AN OBJECTIVE FORECAST OF THE SNOW-MELT HYDROGRAPH IN THE PLAINS REGION

By

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SNOW MELT FORECAST PROCEDURE

1. Introduction:

The Weather Bureau is frequently called upon to provide an advisory or operational forecast for areas where very little observed data can be obtained. Such is the plight of the hydrologist, who, armed with a series of water equivalent measurements and a three day temperature forecast, tends to feel that snow melt flood forecasting falls entirely within the realm of experienced judgment.

The purpose of this paper is not to minimize the importance of experienced judgment that incorporates both climatology and geography, but to emphasize the objective hydrologic tools that can be employed to evaluate snow melt potential as related to flood forecasting.

There are many meteorological factors that affect the rate of snow melt: temperature, relative humidity, albedo, wind, degree of cloudiness, radiation and heat conduction from the underlying soil. However, for a day-to-day objective snow melt forecast procedure, temperature is the most readily obtained meteorological element and can be forecast with the greatest degree of accuracy. Therefore, temperature is the only meteorological parameter considered in this paper.

Snow data, both depth and water equivalent, fall in the category of observed data. The significance and areal extent of these data can be determined by field surveys or an adequate precipitation reporting network.

2. Temperature Index:

The utilization of temperature as a parameter of snow melt can be considered in several ways. As:

2.1 Degree days $= \frac{T\ max + T\ min}{2} - 32°$

2.2 Degree days - After Snyder 3/ - From chart based on the daily maximum temperature and the average of the preceding and following minimum temperatures. Chart 1.

2.3 Max Temp. Index as T max - 32°

2.4 Max. Temp. Index as T max - 28°

Examination of observed day-to-day water equivalent measurements in the mid-west during March, 1958, 1960 and 1961 indicate the T (max-32) index will generally reflect the water equivalent change in a snow pack on a day-to-day basis.

3. M = Melt in inches (per degree of T max - 32)

The value for M has been chosen empirically. Examination of ob erved day-to-day water equivalent depletions in the mid-west plains indicate M = .06 during March for a snow pack in the melt stage, when free water is being released to the ground, as well as in the ripening stage. The value of M should vary with season as illustrated in Chart 2.

4. Snow Melt Computation (when M = .06)

In order to establish a procedure for snow melt computation the following assumptions were made:

(a) That 10% of the water equivalent measurement can exist as free water in the pack and represents the ripening of the snow pack.

1/ U. S. Weather Bureau, Kansas City, Missouri.

2/ U. S. Weather Bureau, Kansas City, Missouri.

3/ "Report of Cooperative Hydrologic Investigations," p. 94, Commonwealth of Pennsylvania, August, 1939 (mimeo).

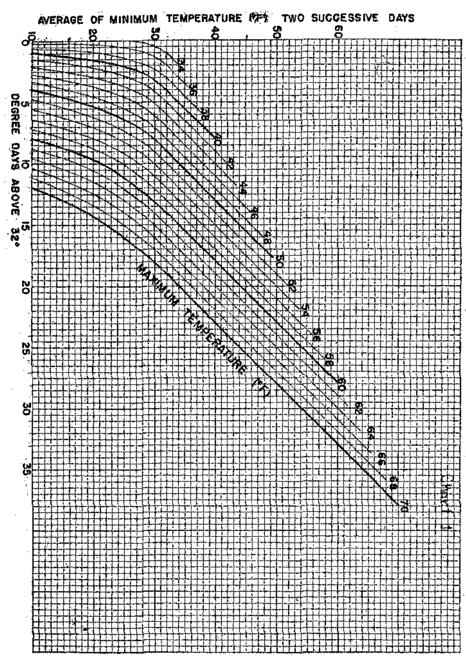


Chart 1

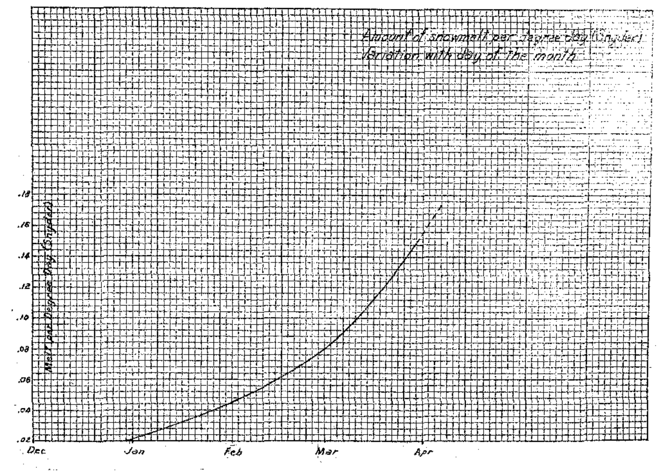


Chart 2

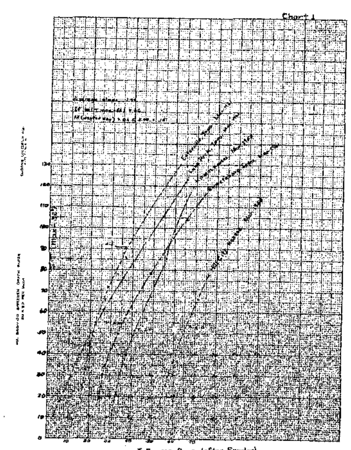


Chart 3

TABLE V

MARCH 1950 DAILY SNOW FREE RUNOFF COMPUTATIONS
BASED ON MAX - 32 x M = .05
*BASED ON DEGREE DAYS AFTER SNYDER M = .15

STATION	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1	2	TOTAL	W.E. 3/18
Trenton, Mo.		.03	.02	.15	.07	.12	.05	.05	.42	.01							1.71	3.50
*									.09	1.05	.02						1.98	
Chillicothe, Mo.					.02	.15	.10	.08	.25	1.28	.15						1.95	4.00
*										1.40	1.10						2.30	
Tarkio, Mo.				.14	.05	.15	0	.12	.48	.77	0	.14			.15		2.06	4.00
*									.09	1.46	.62	.14			.15		2.45	
Maryville, Mo.							.01		.03	.34	1.01	.76	.15		.06		2.36	4.00
*										.06	1.05	.82	.15		.06		2.84	
Bethany, Mo.					.02	.04	.03	.06	.10	1.19	.67		.45		.07		2.09	4.50
*									.02	1.15	1.27		.45		.05		2.67	
Grant City, Mo.					.03	.07	0	.07	.34	.43	.94		.37	.02	.01		2.73	4.50
*									.05	1.35	1.29		.32	.02	.01		2.96	
Albany, Mo.				.10	.07	.35	.00	.15	.54	.49	0	.26	.04		.02		2.21	4.00
*									.18	1.55	.39	.26	.06		.03		2.65	
Conception, Mo.						.04	.06		.25	1.10	.94		.72		.04		2.15	3.50
*										1.08	.68		.32		.04		2.12	
Amity, Mo.					.03	.10	.08	.02	.40	1.19	.73		.35		.04		2.40	4.50
*									.07	1.85	1.20		.34		.01		2.85	
Hamilton, Mo.				.01	0	.06	0	.09	.33	1.26			.10		.06		1.89	3.50
*										1.70			.10		.04		1.80	
Brookfield, Mo.				.07	.06	.21	.05	0	.47	.76							1.65	3.50
*									.15	1.70	.05						1.93	
Unionville, Mo.						.03	0	0	.27	.72	1.30		.18		.10		2.80	4.50
*										.70	1.70		.18		.10		2.68	
Columbia, Mo.					.01	.19	.09	.10	.84	.15			.04				1.42	3.00
Kirksville, Mo.									.01	.79	1.50	1.05			.15		3.50	6.00
*										.20	2.15	1.45			.15		3.80	
Bedford, Iowa						.02	0	0	.24	.92	1.20	1.10	0		.10		3.58	6.00
*										1.00	1.70	.85			.10		3.66	
Greenfield, Iowa										.10	.65	.92	.40	.62	.06		2.78	5.00
*										.12	1.35	1.35	.81		.06		3.42	
Corning, Iowa									.02	.41	.72	.73	.34	.40	.02	.04	3.08	5.50
*										.30	1.20	1.40	.41		.02		3.33	
Creston, Iowa										.34	.80	1.10	.34	.22	.09		2.59	5.50
*										.05	.60	1.70	.34	.36			3.23	
Mt. Ayr, Iowa									.01	.40	1.09	1.18	.69				3.32	5.80
*										.20	1.52	1.50					3.22	
Osceola, Iowa				.04	.03	.07			.34	.70	.91	.00	.19		.09		2.32	4.00
*										.65	1.65	1.06	.19		.09		3.44	
Chariton, Iowa				.02	.06	.08	.04	.05	.34	.76	1.19	.15	.45		.15		3.25	5.00
*										.48	1.70	1.05	.45		.15		3.77	
Lamoni, Iowa									0	.34	.84	1.60	.34	.92	.07		3.81	4.00
*										.05	1.05	1.85	.60	.34	.07		3.56	
Brookfield, Iowa				.07	.06	.21	.06		.47	.76							1.65	3.50
*									.18	1.70	.05						1.93	
Centerville, Iowa									.11	.74	.71	1.50	.68		.05		4.02	6.00
*										.50	1.25	1.75	.45		.05		3.97	
Corydon, Iowa						.01			.19	.76	.84	1.25	.15		.07		3.47	6.00
*										.16	1.52	1.52	.10		.07		3.42	

Chart 4

(b) That, when this 10% of the snow pack is forecast to exist as free water, the pack is ripened and release will begin in proportion to M. At this point melt is defined as the release from the pack and is available for infiltration into the soil or basin runoff.

Employing M as .06, daily melts are computed as shown below:

Day	1	2	3	4	5
W.E.	5.00	-	-	-	4.60
T max	28	34	37	40	50
Melt	0	.12	.30	.48	1.08
Initial Free Water	0	.12	.42	.90	-
Total Ripened Free Water (10%)	.50			.50	
Release from Pack				.40	1.08

5. Snow Melt Computation (degree day)

Chart 3 reflects the individual observed station relationship between T max - 32 index and degree days (after Snyder). Note that the Snyder degree day method of computations tend to delay computed snow pack ripening. During active melt periods the average slope is roughly 2.5 with a resultant degree day M = .15". All computation of station runoff in the succeeding portions of this paper assume both a M = .06 melt per T (max - 32) and M = .15" melt per degree day (after Snyder) and illustrate a March situation. See Chart 4.

This method of estimating the depletion of a "plains" snow pack agrees favorably with observed data. Note Chart 5, comparison for forecast melt versus observed day-to-day snow depth depletion.

6. Basin Runoff Computation

The conversion of daily snow melt release to basin runoff is executed by use of the basin rainfall-runoff relation. In this consideration the initial API must be determined giving due regard to the soil condition prior to the accumulating snowfall. In much of Kansas, Nebraska and the Dakotas, the initial API will be zero. Throughout other areas of the midwest, a frozen ground condition may be reflected in a year-to-year rainfall-runoff analysis. The API = 0 and frozen ground represent the extremes of possible basin runoff. Survey parties and the snowfall observer can help the forecaster in estimating an initial API value.

7. Summary of Procedures.

This procedure is empirically fitted to observed day-to-day water equivalent or snow depth measurements (using estimated density). No effort has been made to correlate with any other meteorological elements. Many of the elements are inter-correlated and forecast errors may either accumulate or compensate.

SNOW MELT UNIT HYDROGRAPH

1. Introduction:

Although the unit hydrograph has not proven to be satisfactory in forecasting the snow melt hydrograph, the snow melt unit hydrograph developed in this paper is fashioned on the unit graph approach, but derived from the diurnal variations observed on the typical snow melt hydrograph. This snow melt unit hydrograph development has been restricted to drainage basins where observed diurnal peak time is less than 24 hours.

2. Snow Melt Unit Hydrograph Development:

Separation of daily snow melt runoff hydrographs can readily be accomplished in hydrographs with marked diurnal variations. See Chart 6. Incremental melt graphs of Chart 6 are adjusted to represent one inch of snow melt runoff as defined in unit hydrograph development. See Chart 7.

This type of analysis assumes:

a. An even melt over the runoff basin.

b. At temperatures below 32°, melt is halted.

c. That the runoff peak is controlled by the diurnal melt period and <u>not</u> the area center of mass of the basin. Thus, all diurnal peaks occur within the period of succeeding minimum temperatures. Chart 8 shows diurnal peak times vary with the size of the drainage area in the area of study.

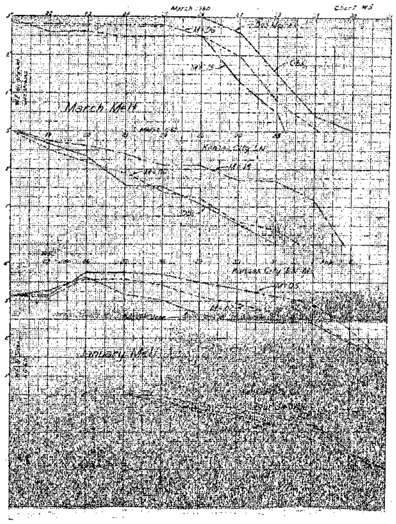


Chart 5

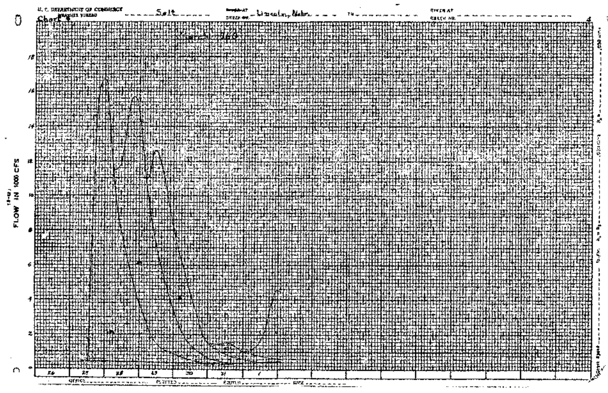


Chart 6

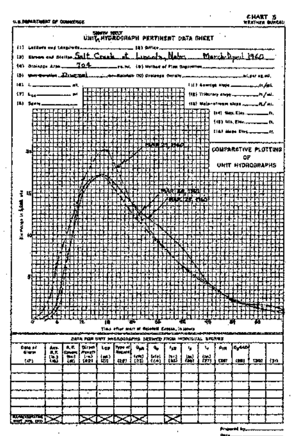


Chart 7

3. Snow Melt Unit Peak Per Square Mile Chart:

This relation, see Chart 9, is a very useful tool in melt unit graph development. The points on this chart should fit a family of curves defined by the physical parameters of the basin. These parameters would influence a similar chart developed with unit hydrograph data and their inclusion might have improved the simpler relation used in this study. A resulting family of curves could be incorporated with a term such as $\frac{(L \times L_{ca})^{\frac{1}{2}}}{S}$, where L = Length of basin, L_{ca} is the center of mass, and S is the basin slope.

This chart enables the peak CFS per square mile to be approximated for large drainage areas where diurnal melt hydrographs are more or less obscrued in the observed flood hydrograph. Here again, the time to peak of the snythetic snow melt unit graph is assumed to be less than 24 hours as defined by Chart 8.

4. Use of Snow Melt Unit Graph:

On a forecast basis snow melt release is generally considered to begin at noon, and the diurnal peak to occur between 9 p.m. and 6 a.m., (9 to 18 hours).

The size of the drainage areas considered is restricted only by the storage characteristics of the particular stream. If the unit hydrograph analysis is satisfactory for a given basin, the snow melt unit graphs are also applicable. See Chart 10.

In basins where valley or channel storage is a dominant factor, a snow melt hydrograph may be approximated utilizing a peak CFS - time of travel curve or a more sophisticated approach such as Kohler's L and K curves. It is assumed that the peak CFS per square mile chart defines the K in the Kohler L and K type of routing. L, or approximate travel time, can then be applied to the forecast snow melt hydrograph as illustrated in Chart 11 and Chart 12 to obtain the final forecast.

5. Summary of Procedure:

Snow melt unit graphs are developed from diurnal melt hydrographs and extended to larger basins by use of the peak CFS/square mile chart. Snow melt unit graphs peak in 9 to 18 hours. Snow melt forecasts can be made for large basins by employing the existing travel time or lag curves.

GENERAL SUMMARY

This paper presents a simple approach to computing daily snow melt runoff and applying runoff to snow melt unit graphs. Forecast temperature is the only meteorological parameter required to make daily snow melt <u>runoff</u> forecasts.

During the collection and study of the presented data it has been found that a maximum temperature index may more nearly forecast the visible depletion of the snow cover and observed daily changes in water equivalent samples. However, the degree day approach provides a more consistently reliable volume forecast of the snow melt hydrograph. Since the snow samples are most often taken in the vicinity of the precipitation gage where the exposure is unobstructed by trees, structures or slopes this result should not be unexpected.

While it may be said that this approach over-simplifies the general snow melt problem, it should be pointed out that the analysis follows the general procedures used in rainfall-runoff and unit hydrograph development and allows the maximum use of temperature forecasts.

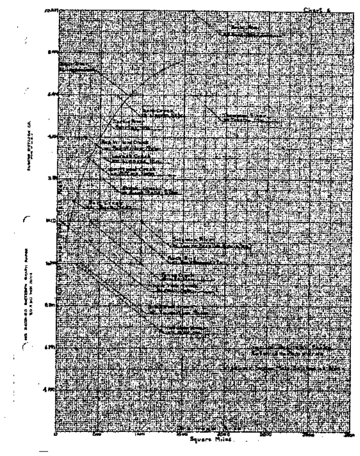


Chart 8

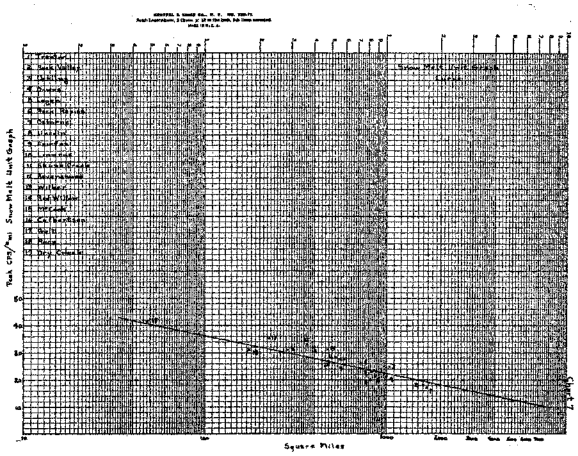
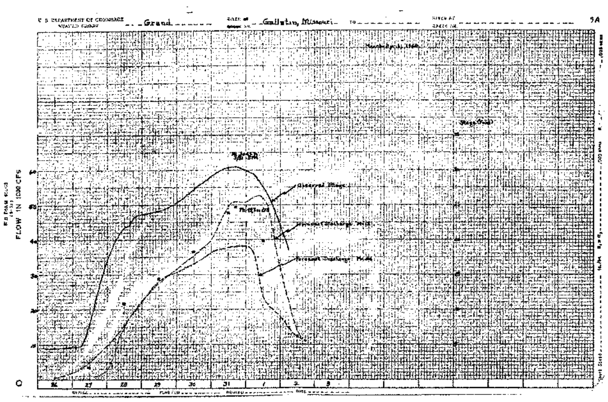


Chart 9



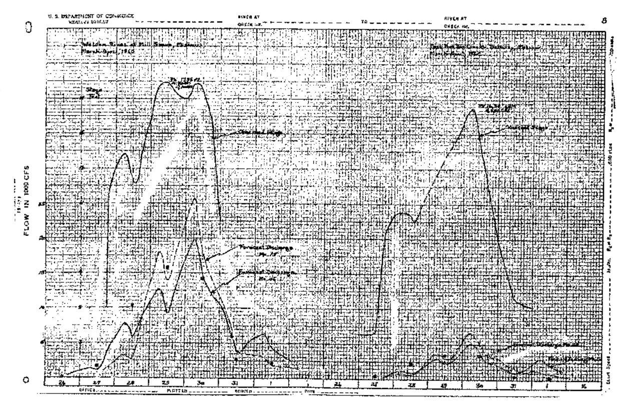


Chart 10

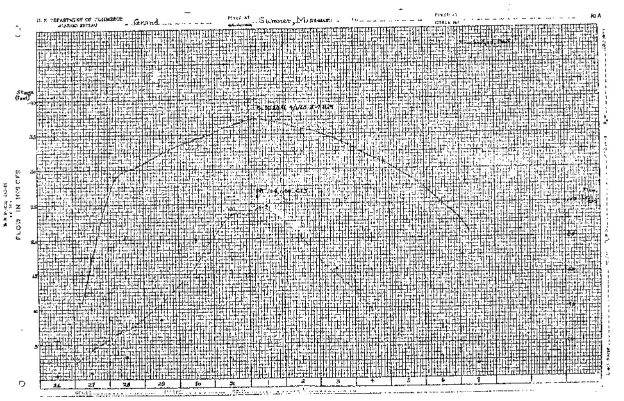


Chart 12