, Illinois	6310	58%	28	123	7	10	36	119	8
Minneapolis, Minnesota	7853	60%	17	155	29	12	37	113	5
Denver, Colorado	6132	38%	34	153	7	17	43	86	2
Kansas City, Missouri	4888	55%	55	101	2	5	49	101	8

†—Less than one day every other year.

nearly north and south, tend to block some of the cold air to the west and partially shield the coastal states from the worst of the cold. Even so, occasionally an especially severe cold outbreak will penetrate into the southeast to the Gulf of Mexico and the Atlantic Ocean. These are few, however, and do not persist for long.

At all seasons of the year, there is a fairly constant flow of warm, moist air from the Gulf of Mexico and from the adjacent part of the Atlantic into the southeastern states. The interaction of the warm air with the winter cold outbreaks from the northwest produces frequent and wide-spread precipitation which falls most often in the form of rain. Of course, in the more northern states of this region, there are occasional snowfalls, but, except in the mountains, the snow does not remain on the ground long; in the southernmost states snow is a rarity and almost always melts as it falls. In these sections one may live years without seeing snow more than once or twice.

The winter climate of the southeast may be summed up, therefore, as being warmer than that to the north and west and having more precipitation and higher humidity than the western winters. The usual humidities are such as to cause the occasional cold spells to be more uncomfortable than would be the case if the air were drier. By any definition, however, the southeastern winters are more mild than elsewhere in the United States, with the possible exception of those in southern Texas, southern Arizona, and along the Pacific Coast; these will be discussed in another article in this series.

The southeastern summers range from warm and humid to hot and humid. The main reason for this is the continued inflow of warm, moist air from over the Gulf of Mexico. Even so, frequent thundershowers, which are the main source of precipitation during the summer, afford relief. The very high summer temperatures of the Great Plains, from the border of Mexico to the Canadian border, are rarely if ever experienced in the southeast. Here the higher temperatures occur inland although they do not go above 95° very often; along the Atlantic and Gulf coast, the daily maximum temperatures are somewhat lower, but the humidity is higher.

From the above remarks, one can begin to understand how the four major geographical features, mentioned earlier, operate to control the southeastern nclimate. In the same order they weren listed previously:n

1.nFrom the much colder land expanse to the far northwest comen the cold air outbreaks in the winter that penetrate the southeasternn states. However, the cold wavesn are normally less frequent, lessn severe, and do not persist as long in the southeast as they do in then northern, central, and Rockyn Mountain states. Between coldn spells, the weather is comparativelyn mild and even occasionally balmy; naturally, the mild or balmy periods are more frequent and moren pronounced in Florida and in then nearby states along the Gulf andn the Atlantic coasts.n
2.nThe Appalachian mountains frequently offer some protection inn winter to the states immediately ton the east. Along the mountain tops, snow is more frequent in the winter and stays on the ground longern than elsewhere in the region. Here,n too, the humidity is lower and then temperatures are lower in summern and in winter. Greater, also, is then daily temperature range (difference between the daily high andn the nighttime low temperatures)n in the mountains.n
3. The Gulf of Mexico and the adjacent portion of the Atlantic aren the major sources of precipitationn and high humidity for the southeast. These bodies of water are,n also, a moderating influence onn temperatures along the coasts andn for perhaps a 100 miles inlandn from the Gulf and a somewhat less distance inland from the Atlantic coast. They operate, therefore, to produce more even temperatures, both throughout the day and from summer to winter; i.e. summer maximum temperatures are lower and winter minimum temperatures are higher in the costal strips than farther inland. (Note: Because the air flow over the U. S. is primarily from the west, the Atlantic Ocean does not exert nearly the same degree of moderating influence on east coast temperatures as does the Pacific Ocean on West coast temperatures; the Pacific Ocean effect will be discussed in another article of this series.) As a matter of interest, it might be helpful to mention that the reason large water bodies, such as the Gulf and the Atlantic, ameliorate coastal temperatures is that the deep water heats up more slowly in the daytime and in the summer than does land; similarly, water surfaces cool more slowly at night and in the winter than do land. Therefore, the water is apt to be warmer than the land at night and in winter, and cooler than the land in day and in summer.
4. All other things being equal, then closer an area lies to the equatorn the warmer it is. However, in climatology, as in other fields including industry, all things aren

rarely equal. For instance, equatorial regions, particularly the rainy humid tropics, practically never experience the high temperatures found in a great many areas to the north and south of the equator. Not long ago, the writer worked over two years in rainy tropical Africa, less than 500 miles from the equator, without experiencing the high temperature he found when he stepped off the plane afterwards one hot July afternoon in New York City.

In the United States, the southeast area has a warmer climate than the northeastern states because, if for no other reason, they are farther south. On the other hand, summer temperatures in Birmingham, Alabama, are higher than in Pensacola, Florida, even though Pensacola is 200 miles farther south. Of course, this is because the cooling effects of being on the Gulf is greater than the warming effect of being farther south. Other examples could be cited, but these serve the purpose of demonstrating that one geographic characteristic can modify another as far as the resulting climate is concerned.

Effects of Climate

Obviously, some industrial plants and some operations are more vulnerable to certain climate factors than are others. Also, one climate characteristic, such as high temperature, may have a detrimental or beneficial effect on one industrial operation and practically no effect on others. No attempt will be made, therefore, to produce an exhaustive list of climatic effects; instead the discussion following will identify the primary climatic factors and will include examples of their effects on typical human and mechanical operations in the southeastern states.

Temperature and Humidity

Human comfort can be gaged closely from temperature and humidity readings. There are other contributing factors, of course, such as the absence or presence of direct sunshine and of wind, and there are times when these latter factors are not negligible.

As described earlier, winters in the southeast are mild as compared to most of the rest of the country; heating costs are lower, also. Some idea of the differences can be gained by referring to the table which gives the normal annual heating degree days* for various cities. The cities with lower degree day totals have lower heating costs. An immediate advantage of industrial plant location in the southeast is apparent.

This advantage is offset somewhat by the need for cooling or air conditioning during the warm and humid summers. Unfortunately, there is no generally accepted index to air conditioning requirements that parallels the use of the heating degree day in determining heating requirements. The reason for this is that, in air conditioning, humidity is as important as temperature.

Perhaps the most comfortable temperature range is between 65° and 75° although this will vary with individuals and with the amount of physical work being done. Heavy workers find somewhat lower temperatures more acceptable while desk workers find temperatures lower than 70° uncomfortable. In the comfortable temperature ranges high humidities are not particularly important except to heavy labor. However, at temperatures much lower than these, high humidities lend an additional chill to the air and make it feel colder than the thermometer would seem to indicate; this is a usual situation during the southeastern winters, especially near the coastal areas. In summer, when daytime temperatures consistently exceed, say, 80° to 85° with high humidities, most people experience slight discomfort; at temperatures above 90° with high humidities, nearly everyone feels the weather to be sultry and oppressive. (The effects of very low humidities will not be discussed here since very low humidities occur only rarely and briefly in the southeast; they will be covered in another article in this series.)

Human comfort is important to industrial operations since, unquestionably, worker efficiency drops outside the comfort zone, and the greater the departure of conditions from optimum, the more decided the decrease in efficiency. Some method of air cooling or air conditioning becomes most desirable, therefore, in southeastern industrial plants because of the usual summer weather. Air conditioning, is of course, the most satisfactory solution, but it is also the most expensive. At temperatures below 90°, forced ventilation with fans is reasonably effective even with high humidities, but this becomes nearly useless as a cooling method at temperatures above 90° in the southeastern states. It is only natural, therefore, that air conditioning is becoming widely accepted in the southeast, and, no doubt, not many years from now nearly every office and most industrial plants of importance will be air conditioned, at least in part.

Other Effects

Aside from human comfort considerations, high humidities and temperatures have other effects. For example, under such conditions blast furnace efficiency decreases; inferior castings are formed at 80° temperatures and a relative humidity of 80%; electric equipment and electronic devices are more prone to failure; paper, cloth, and leather suffer from mildew; gummed flaps stick on unused envelopes; steel rusts excessively with relative humidities around 80% or more, and this effect is accelerated by higher temperatures.

In many industrial processes, water is circulated through cooling coils or jackets surrounding tanks or tubs in which products are being formed or, conversely, the tanks may be filled with water which bathes coils through which the product is pumped for cooling. In such cases, the temperature of the water as it is drawn from the outside becomes important since, if its temperature is too high, its cooling effect is reduced. For some processes this may be important, say, along the Gulf Coast where summer temperatures of spray ponds and shallow lakes are quite high. Other processes require preheating of indrawn industrial water before it can be used, and in these cases the higher outside water temperatures are of advantage.

One example of the importance of water temperature will suffice. In the commercial production of ammonia, the ammonia gas is synthesized and then dissolved in water to obtain the commercial product. In this step, cool water is superior because more than twice as much ammonia gas can be dissolved in water at a temperature of 60° than in water at 95°. In storing or shipping the product in tanks, temperature is important, also, because the gas tends to boil out of solution at high temperatures.

It has already been implied that worker efficiency decreases rapidly at temperatures above 90°; the same is true at temperatures below 40°. Again, this range will differ with individuals and with the type of work being done, but this statement should suffice as a generalization applicable particularly to outdoor employees, such as construction workers, and to those working in exposed plant interiors. Lower temperatures affect or limit many activities. Non-enclosed paint shop operations slow at temperatures below 60° and cease entirely at below 40° readings; up to 1/4 of the parts for aircraft frames cannot be pressed satisfactorily at temperatures below 40°; and precision machining suffers in quality at such temperatures. The pouring of concrete and forms stripping at below freezing temperatures is avoided unless for some reason, greatly increased costs are warranted for the necessary protective measures. Also, at below 32° temperatures it becomes difficult to operate compressed air equipment under high humidity conditions; the air moisture condenses and freezes on the exhaust outlets, stopping the equipment. Stockpiled coal or coal being shipped in railroad cars begins to freeze at temperatures which depend on the wind and the amount of moisture in the coal; frozen coal, of course, must be knocked apart with sledges or thawed before it can be handled. The conveyor belts also tend to freeze under the same conditions. On the other hand, stockpiled coal does not oxidize and depreciate in quality as fast under winter conditions as in the hot summer. For example, coal that can be stored for three months in winter and still retain its coking qualities may not retain equal qualities after more than one month of summer storage, when spontaneous combustion possibilities increase also. The optimum coal storage temperature range, from all standpoints, seems to be about 40° down to just above freezing.

Obviously, industrial cold weather problems are not as acute in the more temperate southeastern winters as they are where the winter climate is more rigorous. However, below freezing temperatures are not uncommon in most parts of the southeast as will be seen from the table. Even so, during the rather brief cold spells, there are many precautions or protective measures that can be taken, and, in general, construction activity can proceed with less weather interference than to the north or west. For instance, alcohol can be vaporized into the lines of compressed air equipment to prevent moisture freezing at the exhaust ports.

Precipitation and Winds

By far, most of the precipitation in the southeast falls in the form of rain. This area is well watered, and the supply is sufficient for most industrial purposes, insofar as that statement can be made concerning any area of the country. Of course, when it is understood that the United States used 221 billion gallons of water *daily* in 1955, and that an estimate of 597 billion gallons daily use has been forecast by 1980, it should be more than obvious that there is not enough water to go around. Nevertheless, the southeast as a whole is better off than most parts of the country and no worse off than any. There are spotty exceptions to this general statement, however, and before locating any plant with a high industrial water requirement, a thorough survey of the local water supply and potential is indicated axiomatically.

Traffic Hazards

Snow, sleet, and rain that freezes as it falls are definite traffic hazards, and moderate to severe occurrences can cause plant shutdowns for this reason alone. Of course, the degree to which the falls are effective in stalling traffic depends largely on the community experience in such problems. A snowfall that would cause little comment in New England would probably paralyze traffic in North Carolina for a short time. While snowfalls of, say, five inches or more are uncommon in the southeast (and quite rare in the southernmost states), when they do occur they cause a good deal of trouble temporarily. Freezing rain will collect on electric power transmission lines and on telephone lines, breaking them if the ice accumulation is heavy enough. Freezing rain is not an uncommon event in the more northern states of the southeast area. The table gives the number of days per year with snow or sleet in representative cities.

Rainfall will halt or limit outdoor construction. Of all such operations, excavation activities are the most affected which, of course, is of concern during the construction of the plant. As described earlier, in the southeast the rainfall is fairly well distributed throughout the year. Winter rainfall tends to be more even and widespread, and summer rainfall is mostly of the shower type accompanied frequently by thunderstorms and, much more rarely, by hail. Hail is of little moment as far as industrial plant location is concerned since its main effect is one of damage to glass that may be exposed to the sky; on the average it occurs only once or twice a year at any one spot in this area.

Summer thunderstorms in the southeast are common, and when they are well developed storms, which is frequently the case, their high winds, lightning, and heavy rainfall can cause considerable damage within a short time to power and telephone lines and to roofing that is not well maintained. However, such thunderstorm damage is nearly always local in character because of the spotty nature of the storms, but on occasion a thunderstorm line several hundred miles long will form (called a "squall line") and cause damage along most of its length as it moves in an easterly direction. Local flash floods can result, too. These phenomena are not peculiar to the southeast since they can happen nearly anywhere in the country, but the southeast does have more summer thunderstorms than most other sections. The table compares average annual thunderstorm occurrences for representative cities.

The same weather circumstances that give rise to thunderstorms can also produce tornadoes, and, although they are observed far less frequently than thunderstorms, tornadoes are not rare in the southeast by any means; on the other hand, not as many occur in the southeast as in the midwest. Tornadoes can occur in any month in the southeast but they are more usual in early Spring than at any other season. Their destructive path is small in width (usually a few hundred yards) and short in length (perhaps less than 20 miles average). Naturally, most destruction ensues near the direct path of the tornado, and light-frame dwellings and buildings, such as barns, suffer damage most frequently. Inadequate ground anchorage and the lack of adequately strong connections between the various members of the dwelling or building seem to be the main reasons buildings are damaged or destroyed by tornadoes. Modern reinforced concrete and steel construction, firmly rooted in a solid foundation, is immune to tornado damage except to the glass windows and, possibly, to the roof area.

Many of the record rainfalls in the southeast have been caused by hurricanes. These storms breed in the Caribbean and in the adjacent waters of the Atlantic to the east, mostly during the June through October months. Naturally, not all hurricanes strike the United States coast or come close enough to affect the weather appreciably, but those that do usually cause heavy to torrential rains over a large area. When hurricanes come inland from the Gulf or the Atlantic, the most severe damage nearly always occurs along the immediate coastal strip because of the heavy wave surges (popularly, though incorrectly, called "tidal waves"; the correct term is "storm surge") accompanying such storms. As the storm progresses inland, it tends to spread out over a larger area and weaken in intensity, but the winds may still be high enough to damage some roofs and to uproot trees from ground softened by the heavy rains; power and communication lines and windows may experience damage, also, particularly from falling trees and windblown debris; and the heavy rains can cause local flooding. It should be apparent, therefore, that hurricane danger is greatest in exposed coastal areas which the "storm surges" can inundate. Nearly all hurricane damage to an industrial plant can be avoided by locating it away from the flat coastal region in a site not subject to flooding, and by providing adequate roof anchorage and appropriate storm shutters to protect windows.

In conclusion, it can be seen that the climate of the southeast offers many advantages for industrial and plant sites, not the least of which are the comparatively mild winters. The beach areas from Norfolk southward, and on the Gulf coast, offer seashore recreation for employees; also, the Blue Ridge mountains of the Carolinas, Virginia, and Tennessee attract many vacationists including hunters and fishermen.

Additional information or detailed figures on any point covered in this article can be obtained from the U. S. Weather Bureau, Washington 25, D. C.

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*Heating degree days are calculated from the average of the high and low temperatures recorded each day. If the average is less than 65° the difference represents the value for that day. If the average is 65° or more, no heating requirement is assumed. An average temperature of 45° produces 20 heating degree days; an average of 65°, 70°, 75°, etc., produces zero heating degree days.

NORTH CENTRAL AREA WEATHER FACTORS

By Lothar A. Joos

DEFINITIONS of "climate" may be a written in a number of ways according to one's needs or desires. For example, "*Climate* is the average or sum total of weather experiences at a point or in an area," or, "Today, and possibly tomorrow and yesterday, we are having *weather* but the weather events of the past and of the future are a part of *climate*," or again, "*Climate* advises us to have available both sun suits and umbrellas but it is the *weather* which determines which item will be in use at a particular moment."

A definition which fits into our discussion here might be, "*Climate* describes the total outdoor physical environment as it relates to man's living and working activities."

GEOGRAPHICAL FACTORS: The geography of the North Central Area is attractive to industrial planners. The level terrain favors the construction and operation of railroads and highways and greatly increases the number of possible plant locations. Gently flowing rivers have been well developed for water transportation and economical barge traffic connects Great Lakes shipping with the lower Mississippi Valley and the Gulf Coast.

Although water power is limited, vast supplies of Illinois coal and easy access to the gas fields of the Southwest promise no shortage of energy for centuries to come. Ground water supplies are limited in some areas but fresh water reserves in the Great Lakes and the principal rivers can be considered adequate. In addition there is a large number of surface reservoir sites that can be developed when they are needed.

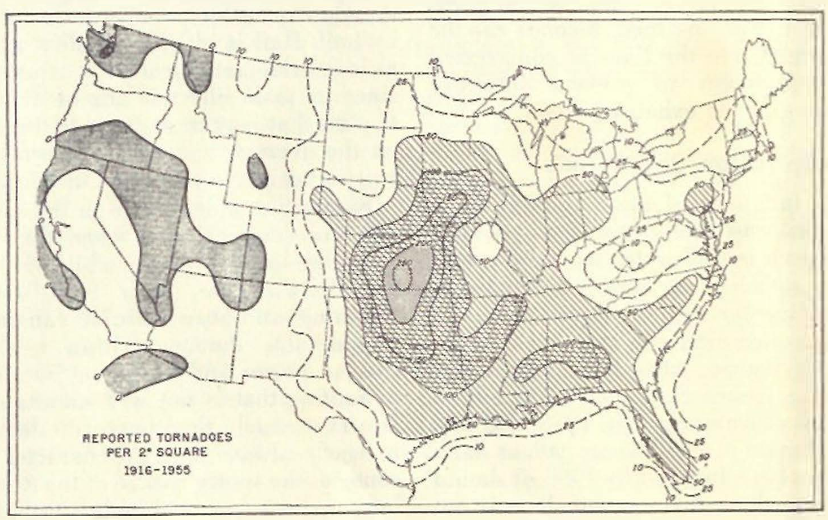
THE PLANT LOCATION PROBLEM: It is probably true that a factory or processing plant will not usually locate in the North Central Area because of climate but in spite of it. For example a large amount of industry is involved with processing the agricultural raw materials of this region. Al-

THE AUTHOR

As a farm boy in Wisconsin, Lothar A. Joos learned well the effect that climate and weather can have on crops, and then he grew up to be a weather man. He currently is the U. S. Weather Bureau's state climatologist for Illinois, with offices at the University of Illinois.

A graduate in chemistry from the University of Wisconsin, he joined the Weather Bureau in 1941. During World War II he completed the accelerated study program in meteorology at the University of Chicago and later served as a Navy meteorologist in the Western Pacific. He was for eight years in charge of the Weather Bureau offices in Madison, Wisconsin, and took his present position in 1955.

Mr. Joos is a professional member of the American Meteorological Society and member of the American Geophysical Union.



The map shows the total number of reported tornadoes per two degrees latitude-longitude square over the United States in the period 1916-1955.

though a remote location would be impractical there would often be a possible range of location of a couple of hundred miles.

Within that range a thorough analysis of weather statistics should permit one to minimize the total of the various costs of climate. Such an analysis might balance the cost of air conditioning in southern locations against the larger heating load farther north: cloudiness in Michigan against sunshine but greater storminess in Kansas; the greater cost of shelter in northern winters against increased cost of site drainage in southern latitudes.

The analysis might estimate the probable snow loads on roofs and the economics of a snow melting system. the directions from the plant in which air pollution would most frequently be objectionable, the stream flow characteristics of rivers, or the yield of surface water reservoirs where ground or river water is not adequate. Such analyses are most efficiently carried out by engineers who understand both the problems of industry and the use of weather records.

There are a number of consulting firms which are qualified and experienced in handling problems in industrial climatology. Whether the work is done by company engineers or by a consultant the records, facilities, and experience of the U. S. Weather Bureau's Office of Climatology are available.

As illustration of a plant location problem, a certain industry was considering a location in southern Illinois where nearby all industrial and municipal water supplies are taken from surface reservoirs. The process requires cooling water at a temperature of 70 degrees F. or lower the year around. Since water is limited and subject to strong warming in mid-summer the only practical way to obtain the required cooling would be through the use of cooling towers. Cooling tower efficiency is limited by air temperature and humidity.

In any case there can be no cooling to a temperature lower than the wet bulb temperature of the air. Since the wet bulb temperature is recorded hourly at all Weather Bureau airport stations it was fairly easy to make a preliminary analysis for southern Illinois conditions. The analysis showed that in an average July the wet bulb temperature is above 70 degrees for approximately 40 per cent of the time and that summertime operation of cooling towers would be impractical.

CLIMATIC PATTERNS: The climate of the North Central Area is characterized by great variability with large changes from winter's snow and frost to summer's warmth and occasional heat. Maximum temperatures have climbed to above 100 degrees F. in all the states and above 100 in most of them.

Low readings below minus 30 degrees occur every winter in the northern tier of states but much less frequently in the latitude of southern Missouri. Annual minimum temperatures are near zero in Oklahoma. The central area is cut off from the moderating influences of marine climates by distance since the Gulf of Mexico lies some 400 to 1000 miles to the south.

The prevailing westerly winds of this area almost eliminate the influence of the Atlantic Ocean. These same prevailing westerlies drive Pacific Ocean storms and air masses across the Continental Divide but this process wrings out most of the atmospheric moisture on the western slopes. The resulting "rain shadow" casts its desiccating influence over that row of states which extends from North Dakota to Oklahoma in the North Central Area. Moving eastward from the Continental Divide, average annual rainfall increases until the Mississippi River is reached.

Over the Mississippi Valley in general there is also a decline in annual precipitation as one moves northward from the Gulf of Mexico; this is true because the Gulf is the principal moisture source region for the area.

While mountain ranges and distance effectively protect the North Central Area from oceanic influences, there are no protecting mountains to the north. The entire northern flank lies exposed to invasions of frigid air masses moving south from the Canadian Arctic. Most descriptive of this situation is the lament of the North Dakota homesteader that, "there is nothing between here and the North Pole except a couple of barbed wire fences."

These same Arctic Air masses occasionally move right on through to the southern and southeastern states where they cause snow on the Gulf coast and freezing in Florida. Naturally the air masses are warmed somewhat as they leave the snow zone and move over the bare and usually unfrozen ground to the south. However the northern states feel the full force of the cold so that North Dakota and northern Minnesota have reported temperatures colder than minus 50 degrees on several occasions.

The great amount of change between winter and summer and the frequent short period fluctuations of temperature cloudiness, humidity, and wind direction caused by the numerous storm systems that move eastward across the North Central Area are viewed with mixed emotions by the inhabitants. Praise or condemnation flow according to the temperament, health, and business activities of the individual.

Extremes in climate themselves create much business activity through the production of climate-related goods and services. Houses must be insulated and heated, winter roads must be cleared of snow and ice, and even the manufacture of snow shovels and automobile anti-freeze represent important items of commerce.

Great Variability

Since climate in the North Central Area shows such great variability, it is unlikely that an industry seeking a particular climate will locate in this part of the country. If certain outdoor conditions are considered optimum or necessary for a process, it is obvious that such conditions will prevail during only part of the year. Location of industry within the North Central Area is primarily for reasons of raw materials, labor supply, nearness of markets, or availability of water, power, transportation facilities, etc.

Nevertheless, there is sufficient variation so that a proper location within the area may minimize climatic handicaps. The following discussion of climatic elements will mention many of the items that might be covered in an industrial climatological analysis.

TEMPERATURE: To anyone accustomed to a tropical or a maritime climate, the winter weather of the

North Central Area must appear very formidable indeed. Winters are always cold. Not every winter will have heavy snow, blizzards do not occur every year, and severe ice storms are relatively rare but winter frost and freezing temperatures are inevitable.

In upper Michigan and adjacent areas the freeze-free season is barely four months long. Even in central Illinois and northern Missouri freezing temperatures are likely during at least half of the year. Most of the area has a heating season nine months or more in length.

Although cold winters are inevitable there is a considerable variation in the intensity and duration of the cold. The heating degree day load varies from only 4000 units in southern Missouri and 3500 in Oklahoma up to 10,000 units in extreme northern Minnesota. In the same distance the number of days with minimum temperatures of zero or lower ranges from one in the extreme south to sixty in the extreme north. It is apparent that a native of Cairo in extreme southern Illinois would experience just as much winter discomfort at Duluth or Minneapolis as would a Floridian in moving to Cairo.

Cold weather has a marked effect on construction problems as well as on architecture and design. External water lines must be buried below frost level which requires depths of one or two feet in the extreme south to six to eight feet in the extreme north. Building footings must be at least that deep. Winter excavation in frozen soil is now routine but with added costs. During winter construction, concrete materials must be preheated and protected from temperatures below 25 degrees during the setting period. Bricklayers and plasterers require heated enclosures. All such costs are added to the usual cost of construction.

During the spring season the northward moving sun and longer days quickly warm the land surface. By late June the entire North Central Area receives as much or more sun's energy per day as does any part of Florida or the Gulf coast. Days are 15 hours long in central Illinois and nearly 16 hours long at International Falls, Minnesota. Outdoor living sets the pattern for the season and summer entertainment centers around the backyard barbecue.

Since the entire North Central Area is rather uniformily heated by the sun during the summer months, the resulting north-south temperature gradient is much weaker than in winter. For example during the coldest month of January, normal mean temperatures range from 33 degress at Springfield, Missouri to 7 degrees at Fargo, North Dakota for a difference of 26 degrees. During the mid-summer month of July the difference over the same distance is only 6 degrees; from 77.5 degrees at Springfield to 71.3 degrees at Fargo.

The intensity of summer heat which does occur in North Dakota is rather surprising and may be partly explained by the shortness of the nighttime cooling period. Given the proper weather pattern it seems to be just as easy for the temperature to reach 100 degrees in North Dakota as in central Illinois or Indiana. Naturally the frequency and duration of hot spells are greater in the south. The extreme northern sections of the area average less than 10 days per year with maximum temperatures of 90 or higher; both Kansas and Oklahoma average more than 60 such days per year.

Air Conditioning

It can be seen that air conditioning is needed in almost every part of the area. The hours of operation will be considerably fewer in the northern section but the design specifications for peak cooling load will not vary greatly. Nearly all department stores, restaurants, and hotels are now air conditioned while the cooling of offices and residences is proceeding rapidly particularly in the southern part of the area.

Air conditioner design and the computation of cost vs. benefit ratios require a special type of climatological statistic. The "discomfort index" is the statistic which seems best suited to the filling of this need and was mentioned in the two earlier articles of this series by J. K. McGuire and C. K. Vestal. The discomfort index, or D.I., is based on simultaneous readings of air temperature and wet bulb temperature. The D.I. can easily be computed from routine weather data. Summations above a base temperature can be handled in the same way as heating degree days.

PRECIPITATION: Annual totals of precipitation range from less than 20 inches in the "rain shadow" portions of the plains states to more than 40 inches in eastern Oklahoma, southern Missouri, and along the Ohio River. The seasonal differences are both interesting and significant. As mentioned earlier, the average precipitation tends to decline with distance northward from the Gulf of Mexico.

The farther a point lies from the Gulf moisture source the more likely it is that part of the potential rainfall will be dropped along the way. Futhermore during the winter season the water-holding capacity of an air mass is limited by low temperatures. Winter air masses normally carry a much smaller load of water vapor and have a much smaller potential for precipitation than do warm air masses.

Thus we find that the three-month total of winter precipitation for North Dakota is less than 2 inches at the same time that 3.5 inches per month is falling in the bootheel area of southeastern Missouri. This gradient in precipitation is almost entirely lacking in the summer season. During the three month summer period, total rainfall averages 10 to 12 inches in most of the central and eastern parts of the area and ranges down to 8 inches in the central Dakotas and from 6 to 8 inches in the western Dakotas and in western Nebraska.

During fall, winter, and spring most precipitation results from the storm systems and weather fronts which follow a general easterly course throughout the North Central Area. Rain and snowfall are gentle and show little variation from one county to another. The summer season brings a change in the pattern. Storm systems take a more northerly track and fronts tend to be weaker.

Most summer rainfall results from thunderstorms which are by nature erratic and leave too much rain in one place and not enough in another. The rain that does fall often comes so rapidly as to cause wasteful runoff and erosion. Flash floods are common but not so common as the local drouths that tend to occur nearly every year in some part of the area or another.

Not all summer thundershowers are gullywashers. It should also be pointed out that this type of summer precipitation pattern is rather common and not limited to the North Central Area. In Illinois about half of the annual precipitation results from thunderstorms and the other half from non-thunderstorm rain areas. The average annual number of thunderstorms days ranges from less than 30 in the extreme north to more than 50 in the extreme southern part of the North Central Area.

HUMIDITY: Because humidity characteristics are highly variable from season to season, from air mass to air mass, and even from night to day, it is impossible to do more than generalize in an article of this type. Every seasonal or diurnal change and every passage of a front or storm system brings a change in humidity. The only way to study this problem is through detailed analysis of hourly temperature and humidity records. During recent years more than 20 million hourly observations from all parts of the country have been placed on punched cards. Those interested in existing or potential studies based on such records should contact the Office of Climatology, U. S. Weather Bureau, Washington 25, D. C.

At all seasons of the year, humidity in the North Centarl Area averages lower than in areas to the south and southeast. Any wind pattern which moves air in from those directions will cause rising humidity. At all seasons the humidity in this area will tend to be higher than in areas to the southwest or west. Air masses approaching from those directions have been thoroughly dried by passage over the Continental Divide or through sojourn in desert areas. At all seasons the water vapor content of air over the North Central Area will tend to be greater than in areas to the north but during the summer these differences are often insignificant.

High humidity will normally be a problem only during the summer season and then only during wet periods or when wind flow persists from the Gulf of Mexico area. Mildew formation is sometimes a problem in southern sections. Some swelling of wood and sweating of cold water pipes occurs in most of the area.

During the cool or cold season the water vapor content of the air is lower although the degree of saturation (relative humidity) is generally higher. This is because the colder air has a lower water vapor holding capacity. When this cool air is taken into heated offices and factories and warmed into the 70's the relative humidity drops sharply and may reach a range of 10 to 15% of saturation. This causes excessive drying of materials and the buildup of troublesome electrostatic charges. Evaporation of perspiration isr rapid and the individual feels cool unless air temperatures are rather high.r Drying of mucous membranes increasesr the incidence of colds and respiratoryr ailments.r

These effects are reduced or eliminated by humidification but this does not endr the problem. Raising the air humidity causes condensation on windows and other cold surfaces and the condensed moisture may cause decay in wood frame buildings.

SNOWFALL: Although the North Central Area in winter is a land of snow and ice there is a considerable variation in the amount, frequency, and duration of frozen precipitation. Mean annual snowfall ranges from only 10 inches in the south and even less in Oklahoma up to 60 inches and more in upper Michigan and northwestern lower Michigan. In the northern sections snow is almost the only form of winter precipitation and snow remains on the ground for long periods. The average number of days with one inch or more of snow cover varies from 20 days in the extreme south and even fewer in Oklahoma to more than 120 days in the latitude of northern Minnesota.

In the southern sections of the area, snow is only an incidental part of the winter season. At Cairo, Illinois more than 90 per cent of winter precipitation falls as rain. In most of the North Central Area the amount of snowfall is highly variable from year to year and from storm to storm. Often only a slight change in air temperature is sufficient to change a rain situation into a heavy snow producer or vice versa.r Seasonal snowfall at Chicago hasr ranged from 10 to 66 inches. At Cairo a single winter has produced 48 inches of snow and yet one third of all Cairo winters have less than 5 inches of total snowfall.

WEATHER HAZARDS: The storms of the North Central Area are well known. Although this area is spared the direct effects of the tropical hurricanes which strike the Gulf or Atlantic coasts, this deficiency is balanced by the occurrence of tornadoes, hailstorms, blizzards, and ice storms. Spectacular and devastating as these storms may be, their effect on industry is minor and can be minimized or eliminated through proper construction and through insurance coverage.

The "blizzard" has winds of 40 mph or stronger which carry falling or drifting snow at temperatures near zero or colder. Transportation practically ceases and normal activities are severely curtailed for the duration of the storm. Fortunately the true blizzard occurs only occasionally in the extreme northern states and rarely as far south as Kansas. In most of the area the occurrence of heavy snow with six inches or more in 24 hours, some wind, and temperatures in the 20's can be expected with some regularity, possibly every one to three years on the average.

The North Central Area including Oklahoma has the country's highest frequency of tornadoes. Tornadoes become active in the Gulf coastal states during late winter. Their occurence moves northward with advancing spring and reach the southern parts of the area in early March. The four month period of March through June covers the main tornado season in Illinois and neighboring states to the east and to the southwest. By July the peak of activity has moved into Iowa and parts of Minnesota and the Dakotas. Late summer and fall shows a rapid decline of tornado activity throughout the North Central Area.

The core of maximum tornado activity for the entire country apparently lies over eastern Kansas and western Iowa. However the greatest losses of life and property occur in areas to the east and southeast where population density and the concentration of property subject to damage is much higher. No part of the country east of the Rockies can be considered safe from the threat of tornadoes. Neither Flint, Michigan nor Worcester, Massachusetts are in tornado areas but both have been heavily damaged in recent years. Even in the area of worst activity and on a day when tornadoes do occur there is only about one chance in ten thousand of a particular spot being affected.

With the improved forecast services of the U. S. Weather Bureau plus the operation of local observer networks for the reporting and tracking of tornadoes in progress, the chances for survival have been materially increased. Modern steel and concrete factory and office buildings may be considered tornado-proof although window and roof damage can be expected in any direct hit.

Construction of tornado-proof residences is feasible with modest increases in cost. The usual decision is to build more cheaply and to cover the risk of tornado loss through insurance. This leaves the home-owner with the responsibility for providing his family with shelter in a basement area or the equivalent.

Hail frequency is somewhat higher in the North Central Area than in sections to the east and south. Most parts of the area have only three or four hail occurrences per year and only a small percentage of these are capable of damaging factory installations. Hail frequency rises rather strongly in extreme western parts of the North Central Area, particularly in western Kansas and western Nebraska. These states show an interesting relation between elevation and increased hail frequency. Western Kansas with an elevation near 3,000 feet has four or five times as much growing season hail damage as occurs at elevations near 1,000 feet in extreme eastern Kansas.

INFLUENCE OF THE GREAT LAKES: The climatic influence of these unique fresh water seas is minor compared to the broad scale feature of the climate. There is some modification of temperature in the direction of cooler summers and warmer winters. Since the lakes can act as a source of moisture one might expect increases in precipitation in their vicinity. However during the peak periods of spring and early summer thunderstorm activity, the surface of the lake is relatively cool and this tends to diminish shower activity. The winter season occasionally produces a situation where winds sweep the length of a lake and pick up enough moisture to dump heavy snow in a narrow band along the shore. This effect is notable in the Gary, Indiana area but occurs more frequently in the vicinity of Buffalo, N. Y.

In general the lakes can be said to modify temperature extremes and to increase cloudiness particularly during the winter season. Since winds are prevailing westerly one finds that the western shores are affected only a small portion of the time. Since the entire state of Michigan is practically surrounded by lakes, the lake influences are rather important there.

NORTHWEST AREA WEATHER FACTORS

By M. D. Magnuson

This discussion is limited to the climatic implications and weather applications within the six western and northwestern States—Washington, Oregon, California, Idaho, Montana and Wyoming.

This six state area is large, roughly 650,000 square miles in size; its topography is diverse and heterogeneous, from high mountain ranges and plateaus to valleys reaching below sea level. Climatewise, this area is also "rich." For within its boundaries are located climates which are equivalent to that found in Switzerland or Scandanavia, the Mediterranean or the South Seas and the Ukraine or New Zealand.

About The Author

Marvin D. Magnuson is the Area Climotologist, U. S. Weather Bureau, and covers the six-Northwest States and Alaska. He has been associated with the Weather Bureau for the past 12 years in positions in Iowa, South Dakota, and is currently located in Seattle, Washington. His experience includes service as a meteorologist during World War II and as a statistician with the U. S. Department of Agriculture. Academically, he graduated from Nebraska Wesleyan University and has studied at the University of Nebroska and University of Coilfornia at Los Angeles.

When examining the climate of this area, three main points need to be emphasized: (a) The number of separate and distinct climates is large, (b)e most of the area has an underlying thread of similarity and (c) thee change of climate with distance cane be rather abrupt and sharp at times.e

To elaborate on these three main points as well as to explain the apparent paradox between points (a) and (b), it is necessary to look briefly at the basic factors that control the weather and climate of this area[4*]. These weather control factors are the pressure zones of the Pacific Ocean, the topography influence, the continental influence and the effect of latitude.

I.e*The Pressure Zones.* One of the most important climatic controls is the persistent pressure pattern that dominates the wide expanse of the Pacific Ocean. This pattern results in two centers of action; one, a semi-permanent high pressure area in the central Pacific and, two, a similarly semi-fixed low pressure area in the north Pacific, more commonly known as the "Aleutian Low."

The interaction of these two centers of action as well as their seasonal changes (the Aleutian Low predominates in winter while the high pressure area prevails during summer) results in a pronounced precipitation and wind regime that reaches a maximum in winter and a minimum in summer. In addition, the Pacific Ocean, itself, contributes a major stabilizing influence by modifying the temperatures.

The prevailing westerly winds carry this modifying influence for many miles inland although the effect is diminished by mountain ranges and by distance inland. For areas, particularly north of 40° latitude, the marine effect is such that the area is cooler in summer than one would expect for its latitude; in winter, it is warmer. The Continental Divide in Montana and Wyoming is about the limiting line of these effects.

II.e*Effect of Topography.* The topography and the mountain ranges of the West are the main factors that divide the area into many as well as radically different climatic types. For example, the direct relationship between the topography and precipitation is shown in Figure 1 along an east-west line at 47° latitude.

This figure shows that both the height of the mountain barrier as well as the distance from the ocean are important considerations in the overall precipitation pattern. Also to the lee of each mountain range or peak are the well-marked rain shadow areas of minimum precipitation. Besides these effects on precipitation, the

* Superior numbers refer to references at end of article.

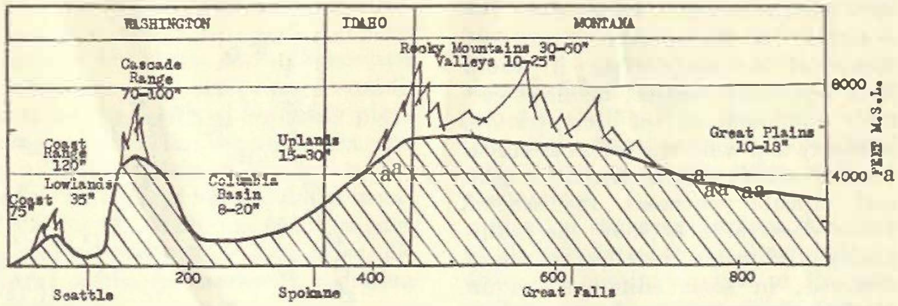


Figure 1—Topography and precipitation profile at 47° N. Latitude. (Vertical scale exaggerated 132 times.)

	Length of Day (Hours)		Altitude of Sun (Degrees)	
	Longest	Shortest	Greatest	Smallest
Canadian Border	16.1	8.3	64°	19°
Mexican Border	14.2	10.0	80°	35°

Figure 2—Effect of latitude upon length of day (sunrise to sunset) and the elevation angle of the sun over the western United States.

CLIMATIC TYPE[a]	GEOGRAPHICAL DESCRIPTION AND LOCATION[b]	
Hot, Dry Summers With Winters		
1. Mild and Dry	Va-Lo Up-Pl	Cal Cal
2. Mild and Moderate	Va-Lo Up-Pl	Cal Cal
3. Cool and Dry	Va-Lo Up-Pl	Cal Cal
4. Cool and Moderate	Va-Lo Up-Pl	Cal, Ida, Ore, Wash Cal
5. Cold and Dry	Va-Lo	Wash
6. Cold and Moderate	Va-Lo	Ida, Ore, Wash
Warm, Dry Summers With Winters		
7. Mild and Moderate	Co	Cal
8. Mild and Wet	Co	Cal
9. Cool and Moderate	Va-Lo	Cal, Ore
10. Cool and Wet	Va-Lo Up-Pl	Ore Cal
11. Cold and Dry	Va-Lo	Ida, Wash
12. Cold and Moderate	Va-Lo Up-Pl	Ore, Wash Cal, Ida, Ore, Wash, Wyo
13. Cold and Wet	Al	Cal, Ore
Warm, Moderate Summers With Winters		
14. Cool and Moderate	Va-Lo	Wash
15. Cool and Wet	Va-Lo	Ore, Wash
16. Cold and Dry	GP Up-Pl	Mont, Wyo Ida, Mont, Wyo
17. Cold and Moderate	Up-Pl	Ida, Mont, Wyo
18. Cold and Wet	Al	Ida, Mont, Wash, Wyo
Warm, Wet Summers With Winters		
19. Cold and Dry	GP	Mont
Cool, Dry Summers With Winters		
20. Mild and Moderate	Co	Cal
21. Mild and Wet	Co	Cal, Ore
22. Cool and Moderate	Co	Wash
23. Cool and Wet	Co	Ore
24. Cold and Wet	Al	Cal, Ore
Cool, Moderate Summers With Winters		
25. Cool and Wet	Co	Ore, Wash
26. Cold and Dry	Al	Ida, Mont, Wyo
27. Cold and Moderate	Al	Ida, Mont, Ore, Wyo
28. Cold and Wet	Al	Cal, Ida, Mont, Ore, Wash, Wyo
Cool, Wet Summers With Winters		
29. Cold and Moderate	Al	Mont

a. Breakdown into climatic types based on:

Summer (July) Temperature (°F)		Winter (January) Temperature (°F)	
Hot	over 75°	Mild	over 45°
Warm	60°–75°	Cool	32°–45°
Cool	under 60°	Cold	under 32°
Precipitation (In.)		**Precipitation (In.)**	
Dry	under 1"	Dry	under 1"
Moderate	1-2"	Moderate	1-4"
Wet	over 2"	Wet	over 4"

b. The following general geographical descriptions are abbreviated as follows:

Al — Alpine		Up-Pl —	Uplands and Plateaus
Co — Coastal			
GP — Great Plains		Va-Lo —	Valleys and Lowlands

Figure 3—Location and description of the Climates of the Northwest.

altitude and local relief produces contrasting temperature differences as well as variations in the growing season within relatively short distances.

III. *The Continental Influence.* The continental or the interior location has an important influence upon the climate of the large central land mass of the United States. The area east of the Continental Divide in the States of Wyoming and Montana comes directly under this influence. In winter, the cold Canadian air masses make frequent intrusions over this area while in summer, warm continental winds from the south are common.

Thus, the annual variation in temperature becomes much greater and the daily temperatures similarly show larger and more frequent fluctuations than more coastal locations. The precipitation regime also changes in this area with the maximum amounts in early summer.

IV. *Influence of Latitude.* Whereas the latitude effect—by determining the amount and intensity of solar insolation—is of primary importance over most of the United States, its effect over the West is less noticeable due to the over-riding topographic and marine influences. For not only do the isotherms (lines of equal temperature) tend to align in north-south directions but also the precipitation follows the same general pattern along contours of elevation.

Some of the indirect effects of latitude are shown in Figure 2. This table shows that there is variation of two hours in the length of daylight hours from the Canadian border to southern California. This factor along with data on sunshine can be related to the amount of supplemental illumination that might be required in a given location for an industrial plant. Also the elevation angle of the sun changes considerably over the area. This angle changes about one degree for every 70 miles in a north-south direction. Application of this fact would be in the orientation of buildings as well as for the specific design of windows and overhangs.

Climates of the Northwest. Our discussion can now turn from the causes of climate for this area to a classification of climatic types. Already it is apparent that the number of climatic types runs into the hundreds. To reduce this number and still illustrate the many different and significant climates, it is possible to consider certain combinations of temperatures and precipitation—the basic climatic elements.

This was done and the results are shown in tabular form in Figure 3. By considering only three classes for temperatures and three for precipitation, summer and winter, it is possible to show 29 separate and distinct climates. In Figure 4, representative locations of each of these 29 types are shown.

To illustrate the classification system, we can examine data for Portland, Oregon. From Weather Bureau publications, the pertinent normals can be extracted. For the summer season, the average July temperature in Portland is 68°, average precipitation, 0.4 inch. For the winter season, the average January temperature is 39°, precipitation, 5.4 inches.

From the legend in Figure 3, Portland would be classified as a climate having warm, dry summers with cool, wet winters. This is climatic type number 10. The table further states that this type is common to valleys and lowlands in Oregon and to uplands (above 1500 feet in elevation) and plateaus in California. Reference to Figure 4 indicates some of the representative locations of this type over these two states.

It can be pointed out that all classification systems (including this one) have certain inherent weaknesses. For example, for the specific purpose of industrial air-conditioning, it would have been more correct to select certain combinations of temperature, humidity and wind movement as classification parameters. However, for general climatic purposes, the scheme above does serve to show the multiplicity of climates as well as the sharp contrasts, in some instances, within a relatively short distance.

Climatic Elements. In any discussion of the climate—of and area—it is usually recognized that the most important element is precipitation. This can be particularly true in regard to industrial operations. For in the past—and also forecast for the future—total water use in the United States has and will continue to be doubled every 25 years.

With this increasing use and demand, water is truly becoming "the lifeblood of the nation." Since the distribution of surface and underground water supply is basically related to precipitation, in the form of rain or snow, it is important to know of some of the characteristics of precipitation over the West. Other elements in the following order will then be treated: temperature and humidity, wind and air stability, and, lastly, the weather catastrophes.

Precipitation. Although Figures 3 and 4 give some general ideas as to the distribution of precipitation over the West, a few additional remarks on other aspects of this element might be in order. In the first place, the range of precipitation varies from less than 2 inches per year in the Death Valley in California to 150 inches in the "rain forest" of the Olympic Mountains in Washington. More generally, over two-thirds of the entire area receives yearly precipitation amounts that total less than 20 inches. To document the variations of this element, the Weather Bureau has a network of raingages averaging 1 per 300 square miles or a total of nearly 2200 locations in this six-state area.[6]

Another distinguishing feature of precipitation is the pronounced seasonal pattern. Whether the yearly moisture is small or large, the greater portion of it falls during the winter season. The only exception to this is the area east of the Continental Divide where the continental influence gives an early summer-time maximum. Equally pronounced is the lack of rainfall—the summer-time drought—which begins in late June or early July and continues rather generally through September.

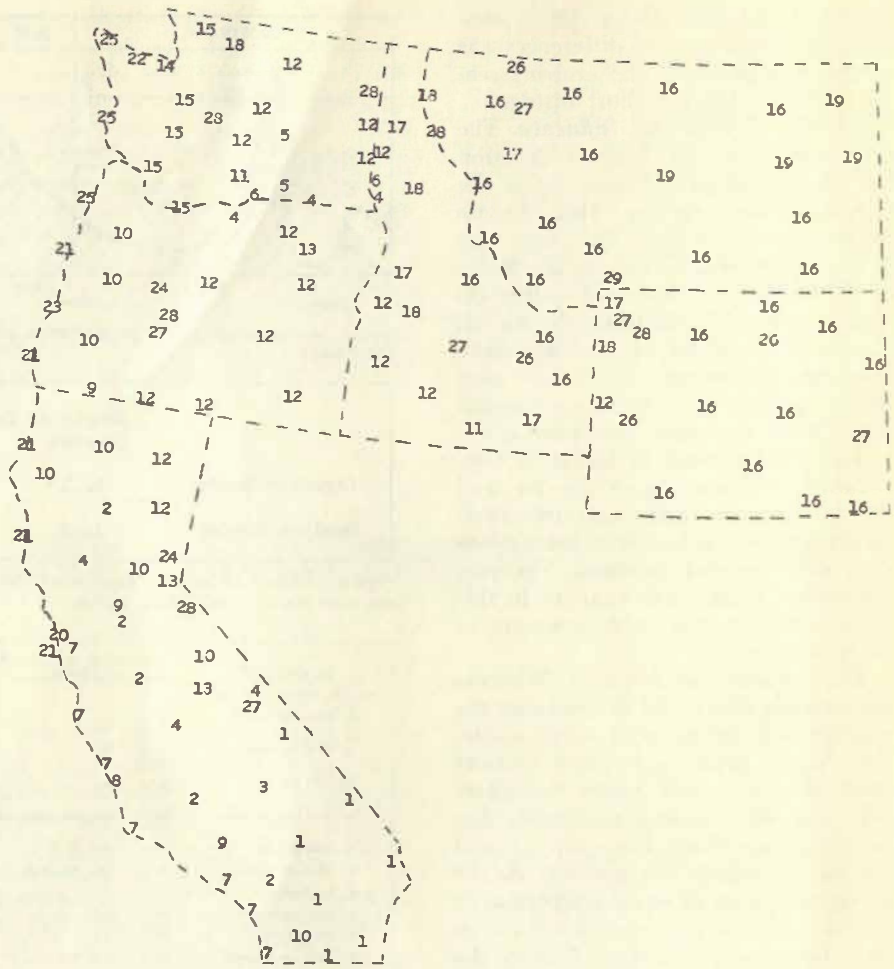


Figure 4—Representative locations of specific climatic types given in Figure 3.

Several factors can be mentioned that tend to minimize this inequitable distribution. At the higher elevations, much of the precipitation falls in the form of snow. This snow pack accumulates during the winter "wet" season and thus becomes a potential reliable source of water supply during the spring and summer melt season.

In this way, many streams and rivers are assured of a more stable year-round flow than what might otherwise be expected. As an example, the Columbia River reaches its peak flow during the season of minimum precipitation.

Also in spite of the fact that this river system flows through broad expanses of arid country, its volume of flow is second only to the Mississippi. With this source of moisture at high elevations, the West has the highest hydroelectric power potential in thee nation.[18, No. 1]

A lower rate of precipitation intensities also contributes to the conservation of the West's water supply. This is particularly helpful in reducing the amount of runoff and also assisting the recharging process for underground water supplies. Heavy bursts of rain or the more common "cloudburst" are rarely experienced—the main exceptions would be thee areas under direct continental influence and the mountainous areas ine southern California.e

For example, Portland, Oregon, receives yearly precipitation of 40 inches. Yet the maximum downpour in one hour has not exceeded 1⅓ inches. Elsewhere over the country where similar yearly rainfall occurs, these intensity rates are from 2 to 3 times greater.[14] At this point, it can be further emphasized that monthly or annual precipitation amounts, whether large or small, are poor indicators of the potential rate of rainfall for short periods of time.

For this reason, the Weather Bureau has a nation-wide network of special recording precipitation gages from which short period intensities are computed and published. Around 700 gages are in this network in the West.[10]

Snow is important in building design and for operational problems in some locations [12] because of the additional stress that it places on roofs or because of the curtailment of unrestricted out-of-door activity. Of course, the heaviest snowfall areas are in the mountains.

The snow line in the Cascades of Washington and Oregon lowers to about 2000-3000 feet. In California, significant snowfall is confined to elevations mostly above 4000 feet in the north to 6000 feet in the south, while elsewhere it ranges from 5000 to 7000 feet. Although the weight of new fallen snow varies somewhat, an average figure is about 6½ pounds per cubic foot. Old snow which has been compacted can increase this figure to 30 pounds per square foot.[2, p. 84] In recent years there has been a substantial increase in the data published on both snowfall and snow depth.[6] Also there are technical reports which relate the ground snow cover to roof cover conditions of various design.[7]

Snowfall, not a signficant factor along the California coast, ranges from a trace on the southern coast line up to 3 inches at some northern points. Similarly the coast line of Oregon and Washington seldom receives any snow.

Temperature and Humidity. Next to precipitation, the effects of temperature [9] and humidity become of importance to industrial interests. The problems associated with cold weather, hot weather and dry or humid conditions are somewhat different and each to a degree is found in the West.

The factors of elevation, latitude and continental influence combine to give the largest cold weather index to areas in Montana and Wyoming. Probably the best general index to cold weather and its associated problems of fuel consumption is heating degree days.

On this basis, seasonal heating degree days reach totals varying from 7000 to over 9000 degree days in Montana and Wyoming. Minimum heating requirements (seasonal values of less than 2000 degree days) are found in southern California.

Current and historic series of detailed degree-day data are now available in recent publications of the Weather Bureau.[6] Also for planning purposes, methods have been developed for estimating seasonal degree-day probabilities [20] or design temperatures [21] for any location in the country.

In hot weather climates, it becomes important to know and differentiate between the dry and humid conditions, for the factor of humidity plays an important role. The main hot and dry climates of the West are in the central valley and the southeast areas of California. With the hot sun, dry air and predominating clear skies, the control of the intense solar radiation is important.

For industry, this means large but lightweight buildings, the maximum utilization of awnings, sunshades and other protective devices and the use of building materials of low heat absorptive qualities. Another control device that works in both dry and humid climates is a system of fine water sprays or a trickle of water on roof tops.

This control gives considerable cooling to both roofs and walls of a building. In a humid climate, it has been shown that a minimum of 10 gallons per square foot per month gave satisfactory cooling results;[1] in dry climates, the consumptive rate would undoubtedly be a little higher. For cooling and air conditioning in the dry climates, the relatively simple evaporative cooling devices are entirely adequate.

A slight but steady movement of the air is also of advantage in hot climates. This factor of ventilation is particularly important as the humidities increase but only up to a certain point.[15] The warm and sultry conditions that are found in the central and eastern United States are not found in the West.[19]

The areas with the high temperatures in the West are the ones with low humidities or essentially arid climates. This does not mean to imply that problems associated with water vapor in the air do not exist. Actually, coastal areas and inland for some distance experience rather high relative humidities during the winter season—associated with the cloudy and rainy regime. For example, in a study of the corrosion of metals and deterioration of materials, it has been shown that the index of deterioration reaches a maximum value of 25 along the coast. (Ratings for this index range from zero in the deserts to 100 in the moist tropics.[2, p. 186])

Wind and Air Stability. Wind speed and direction must also be taken into consideration in both the siting and construction of industrial buildings. And with the growing awareness of air pollution, a study of the atmospheric stability must be undertaken if smoke or noxious fumes must be dissipated. Wind conditions are so highly variable in the West that only some general statements can be made; however, some pertinent rules will be summarized.

Most of the area—except that part of California south of about latitude 40°—lies within the belt of the prevailing westerly winds. This zone is characterized with a rather steady wind pattern and frequent weather disturbances, except in summer, result in good overturning and mixing of the air.

But there can be many exceptions to this general pattern as elevations and topography — the valleys and mountain slopes — exert local effects that may counteract or reverse the general wind patterns. Even the Columbia Basin in Oregon and Washington, a large interior depression, has wind patterns that are local and unique.

During the summer, the general circulation pattern weakens so that the winds are generally weak and erratic. Here the main exceptions are the coast line where steady northwesterly winds prevail and the area east of the Continental Divide where moderate southerly winds persist. Wind data are currently available from over 100 locations in the West. [5, 13] However, some of these locations are non-representative of the general area so that considerable care needs to be exercised in the interpretation of all wind data.[12]

Weather Catastrophes. Any violent or unusual rare occurrence of weather phenomena can be considered a weather accident or catastrophe.[11] Our discussion here will be limited to a brief one of the nature and distribution of the following phenomena: hurricanes and tornadoes, thunderstorms and windstorms, blizzards and snowstorms, heavy rains and floods, and air pollution.

Hurricanes and Tornadoes. Tropical storms or hurricanes may affect S. California but not with the intensity of East Coast storms. The tornado, which is a phenomenon of primarily continental areas, reaches its greatest frequency for this area in eastern Montana and eastern Wyoming averaging 1 to 2 occurrences in each state per year. The remainder of the area has average occurrences of 1 tornado every several years. This area can be considered outside the tornado belt.

Thunderstorms and Windstorms. Although these phenomena are neither particularly violent nor rare, there are certain characteristis which bear special mention. First, thunderstorms are comparatively few and mild along the coast but increase to a maximum of about 50 per year in the mountains of Wyoming.[4] Hail, which is the more destructive component of some thunderstorms also follows about the same distribution patterns.[8] Because of the variations in the size of the hail stone as well as the size of the storm path, careful interpretation of these storms is necessary. Similar care must be exercised in regard to windstorms, for here the effects of topography control the extreme nature of the storm.

For example, favored topographical locations in California give rise to the so-called "Santa Ana's," a strong and dry desiccating wind that reaches speeds exceeding 100 mph in the vicinity of mountain passes and over 60 mph at lower elevations.

Another example would be the occasional gale-like winds that funnel in both directions up and down the Columbia gorge between Washington and Oregon. These winds are extremely local in nature and considerable variations can be expected with change in elevation or in distance.

Blizzards and Snowstorms. The true blizzard — a combination of very strong winds, extremely low temperatures and snow—is confined to the States of Montana and Wyoming. Only rarely do storms of this severity occur west of the Continental Divide. As might be expected, snowstorms are common in the higher elevations of the mountains and a succession of these each winter contributes to the substantial water storage that is released each spring and summer.

Heavy Rains and Floods. For these phenomena, there are both a regional and seasonal pattern. West of the Cascade-Sierra Nevada ranges, occasional heavy rains come during the winter rainy season. Whereas the intensity of fall for periods of one hour or less are not unusually heavy [16, 17a] (generally less than one inch per hour), the flood producing rains are from substanital falls in periods of one day to one week (low intensity, high volume).

In contrast there are several areas that experience their exceptional heavy falls of rain in the summer and similarly pose a threat of some flooding of local low areas. The mountains of southern California are one area where occasional torrential downpours (high intensity but low volume) flood an isolated canyon or "dry wash" area.

Another area consists of Montana and Wyoming where downpours of one inch per hour or more can be expected every two years during the spring and summer months. Actually the risk of flooding by heavy rains depends not only on the nature of the ground surface but also on the slope and size of the drainage area.

Air Pollution. The atmosphere has been called the "world's greatest sewer," for man has not been too careful in controlling the amount or the type of waste products that are discharged into the air. These waste products are in various forms such as solid particles (dusts, fumes and smoke), liquids or mists, and gases or vapors.

Whenever there is an excessive release of any one or combination of these pollutants into the air or whenever the atmosphere fails to adequately disperse the pollutants, air pollution can become a major problem. In the West, the Los Angeles basin [3] is known for its high incidence of "smog" during the summer and fall. Because of mountains on three sides and a persistent temperature inversion overhead, the contaminated air is prevented from escaping in any direction.

Other coastal areas with similar restricted topography are potentially areas of some ir pollution because of the coastal-wide atmospheric condition of temperature inversion. In other areas, valley floors or small sheltered valleys also may have a potential for restricting air movement under certain conditions and should, therefore, be studied if pollutants are to be discharged into the atmosphere.

By increasing the height of a smoke stack or by choosing an alternate plant site, the problems of air pollution can be greatly minimized.

Summary. In conclusion, the West with its irregular and varied relief offers to the industrialist or business planner a wide selection of climatic types. At the same time, much of the area is free from many of the more violent weather phenomena as well as from the sudden weather changes on a day-to-day basis.

In addition, for the more hardy individual, thousands of acres of land have been dedicated as wilderness or primitive areas to remain in their natural state except for trails, etc. Areawise, there is an abundance of space for expansion or development of industrial sites. Climatewise and businesswise, the West is truly "the land of great promise" for the future.

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SOUTHWEST AREA WEATHER FACTORS

By P C. Kangieser

THIS is the last in a series of articlesa on the climate in various sections of the continental United States and its relation to industrial plant location. The geographical area covered in this article will be Nevada, Utah, Colorado, Arizona, New Mexico, and Texas. This area comprises over 1/4 of the total land area of the continental United States and contains some of the greatest variations in altitude (and climate) in the country. Therefore, after a general discussion of the general climatic features of the whole area, each State will be treated separately in more detail.

At the outset, it will be necessary to have some understanding of four important factors which exert an influence on local climate. These are: (1) latitude, (2) altitude, (3) moisture sources, and (4) orientation of mountain ranges. Briefly, these factors are important in the following ways.

(1)a *Latitude.* Other exposural factors being equal, stations at higher latitudes are cooler than those farther south. This effect produces a decrease in mean annual temperature of approximately 1.5° to 2.0° F. per 1° latitude increase.

Latitude also affects the distribution of precipitation in the western United States. During the winter, many storms enter the west coast and move across the country in a general west to east direction. This behavior, together with the fact that more storms enter the coast at high than at low latitudes, means that there is a tendency for high latitude stations to get more winter precipitation than those at lower latitudes.

ABOUT THE AUTHOR

Although he was born in Topeka, Kansas, Paul C. Kangieser was reared in the sunshine of Los Angeles and knows whereof he speaks about the weather of the Southwestern United States. A graduate of the University of California at L.A., Mr. Kangieser served as weather officer at several air bases in the U. S., India and China. Beginning his Weather Bureau service in 1946 as flight-advisory forecaster at Oakland, California, he subsequently held other positions in San Francisco, New England and Washington before returning west as State Climatologist for Arizona.

(2)a *Altitude.* Again, other factorsa being equal, higher altitude stations are cooler than lower altitude stations. The amount of decrease of mean annual temperature with increasing height averages about 3° F. per 1,000 feet.

In addition, high altitude stations usually receive more precipitation than nearby stations at lower levels. This is due to the added lift given to moist air as a storm moves over a mountain range. This lifted air expands, cools, and its moisture is precipitated as rain or snow. Thus, greater amounts of rain or snow can be expected with increasing elevation.

It should be emphasized that these "rules of thumb" for the effects of latitude and altitude on climate depend on "other factors being equal." Needless to say, other things seldom are equal, so that these rules can be applied only in discussing large-scale climatic features as indicated by long-term averages.

(3)a *Moisture sources.* The amounta of precipitation and humidity observed at a station are both highly dependent on (a) the distance from the station to a large source of atmospheric moisture, and (b) the location of this source with respect to prevailing winds. For these six southwestern States, the major sources of water-vapor are the Pacific Ocean and the Gulf of Mexico. The Gulf of California sometimes supplies moisture for local storms in southern Arizona, but it cannot be described as a major moisture source, even for that State.

(4) *Orientation of mountain ranges.* The orientation with respect to prevailing winds (as well as the altitude) of nearby major mountain ranges, exerts important effects on local climate. Stations on the lee side of high mountains frequently get less precipitation than those on the windward side. Leeside stations also tend to be warmer than those on the opposite side of the mountain range when at approximately the same elevation.

Seasonal Weather Patterns Of The Southwest

Seasonal weather changes over this six-State region are largely the result of the seasonal migration of two large high-pressure centers: the "Pacific High" and the "Bermuda High."

The Pacific High. This is a large high-pressure area, or "anticyclone", which occupies a large portion of the Pacific Ocean between California and Midway Island. During the wintertime, it is in its most southerly position and is relatively weak. This allows storms to swing around its northern edge and enter the west coast, sometimes as far south as Lower California. During the summer, however, the Pacific High increases considerably in strength and is normally centered farther to the north and east than in the wintertime. Thus storms are "blocked" from entering the west coast except at high latitudes, and Pacific Ocean cyclonic storms have little effect on the weather in the southwestern States in the summer.

The Bermuda High. Another large region of high atmospheric pressure is situated in the southern North Atlantic Ocean, to the east of Bermuda. During the winter this center is weak and far out to sea, but as summer approaches it builds a strong extension of high pressure westward into the Gulf of Mexico. This produces a deep flow of water-vapor from the warm waters of the Gulf over portions of the southwestern States.

Cold-Season Patterns (October-March)

As a result of these large-scale changes in the atmospheric circulation, storms track across Nevada, Utah, and Colorado more frequently during October-March than over the three southern States. However, as the moist marine air rides over the lofty Sierras and Cascades, it is lifted, expands, cools, and a major part of the moisture it contains falls out as precipitation on the western slopes and summits of these ranges. For this reason, when storms enter Nevada, they have less potentiality for producing precipitation, and lower elevation sections in the western half of that State receive little precipitation during this season. The eastern half of the State is more mountainous and receives somewhat more winter precipitation than the western part. The more rugged terrain in parts of Utah and Colorado provide each of those states with more cold-season precipitation than Nevada. The diminishing effect on rain and snow in this region by the passage of storms over the west coast ranges, is well indicated by the fact that the highest mountain stations in Colorado average only about one-seventh as much cold-season precipitation as high elevation stations in the Sierra and Cascade mountain ranges.

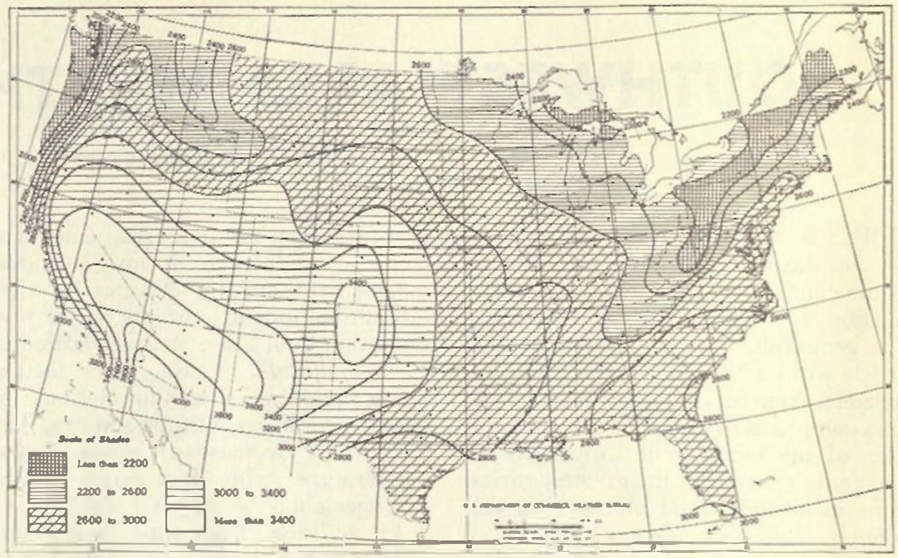
Although not as many cold-season storm tracks across the southern three States, other features help to compensate for this lower frequency of storm passage. Storms entering Arizona and New Mexico usually have not crossed the highest ranges of the Sierras, but have entered the continent via southern California or, sometimes, Lower California. For this reason they are not so depleted of moisture as storms with higher latitude trajectories. This fact, coupled with the rugged terrain in both States, gives them more cold-season precipitation than Nevada, in spite of the latter's higher latitude.

In the case of Texas, there is a tendency for storms that have crossed the Continental Divide to intensify after they have moved into Texas and have received an additional inflow of moist, warm, tropical air from the Gulf of Mexico. Thus, although the flatlands of western Texas receive little cold-season moisture (due to lee-side effects of the Continental Divide), increased moisture from the Gulf of Mexico assures ample precipitation over the eastern section of Texas, which has the greatest annual precipitation of any of the other five States.

Warm-Season Patterns (April-September)

In spring, the Pacific High strengthens and moves northward; storms become less frequent and tend to move across the country at higher latitudes. Late in the spring and early summer, the Bermuda High develops its western extension into the Gulf of Mexico and warm, moist, tropical air from that source begins to move from a southeasterly direction over the Southwest. This flow gets weaker farther to the west and less moisture is transported inland. Texas, New Mexico, and Colorado are far enough east that most parts

Average Annual Amount of Sunshine, In Hours



of those states are normally under the influence of this warm-season flow. Western Arizona and western Utah, however, receive considerably smaller amounts of moisture than their eastern sections. Nevada is too far west to receive significant Gulf moisture, so that its precipitation is also very light during the warm-season, making it the driest State in the country for the year as a whole.

During September, the Pacific High and the Bermuda High begin to weaken. By fall, storms from the Pacific start moving across the country at lower latitudes and the Pacific Ocean gradually takes over again as the major storm source for the Southwest.

A Closer Look At Southwestern Climate

So far we have had only a general picture of weather patterns in these six States. Now let's look at the climate of each one of them in more detail.

Nevada Nevada is, for the most part, a vast plateau with many mountain ranges, most of them 50 to 100 miles long, running generally north and south. The eastern part of the State averages between 5,000 and 6,000 feet in elevation; the western portion between 3,800 and 5,000 feet above mean-sea-level. The massive Sierra Nevada Range lies just to the west of the State and has a marked influence on its climate.

The most striking features of Nevada's climate are bright sunshine, little precipitation in valleys and deserts, dry air of great clarity, and very large daily temperature ranges.

As mentioned earlier, a large part of the air entering Nevada crosses the Sierra Nevada, and loses much of its moisture in California. Nevada has, on the average, less precipitation than any other State, and most of that occurs during the winter season. Precipitation ranges from less than 5 inches in the valleys in the western and southern parts of the State, to 15 to 18 inches in the mountains of northeastern Nevada. Nevertheless, a number of the western valleys are irrigated by the melting snows of the Sierras, so that there are many large ranches raising pure-bred livestock.

Humidities are also very low the year-around. Because of the non-corrosive nature of the atmosphere, outside storage of tools and equipment is feasible for many industrial purposes.

As the sunshine map shows, Nevada receives a large amount of sunshine during the average year. Nevada's air is not only dry but also largely free from haze and other pollutants, so that an unusually high percentage of incoming solar radiation reaches the ground. This property of the air also allows the ground to cool rapidly at night, so that the difference between daytime and nighttime temperatures is about as great as can be found in the nation. At Reno, this difference averages 45 degrees in July and sometimes amounts to over 60 degrees under unusual conditions.

In the northeastern section, summers are short and hot, winters long and cold. In the west, summers are also short and hot, but winters are only moderately cold. In the south, summers are long and hot and the winters short and mild. Prolonged periods of extreme cold are rare due to the mountain barriers. Although afternoon temperatures in the southern part of the State average above 100 degrees in the summer, the extremely low humidities make the heat less noticeable. Evaporative coolers work with great efficiency.

Winds are generally light, and the small amount of wind damage that occurs is usually limited to the east slope of the Sierras. Thunderstorms are infrequent and hail damage is rare. Locally heavy downpours sometimes occur during thunderstorms, but usually affect only sparsely settled mountain areas.

Construction operations are seldom delayed by precipitation. Penetration of walls by direct precipitation is almost unknown. Basements present few water problems and stone and concrete structures, in general, suffer far less deterioration due to water and freezing than in most other States.

Winter Sports

Snowfall in the mountains in the northern part of the State is usually heavy, making skiing a favorite winter sport. The State also offers fishing, hunting, and boating. There are many places of historical interest and a number of widely-known entertainment centers.

Utah The topography of Utah is extremely varied, since most of the State is mountainous. A series of ranges runs generally north and south through the middle of the State; the Wasatch Mountains are part of this group. The Uinta Mountains, which extend east and west through the northeastern portion of the State, make up another principal range. The crest lines of these ranges are mostly above 10,000 feet mean-sea-level. The lowest section of the State is the Virgin River Valley in the extreme southwestern part, with elevations between 2,500 and 3,500 feet.

Precipitation varies greatly, from an average of less than five inches annually over the Great Salt Lake Desert (west of Great Salt Lake), to more than 40 inches in some parts of the Wasatch Mountains. The average annual precipitation in agricultural areas isobetween 10 and 15 inches, making irrigation necessary; however, there is usually sufficient water for most irrigated lands due to the proximity of mountain reservoirs. Runoff from melting snow reaches its peak in April, May, or early June, and sometimes causes flooding along the lower streams; however, damaging floods of this kind are infrequent. Flash floods from summer thunderstorms are more frequent buto affect only small, local areas.

Temperatures above 100 degrees occur occasionally in summer in nearly all parts of the State. Low humidity, however, makes such temperatures more bearable in Utah than in more humid regions. During the warmer season of the year, a large percentage of commercial establishments and factories throughout the State are air-conditioned by refrigeration methods, but only a small portion of residences are so air-conditioned. Due to the low humidity, evaporative coolers operate very efficiently and are used extensively in private residences. Temperatures below zero during winter and early spring are uncommon in most areas of the State; prolonged periods of extremely cold weather are rare, due to the sheltering effect of the mountains east and north of the State.

Sunny skies prevail most of the year. For example, Salt Lake City averages between 65 and 75% of possible sunshine during spring, summer, and fall, with about 50% of the possible amount in wintertime. Smoke pollution is somewhat of a problem in the valleys of northwestern Utah, and is worse during the late fall and winter months when cold, stable air settles over the Great Basin, sometimes for several weeks at a time.

During the summertime, plenty of sunshine, dry air and moderate wind movement combine to produce rapid evaporation. This aspect of the Utah climate is utilized by a number of salt companies to produce salt from the brine of Great Salt Lake by the evaporation process. The production of salt by this method begins in the spring and continues until fall.

Tornadoes are rare. Blizzards occur rather infrequently during the colder season of the year and are usually of short duration. Hail storms occasionally cause damage over small areas during the spring and summer months, although the hail is generally small. Dust storms also are observed at times, and are more likely during the spring.

Since winter snowfall is moderately heavy, particularly in the northern mountains, skiing is a favorite pastime. There are numerous recreational and tourist attractions, such as lakes, rivers, historical areas, national parks, national monuments, and national forests. Fishing, big game hunting, and upland game-bird hunting are excellent.

Colorado Colorado is the highest State in the Union. Its average altitude is about 6,800 feet above mean-sea-level. Approximately three-quarters of the nation's land above 10,000 feet altitude lies within its borders. The State has 54 mountain peaks that are 14,000 feet or higher, and about 830 peaks between 11,000 and 14,000 feet. Nearly all of the western half of the State is mountainous, while the eastern half is generally flat, broken by occasional rolling hills and bluffs.

Rugged Topography

The rugged topography of western Colorado results in large variations in climate from place to place. Lamar and the summit of Pikes Peak differ by 35 degrees in mean temperature—a difference in 90 miles equal to that between Florida and Iceland. The average annual snowfall at Cumbres is near 300 inches, while less than 30 miles away at Manassa it is less than 25 inches. The climate of the eastern, or plains, part of the State is distinctly continental. Its general features are low relative humidity; a large amount of sunshine; light rainfall, confined largely to the warmer half of the year; moderately high winds; a large daily range in temperature; high daytime temperatures in summer; and generally in the winter, some protracted cold spells.

A distinct difference between the climate of the western and eastern halves of the State is the comparative uniformity of weather from day to day in the western section, especially in the lower mountain valleys. Also, the cold waves of the eastern plains are comparatively rare in the western part of the State. Mountain valleys in the western section (the South, Middle, and North Park areas) provide some of theo finest cattle grazing lands in the country. The valleys of the Gunnison,o Dolores, and Colorado Rivers in theo extreme western portion are the site ofo extensive orchards of peaches, pears, apricots, and other fruits. Other sheltered valleys of western Colorado areo used to raise vegetables, wheat, spring grains, alfalfa, and sugar beets.o

At the western edge of the plains, nearing and into the foothills of the mountains, there are a number of significant changes in the climate as compared to that of the plains proper. Winds are much less severe, temperature changes from day to day are not as great, summer temperatures are lower, and winter temperatures are higher. Precipitation, which decreases gradually from about 17 inches annually along the northeastern border to less than 14 inches near the mountains, increases rapidly with increasing elevation in the foothills. At the present time, the heaviest concentration of population and industry lies in this zone, near Denver in a belt running north and south and about 50 miles wide.

Occasional Blizzards

Blizzards affect all of the eastern plains at times, but are most frequent in the northeastern corner of the State. There is also a fairly high frequency of damaging hail in the northeast. Tornadoes rarely occur in western Colorado and, in general, their frequency increases over the plains toward the eastern border of the State.

On the whole, Colorado has a cool, invigorating climate. During the summer there are hot days on the plains, but generally these are relieved by afternoon thundershowers. The mountain regions are nearly always cool. Humidity is generally quite low, which provides a relatively comfortable feeling, even on hot days. The thin atmosphere allows a greater penetration of the sun's rays and provides pleasant weather during the winter; this accounts for the relatively thin clothing skiers are frequently pictured wearing amid deep snow drifts.

Recreational activities throughout the State are numerous. The heavy snows provide unexcelled winter skiing, and many of the higher slopes remain blanketed well into the summer season. Excellent camping facilities are provided by the many national forests and national parks.

Arizona Arizona is the 6th largest State of the 49, but there are only about 1 million residents and approximately ½ of these live in the vicinity of Phoenix in the Salt River Valley. Much of the southern part of the State is flat desert country, noted for its sunsets and as a national habitat for the giant Saguaro cactus. Rugged mountains cover the central and eastern sections, with colorful high-elevation mesa country in the northeastern and the Grand Canyon in the northwestern sections of the State.

Clear skies are an outstanding feature of Arizona's climate. As the accompanying sunshine map shows, the highest average annual amount of sunshine in the United States is received in the desert section of southern Arizona. In Phoenix, where records have been kept kept since 1895, 85% of the possible amount of sunshine is totalled in an average year. Clouds are rare even in winter, and the cloudiest month in Phoenix (January) still averages 76% of the possible amount, which is more than the majority of Weather Bureau stations in the country average during their sunniest month.

Low humidity is another distinctive feature of Arizona climate. In the desert areas of the State, humidities are low enough in summer to make evaporative coolers efficient. Supplying such coolers for home and industry has become a major business in recent years. Evaporative cooling towers also operate well for most industrial purposes. Temperatures vary considerably over the State. For example, winter temperatures in Yuma (in the southwestern desert at 200 feet above mean-sea-level) closely approximate summer temperatures at Flagstaff (in the northern mountains at 7,000 feet). Summertime temperatures in the desert are usually over 100 degrees in the afternoon, but drop into the seventies at night because of the dryness of the air. Winter temperatures in the desert usually reach the middle sixties or low seventies in the afternoon and stay above freezing at night, although frosts have occurred in all sections of the State. The ground seldom freezes in localities below an elevation of 3,000 feet, but near 9,000 feet the frost level usually extends to 3 feet or more during an average winter.

Precipitation ranges from barely 3 inches in the extreme southwestern corner to more than 30 inches per year in parts of the White Mountains in the east-central section of the State. Irrigation projects usually provide sufficient water for agriculture and industry, but local water shortages can develop in severe drought years. Heavy downpours of short duration sometimes occur during the summer, but are associated with thunderstorms which usually cover a relatively small area; the maximum 1-hour rainfall observed in Arizona is about 1.5 inches, compared to 3 to 4 inches in many other States. Heavy rain of longer duration, say 24 hours, is even rarer because such rainfall is usually produced by hurricanes, and these seldom affect this region; maximum 24-hour totals are between 4 and 5o inches in Arizona, compared to 10 too as much as 20 inches in other States.o

Hail sometimes occurs with some of the more severe thunderstorms, especially during the summer season. The incidence is well below that in most of the other western and midwestern States, however. Damaging tornadoes are also rare in Arizona.

Smoke pollution is a growing problem as population increases, especially in the Salt River Valley where the growth is particularly great. The temperature inversion that traps the pollutants near the ground, however, normally disappears each afternoon; therefore, it is unlikely that a problem will develop comparable to that faced by some cities on the west coast, where temperature inversions sometimes persist for long periods.

Outdoor run

Recreational facilities for employee enjoyment are numerous. In the out-of-doors department, skiing is available during the winter, while hunting and fishing are popular during the other seasons. In the summertime, a one-hour drive northward over a modern high-speed highway takes Salt River Valley residents away from desert heat to high pine country where air-conditioning is not required. Boating is becoming increasingly popular, as many of the State's reservoirs have been opened to this sport.

New Mexico The topography of New Mexico is extremely varied, with elevations ranging from 3,000 feet along the southeastern border to about 14,000 feet at the top of the highest mountains. Approximately the western two-thirds of the State is mountainous, while the eastern third is plains—a western extremity of the Great Plains area.

New Mexico is semiarid. Some farming is done without the aid of irrigation, but for the most part, all agricultural areas are dependent upon irrigation for successful crops. Precipitation varies from less than 10 inches in the Rio Grande and San Juan Valleys to over 30 inches in the high regions along the north-central border. Most of this moisture comes in summer thunderstorms and prolonged rains are rare, especially in the central and western sections. Some of these showers are rather intense and amounts of 2 inches of rain per hour have been observed in the southeastern part of the State. This rate of rainfall is still only about ½ as great as maximum intensities observed in many of the eastern and southern States.

Snow falls in every part of the State, increasing in amount with altitude and latitude from 2 to 5 inches per year in the lower Rio Grande Valley to nearly 300 inches over the crest of the main ridge of the Sangre de Cristo Mountains.

Temperatures vary widely with elevation and latitude, the annual mean decreasing from the middle sixties in the lower Pecos and Rio Grande Valleys to the middle thirties at the higher stations in the Sangre de Cristo Mountains. The eastern section has some of the characteristics of the Great Plains, with large daily, monthly, and annual variations in temperature. Over the mountains in the western sections these variations are not so great.

Humidities are usually comparatively low, generally ranging from about 60% in the morning hours to 30% in the afternoons, and dropping to 20% or less in late winter and spring. Evaporative cooling is quite effective throughout the State.

As the map indicates, New Mexico receives an abundance of sunshine. The frequency of clear skies is high during the winter as well as the summer months.

The prevailing direction of the wind in New Mexico is west or southwest for nearly all localities, with a few variations from these directions due to local topography. Average wind speeds are fairly high in all but sheltered districts, particularly during the spring and early summer months. The wind is usually strong and steady enough to operate wind-driven pumps and electrical generators with good reliability. There is enough air movement throughout the State that smoke pollution probably will not be a problem as industry develops. At the same time, there is seldom enough wind to hamper construction activities.

Tornadoes have occurred in all sections of the State but occur most frequently over the eastern plains. Blizzards are also most common to the eastern plains. Hail accompanies many of the thunderstorms with the most damaging storms in the southern and eastern part of the State. Blowing dust sometimes becomes a problem for short periods during late winter and spring.

Natural Beauty

The State is widely known for its great natural beauty and offers many places of interest for the sightseer. Fishing and hunting are also very good, particularly in mountain areas.

Texas With the exception of the area west of the Pecos River in extreme western Texas (the Trans-Pecos Area), the terrain of Texas consists mostly of flat or gently rolling plains country. The Trans-Pecos Area is a plateau 3,000 to 5,000 feet high, and is traversed by several mountain ranges which are part of the Rocky Mountain system.

The climate over the major portion of the State is continental, characterized by rapid changes in temperature, marked extremes, and large temperature ranges, both diurnal and annual. The climate in the mountains of the Trans-Pecos Area is cooler throughout the year than that over most of the adjacent lowlands; however, the day-to-day extremes are not as great during the winter due to the sheltering effect of the mountains. The moderating influence of the Gulf of Mexico on temperatures extends about 100 miles inland, so that a coastal strip has a climate bordering on the marine type—characterized by comparatively pleasant summers, mild winters, cool springs, and warm autumns. Although summer weather along the Gulf is often hot and humid, a sea-breeze can usually be counted on to bring relief in the afternoons. No part of the State is free from occasional periods of excessive heat when temperatures of 100° F. or higher are recorded, nor from occasional periods of freezing temperature; although the coastal counties and the lower Rio Grande Valley experience damaging freezes only at infrequent intervals.

Precipitation is heaviest over eastern Texas, especially in the extreme southeastern part, and diminishes steadily westward. The average amount in the extreme eastern part is over 50 inches per year, while in parts of the extreme west it is less than 10 inches. The greater part of the State has an annual average of over 20 inches, and most of it has enough precipitation to supply agricultural needs without irrigation. However, there is a considerable area west of the 101st meridian where it is necessary to resort to irrigation, where possible, or use conservation methods to produce crops; and there is also a considerable area that cannot be cropped at all.

Snow rarely occurs in the coastal counties. A few stations have never had any in their climatological histories, but the amount increases from the coastal plains to the high plains of the Panhandle, where the annual average is nearly 20 inches.

Hail occurs in all sections of the State, but is infrequent in coastal districts. It is most frequent and severe in the Panhandle counties.

The absence of sheltering mountains or extensive forests, and the great extent of plains and prairies give the wind free play. Wind power is available most of the year for operating wind-driven pumps and generators.

Lots of Sunshine

As the accompanying map shows, the western part of the State, particularly the Panhandle, receives a lot of sunshine. The eastern and southern sections receive about as much as the other Gulf States.

Tornadoes are least frequent in the western and coastal counties and most frequent in the north-central plains area. Hurricanes, on the other hand, affect the interior counties less frequently than the coastal counties. While severe damage has been done to Texas coastal installations by hurricanes in the past, Gulf states farther to the east suffer a greater hazard from these storms.

Nearly every kind of recreational activity is to be found in the State. The mountainous area in the western part of the State offers fishing, hunting, and riding. The coastal region provides a variety of activities the year-around. Hunting and fishing are favorite activities in the pine forests of the eastern section.

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