THE WATER CONTENT OF SNOWSTORMS IN NEW YORK STATE: VARIATIONS AMONG DIFFERENT PHYSIOGRAPHIC REGIONS

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Introduction

The purpose of the present study was to characterize the water content of new snowfall in various regions of New York State as may be determined from standard, published climatological data. This paper represents a preliminary report of results thus far obtained.

The scientific journals and other literature contain many reports on the measurements of water content of the snowpack or snow cover already on the ground and their application to hydrologic and engineering problems. Precise measurements of density (water content) in relation to the kind or type of snow crystal have also been published by a number of investigators. Individual snow crystals have been captured by specially designed equipment and their crystal structure and density carefully determined. On the other hand papers are rather scarce in the literature in which the yield of new fallen snow has been correlated with the corresponding measurement of liquid water equivalent in a variety of storm situations, different geographical locations or in relation to other meteorological parameters.

When precipitation occurs in the form of snow (or other frozen form) the daily summary observation at Weather Bureau First Order and cooperative weather stations consist of two related figures: one the snow measurement to the nearest 0.1 inch and the second, the water equivalent of this snow to the nearest 0.01 inch. These measurements are made, presumably, by competent, conscientious observers who are following instructions given in standard weather observation manuals. They are subsequently published in CLIMATOLOGICAL DATA and other formal ESSA publications to be utilized in various ways by the readers and users of climatological data.

The published daily (or storm total) snowfall and corresponding water equivalent measurements, just cited, were the basic data for the study we are reporting. It is clearly recognized that the accuracy of snowfall measurement is not always what we desire. Therefore, it should be emphasized that the snow/water content ratios reported in this paper are not to be interpreted as precise physical measurements. Rather, they should be considered as comparative ratios derived from standard climatological observations, albeit that they incorporate errors which we know exist in snowfall measurement.

Objectives and Methods of the Study

This study was undertaken to determine the following:

1. Variations of the snow/water content ratio (expressed as inches of snow needed to yield one inch of liquid water) of new snowfall at a single weather station in New York State. Included are the mean ratio of a large number of snowstorms, the extreme ratios and the range of ratios encountered in a majority of cases.

2. The variation of the mean ratio among different physiographic regions of New York State.

3. The variation of the mean seasonal ratio among different winter seasons at an individual station.

4. A comparison of the mean ratio in a given winter season between two or more of these physiographic regions.

The stations selected and the physiographic region represented by each are listed below.

Station	Physiographic Region
Buffalo	Great Lakes Plain -- Erie
Syracuse	Great Lakes Plain -- Ontario
Binghamton	Southern Plateau
Tupper Lake	Adirondacks
Albany	Hudson River Valley
New York (Laguardia)	Atlantic Coast

The combination of factors influencing the occurrence and form of winter precipitation, such as elevation, topography, nearness of large bodies of water, proximity to winter storm systems, etc., is different among each of these six regions of the Empire State. The stations were selected on the basis of good reliable snowfall observations and the ease of extracting the required data from published climatological records. Each station was also chosen as being reasonably representative of the snow climate of its region.

The period of record sampled for this study consisted of 12 winter seasons, 1951-52 through 1962-63. The total number of snowstorms varied from about 70 at New York City and 160 at Albany up to approximately 300 at the other four points.

Only snowfalls of 1.0 inch or more were considered. Storms were rejected in which part of the precipitation fell in liquid form and for which phase of the storm an acceptable or accurate measurement was not available. In other words all snowstorms in our sample consisted of precipitation entirely in solid or frozen form, or virtually so. Separating out those storms in which rain was mixed with snow was aided by hourly observations of temperature, precipitation amount (liquid) and form of precipitation at the First Order stations. Although these observations were lacking at Tupper Lake, the cooperative observer was thoughtful enough to document each storm with notes listing the times of occurrence of rain when both liquid and frozen precipitation occurred. Thus we were able to reject storms which included both rain and snow. We are therefore confident that the ratios determined in this study represent precipitation in the form of snow or other frozen hydrometeors. We see no value in relating the liquid measurement to the snowfall yield of a given storm (snow/water content ratio) when a portion of the liquid equivalent reached the ground in an unfrozen form.

The winter (snowfall) season was divided into three portions in order to determine whether the water content of early or late season snows differed appreciably from that of mid season storms. In a somewhat arbitrary manner the period of October through December 15 was taken as early winter. March 1st to the end of the snowfall season was designated as late winter, thereby leaving the interval from December 16 through the month of February as the mid portion of the winter season.

In the discussion of results to follow it should be remembered that the value of the snow/water content ratio (hereafter called the snow/water ratio) varies directly with the dryness of the snow. Conversely, the smaller the ratio the more dense, heavier or wetter is the snow.

Results and Discussion

The mean snow/water ratio for all storms in 12 winter seasons is given in Table 1 for each station.

Of the regions investigated the Southern Plateau has the driest snows, as represented by a very high snow/water ratio of 19.9 at Binghamton. The hilly terrain of

south central New York is subject to frequent, and occasionally substantial, snowfalls of the instability or flurry type which occur with prevailing winds between 270 and 360 degrees. Relatively, dry, light weight snows are also characteristic of the Syracuse area where the mean ratio was determined to be 18.8. The plain to the southeastern and eastern lee of Lake Ontario, in which Syracuse is a central point, is subject to much snowfall coming from the northwesterly quadrant, in off the Lake. Such snows are usually quite dry, lightweight and low in water content.

Table 1. Mean snow/water content ratio of all snowstorms sampled at each of 6 different geographical points in New York State. Period of record: 1951-52 through 1962-63.

Station	Elev. (ft.)	12-yr. Mean Snowfall (in.)	No. Snow Storms Sampled	Mean Ratio Snow/Water Content*
Buffalo	695	98	286	13.5
Syracuse	420	111	313	18.8
Binghamton	1590	88	297	19.9
Tupper Lake	1700	98	338	17.0
Albany	275	63	162	12.8
New York (LGA)	15	26	71	10.0

*Ratio expressed as inches of snow to yield 1.00 inch of liquid water

The Adirondack region of northern New York is interesting with respect to the water content of new snow. A survey of 338 storms at Tupper Lake yielded a mean ratio of 17.0. Snows in this second mountainous, high elevation region of the State were found to be somewhat heavier in water content on the average than those in the Southern Plateau. This was a result opposite to that which we expected to find. It appears that factors influencing the water content of snowfall are rather complicated as they affect the Adirondacks. The region on the whole is favored by a dry, continental-like winter climate with relatively little influence from lake-effect weather. However, under certain synoptic situations, moist air masses from a southerly direction flow aloft into the region.

Snowfall density was found to be very similar between the Hudson River Valley and Lake Erie regions. A sample of 162 snow storms at Albany resulted in a mean ratio of 12.8, while a somewhat greater number of snows at Buffalo produced a mean of 13.5. The snow climate of the Hudson Valley is under considerable coastal or maritime influence, which, as suggested earlier, extends northward into the Adirondack region, but continental air masses are dominant. Buffalo and the lake plain of extreme western New York receives snowfall mostly from southerly or southwesterly flow ahead of continental storms with at least some trajectory across the waters of Lake Erie. Some snow occurs in northwesterly flow but amounts are considerably less than in the eastern Lake Ontario plain. Maritime influence off the Atlantic Ocean is minor in comparison to eastern regions of the State.

The coastal sector of New York State was the only one in this investigation where the snow/water ratio closely matched the commonly applied rule which assumes each 10 inches of snow will yield one inch of liquid equivalent. Snows in the New York City area showed a mean ratio of 10.0 and the great majority of storms deviated relatively little from this figure.

It is difficult, if not premature, to offer a complete explanation of the mean snow/water ratios just described for different regions of the State without a study

of relevant processes in the upper atmosphere. Flow patterns, temperature conditions, atmospheric stability and the availability of precipitable water in the upper air are obviously factors affecting the moisture content of snow reaching the ground. An investigation of these factors has yet to be undertaken.

One concluding remark in regards to the data for the six stations in Table 1. The statistical significance of the differences in the mean ratios has not been determined.

The mean snow/water ratio in each of three winter periods is presented in Table 2 for each station.

Table 2. Mean snow/water ratio during different portions of winter season at each of six points in New York State. Period of record: 1951-52 through 1962-63.

Portion of Winter*	Ratio of Snow/Water Content					
	Buffalo	Syracuse	Bing-hamton	Tupper Lake	Albany	New York (LGA)
EARLY (Oct. 1-Dec. 15)	11.5	19.2	22.2	17.4	16.6	8.8
MID (Dec. 16-Feb. 28)	15.5	19.8	21.4	17.8	12.8	10.3
LATE (Mar. 1-May 15)	9.6	15.1	14.3	11.2	10.6	10.0

Number of storms represented per station

Early Winter: From 25 to 75 upstate and 10 at New York City.
Mid Winter: From 100 to 200 upstate and 50 at New York City.
Late Winter: Similar number as in early winter.

Binghamton, Syracuse and Tupper Lake, the three stations with the driest snowfall, show a very similar mean ratio between snows of the early and mid portions of the winter. Both early and mid winter snows are somewhat drier (higher ratio) than the mean ratio found for all snowstorms at each of these stations. A mean ratio of more than 21:1 was determined for the Southern Plateau (Binghamton) region. Early and mid winter snows average close to 20:1 at Syracuse.

Snowfall at Albany appears to be much drier in the early winter than in the middle portion of the season. The ratio for November and early December snows was 16.6, well above the 12.8 average for mid season. Buffalo shows the reverse situation. Early season snows are appreciably wetter with a ratio of 11.5 in comparison with 15.5 for late December, January and February snowfall. The warmer temperatures of Lake Erie waters is very likely a factor in this difference. The differences between Albany and Buffalo for the same portion of the winter are striking in view of the similarity of the mean ratio for all snowstorms shown in Table 1.

The coastal section of New York State, like the Lake Erie Plain, experiences wetter, more dense snowfall in the early winter than in mid winter, although the difference is not appreciable. Unfortunately, the number of snowstorms occurring in 12 winter seasons totaled no more than about 10 each during the early and late portions of the winter. About 50 storms were found during mid winter, providing a more desirable sample size.

Late season snows were found to be the wettest at all stations except New York

City, where the mean ratio was virtually the same as in mid winter. The Great Lakes Plain, Southern Plateau and Adirondacks show a considerable decrease in mean ratio from mid to late winter snowstorms. Snows occurring in these regions in March and April are appreciably wetter and heavier than those during the coldest months. The Albany data indicate the Hudson River Valley to be a region of New York State where the snowfall tends to become more dense as the winter season progresses. The greater decrease in the mean ratio occurs from early to mid winter followed by another but a smaller decrease in the latter third of the season.

Around each of the mean snow/water ratios shown in Tables 1 and 2 there was considerable variation, as well as a wide range among the individual snowstorms within the station sample. To provide some information on the range of ratios encountered the data in Tables 3 and 4 are presented. These data represent the upper limit of the ratios found for the wettest 20 percent of storms in our sample (Table 3) and the lower limit for the driest 20 percent of storms (Table 4). In other words, 60 percent of the storms per portion of the winter per station had a range of snow/water ratios between these two limits.

Table 3. Upper limit of snow/water ratio in WETTEST (heaviest) 20% of storms. Variations among six points in New York State during entire and portions of winter season. Period of record: 1951-52 through 1962-63.

Portion of Winter	Ratio Limit of WETTEST 20% of Storms					
	Buffalo	Syracuse	Bing-hamton	Tupper Lake	Albany	New York (LGA)
EARLY (Oct. 1-Dec. 15)	8.3	12.4	10.3	9.7	7.8	7.3
MID (Dec. 16-Feb. 28)	9.6	12.3	12.1	10.0	8.6	8.8
LATE (Mar. 1-May 15)	7.3	9.7	8.5	7.7	6.7	6.9
ENTIRE (Oct. 1-May 15)	8.3	12.4	11.4	9.5	7.5	7.4

Considering the station data for the entire winter, the bottom row of figures in Table 3, it may be seen that a small fraction of snowstorms have ratios of about 7.5 or lower in the Coastal and Hudson Valley regions and 8.3 or lower near Lake Erie. In the regions represented by Syracuse and Binghamton only 20 percent of the snows had a ratio of 12:1 or lower.

Late winter snows in 20 percent of storms sampled showed a ratio of less than 10 even in the regions of driest snowfall. At Buffalo, Albany and New York City two out of ten late winter snows had ratios of about 7 or less. The data in Table 3 provide further evidence of the greater water content of snowstorms that occur during the latter two months of the season.

Corresponding data at the dry end of the scale, tabulated in the bottom row of Table 4, reveals a wide spread in the ratio limit among the six stations. Twenty percent of the snows at New York City have a ratio of about 12 or higher but for the same proportion of snows at Albany the ratio limit increases to 15.3. In the central and northern interior of the State where some 300 storms were sampled per station about 60 of them had ratios equal to or greater than 22.5 in the Adirondacks up to at least 27.5 at Binghamton. Such dry, snowstorms were comprised largely of those yielding less than three inches of snow and less than 0.1 inch of liquid in the melt.

Attention is called to the ratios listed in Table 4 for the early and mid portions of the winter at Binghamton, Syracuse and Tupper Lake and for the early winter

at Albany. Ratios of at least 25 were determined for 20 percent of the storms at each of these stations with a very dry threshold of 35 at Binghamton.

Table 4. Lower limit of snow/water ratio in DRIEST (lightest) 20% of storms. Variations among six points in New York State during entire and portions of winter season. Period of record: 1951-52 through 1962-63.

Portion of Winter	Ratio Limit of DRIEST 20% of Storms					
	Buffalo	Syracuse	Bing-hamton	Tupper Lake	Albany	New York (LGA)
EARLY (Oct. 1-Dec. 15)	15.0	24.4	35.0	25.0	25.7	10.0
MID (Dec. 16-Feb. 28)	20.0	25.3	29.4	25.0	15.3	12.5
LATE (Mar. 1-May 15)	12.3	19.1	20.0	15.0	14.3	12.0
ENTIRE (Oct. 1-May 15)	17.5	24.3	27.5	22.5	15.3	11.9

The extreme wettest ratio of any single snowstorm was near 4:1 for each of the six stations. The extreme driest ratio varied from 17 at New York City up to no less than 60 at the upstate stations. One snowfall at Tupper Lake had a ratio of snow to water of 100:1, while at Binghamton one snow was so dry as to require 80 inches to yield one inch of water.

Table 5 lists some of the most interesting data of this study, namely, the mean snow/water content ratio of storms in each of the 12 winters at the individual stations. A wide variation from season to season is clearly evident at each station. For the sake of brevity let us confine a discussion of these results to one or two stations.

Table 5. Mean ratio of snow/water content in each winter season from 1951-52 through 1962-63 at six stations in New York State.

Winter Season	Mean Ratio Snow/Water Content					
	Buffalo	Syracuse	Bing-hamton	Tupper Lake	Albany	New York (LGA)
1951-52	14.4	15.7	17.7	12.6	11.4	6.6
1952-53	13.6	16.3	17.8	18.6	11.3	11.3
1953-54	14.1	16.8	20.5	17.5	15.0	10.2
1954-55	11.8	20.1	23.1	13.1	8.9	11.1
1955-56	9.8	19.9	18.2	22.6	11.9	10.3
1956-57	12.1	18.1	18.3	16.7	15.0	9.8
1957-58	11.1	23.1	22.2	16.1	13.4	9.7
1958-59	11.4	17.8	22.2	15.4	18.0	10.4
1959-60	9.9	16.9	18.1	15.6	11.1	10.5
1960-61	15.7	18.8	18.6	15.0	11.7	10.6
1961-62	22.0	14.3	23.9	20.7	11.1	9.6
1962-63	20.2	19.6	21.3	18.1	12.4	9.6
12-Season Mean	13.8	18.1	20.2	16.8	12.6	10.0

Buffalo had wet, dense snows in the winters of 1955-56 and 1959-60 with a total of 27 storms each winter yielding mean ratios of 9.8 and 9.9 respectively. The season of 1961-62 was one of dry snowfall as 19 snowstorms produced a mean ratio of 22.0. Thus, in a dozen winters the snow/water ratio has had a spread of some 12 units. In a majority of winters the ratio at Buffalo varies from about 11 to slightly over 14.

Looking at seasonal variation in a region of dry snows Tupper Lake had a mean ratio as low as 12.6 from 22 storms in 1951-52. At the other extreme was the season of 1955-56 in which a mean ratio of 22.6 resulted from a total of 27 snowstorms. The seasonal mean at Tupper Lake is seen to range between 15.5 and 18.5 in most winters.

There appeared to be little or no correlation between the mean seasonal snow/water ratio and total seasonal snowfall at any of the stations during this 12-year period.

It may be noted that the snows of the winter of 1951-52 were unusually wet over New York State. The seasonal ratio for that winter was less than the respective 12-season mean at five of the six stations. The cold winter of 1962-63 produced drier than usual snowfall in western, northern and central New York but in the Hudson Valley and Coastal regions the snows were about average in water content.

Table 6. Mean ratio of snow/water content at Buffalo and Albany, N. Y.: A comparison between each winter season from 1951-52 through 1962-63.

Winter	Mean Ratio Snow/Water	
	Buffalo	Albany
1951-52	14.4	11.4
1952-53	13.6	11.3
1953-54	14.1	15.0 d
1954-55	11.8	8.9 w
1955-56	9.8 w	11.9
1956-57	12.1	15.0 d
1957-58	11.1 w	13.4
1958-59	11.4 w	18.0 d
1959-60	9.9 w	11.1 w
1960-61	15.7 d	11.7
1961-62	22.0 d	11.1 w
1962-63	20.2 d	12.4
12-Season Mean	13.8	12.6

w = Season's ratio wet or heavy compared with 12-season mean at station

d = Season's ratio dry or light compared with 12-season mean at station

Another interesting aspect of the data in Table 5 is a comparison of the ratios at two different stations in the same winter. The data at Buffalo and Albany serve as a good example and are separately tabulated in Table 6. These two stations are at opposite ends of the State and their snow climates are under somewhat differing influences. In the seasons of 1961-62 and 1962-63 the snowfall at Buffalo was much

drier than the 12-season mean but at Albany the mean ratios showed wetter than usual snows in 1961-62 and average water content in 1962-63. A reverse situation occurred in the winter of 1958-59. Albany had the driest snowfall that season of any in the 12-year period of record with a mean ratio of 18.0. Buffalo had wetter than usual snow that same season with the mean of 11.4 or well below the 13.8 mean for the 12 winters. The season of 1959-60 is a case where both stations received snowfall with a water content greater than usual.

It may also be noted that the winter of 1955-56 which resulted in the heavy, wet snows at Buffalo (mean ratio of 9.8) was also the same winter which produced the driest snows of the 12-winter period at Tupper Lake (mean ratio of 22.6). Other pairs of stations show similar differences in the water content of the snowfall within the same season.

Why should the snowfall be characteristically dry in one region of the State during the same winter in which another region experiences relatively wet, dense snowfall? A study of mean upper air contour charts (700-mb., 500-mb., etc.) for the period in question and their companion maps of height anomalies seems clearly indicated to obtain some answers to this question.

Summary and Conclusions

The water content of snowfall has been investigated in six different regions of New York State using the published climatological record from a representative weather station in each. Snowstorms yielding at least one inch of snow and those in which the liquid precipitation measurement was entirely derived from snow or sleet were considered. Storms were rejected in which rain was mixed with snow. Twelve winter seasons, 1951-52 through 1962-63 were surveyed. The total number of qualifying snowstorms varied from 70 in the coastal region up to 300 or more in interior New York State. The winter season was divided into three portions in order to characterize early, mid and late winter snowfall. The water content in this study is expressed as a ratio of snow/water, or the inches of snow required to yield one inch of liquid water.

The mean snow/water ratio was found to range from 10.0 in coastal New York State up to 17.0 in the Adirondacks, 18.8 in the eastern Lake Ontario Plain and 19.9 in the Southern Plateau. Intermediate were mean ratios of 12.8 in the Hudson Valley and 13.5 in the Lake Erie Plain.

The commonly applied rule which assumes each 10 inches of snow is equivalent to one inch of liquid water was shown to be applicable only in coastal areas of this State. The 10:1 rule is not an accurate one in areas like upstate New York except possibly for snowstorms in which a considerable portion of the precipitation fell in rain or liquid form. A generally applied ratio of about 13:1 is suggested for areas removed from the coast but still under some maritime influence. Interior areas where the maritime influence is minor a ratio of about 18:1 should be used for estimation purposes.

Snows occurring in late season (March and April) were found to have appreciably higher water content (low ratio) than those of early or mid winter in all but the coastal region of the State. Early and mid winter snowfall is relatively dry (high ratio) in upstate New York, especially in central and northern regions.

At each station there was considerable variation in the ratios of individual snowstorms. Extreme ratios for single storms ranged from about 4 in the wettest up to 17 in the driest snow at New York City and up to at least 60 at upstate stations. Data are presented showing the ratio limits for the wettest and driest 20 percent of snows at each station.

The mean seasonal snow/water ratio has a wide variation from season to season at each of the stations. Buffalo, for example, showed a range of from 9.8 to 22.0 over a 12-year period. The mean seasonal ratio was found to have little or no correlation with the total seasonal snowfall.

Within the same snowfall season one station may have unusually dry snows for that region while a second station in another part of the State observes snowfall which are relatively wet. In another season the same two stations show the reverse situation.

The initial results of this study, which have been herein reported, clearly indicate that several other paths of investigation need to be pursued in order to fully analyze and explain the water content of snowfall which occurs within and among various regions of New York State.