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MINOR FLOODING ON THE MILK RIVER AFTER AN EXTREME WINTER IN NORTHEAST MONTANA

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1. INTRODUCTION

During the winter of 2003-04 many areas in northeast Montana received record snowfall with extremely high water content. For example, Glasgow, Montana, measured about 180 cm (70.7 in) of snow, more than double the seasonal average snowfall (76 cm; 30 in); surpassing the previous record of 155 cm (60.9 in) during the winter of 1951-52.

The snow water equivalents also were unusually high. Measured values of snow water equivalent (SWE) in many areas were higher than the accumulated precipitation total. For example, between the last week of October and the end of January, Glasgow reported a total of 6.8 cm (2.7 in) of liquid equivalent precipitation. However, at the end of January 2004, Glasgow had a SWE of 15.2 cm (6 in) with 61 cm (24 in) of snow on the ground. This was likely due to the difficulty in collecting snow into precipitation gauges.

In years where more than 112 cm (44 in) of snow fell in Glasgow about 60% of the time the Milk River in Glasgow had flooding with flood stages above 9 m (30 ft) or at least 1.5 m above flood stage (7.6 m or 25 ft). This included the spring of 1952 when the flood of record occurred on the Milk River at Glasgow (10.03 m; 32.9 ft). Given record snowfall on the ground by the end of January, the staff at NOAA's National Weather Service Forecast Office in Glasgow, Montana, community leaders, and residents along the Milk River began preparing for potential major flooding.

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In late-February, the Missouri Basin River Forecast Center issued a spring outlook with a potential crest in Glasgow of 9.75 m (32 ft). A number of factors, including extensive snow water equivalent measurements were used in the model simulation resulting in this prediction.

In fact, the river crested at just below 8 m (25.6 ft) at Glasgow, slightly above flood stage (7.62 m; 25 ft). The Milk River went above flood stage in March (2004) in Glasgow and Nashua (a crest of 6.56 m, 21.5 ft. with the flood stage of 6.1 m (20 ft).

This paper will focus on the lower Milk River (Fig. 1), near Glasgow, and compare the winter and spring hydrology issues of 1951-52 and 2003-4. Also included is a discussion of some sensitivities river modeling in this region.

2. REVIEW OF WINTER 2003-2004

Northeast Montana experienced unusually warm temperatures in September and early October 2003. October was generally dry until the last few days in the month when an arctic cold front dropped south across the area. Temperatures dropped to about 11 C° (20 F°) below average behind the front with widespread snowfall north of the Missouri River in northeast Montana. Snowfall amounts were generally on the order of a few centimeters, but up to 15 cm (6 inches) of heavy wet snow was reported at Opheim, in northern Valley County, and Malta in central Phillips County (Fig. 1). Strong winds of up to 20 m/s (40 mph) created snow drifts up to 1.5 m (5 ft) in northern Valley County.

With the ground covered with snow, November began as the coldest on record with temperatures

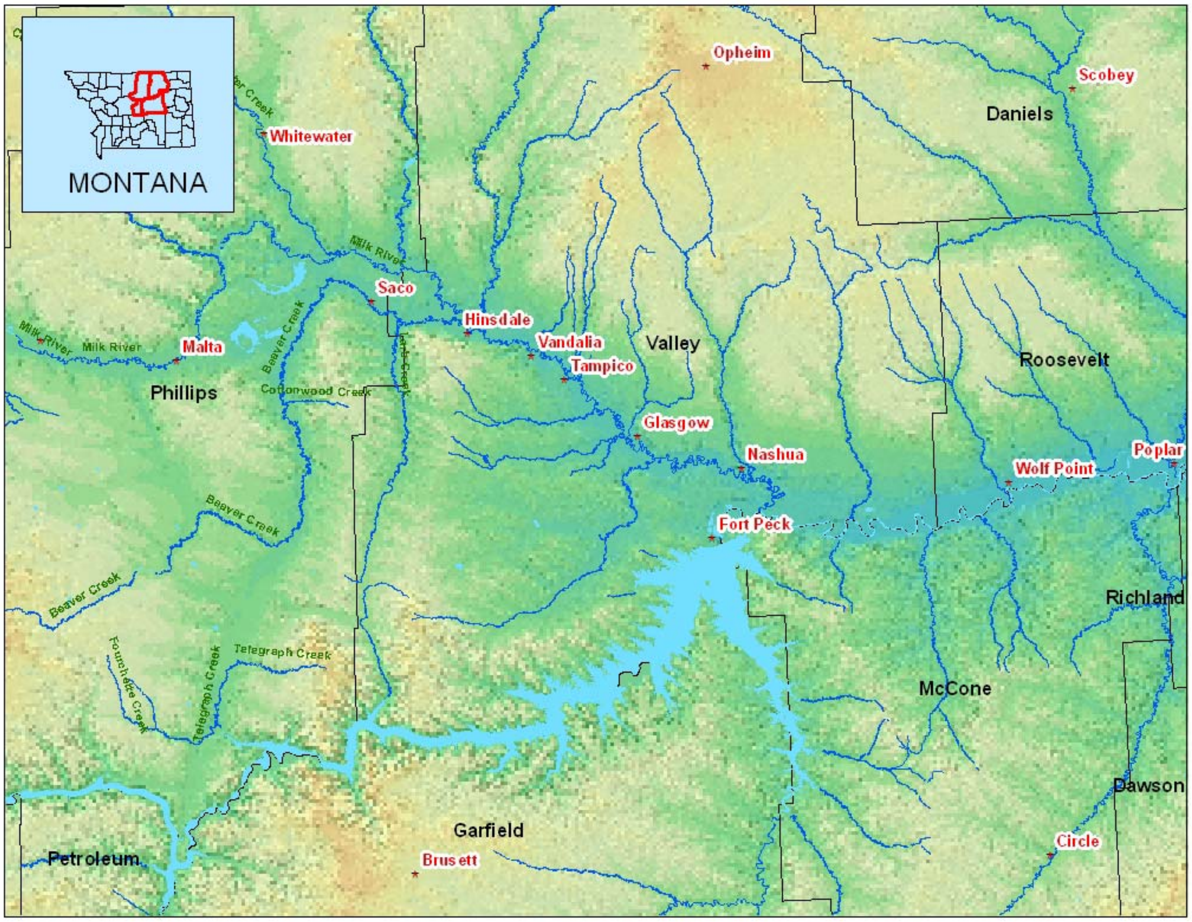

Figure 1. Topography map of the Milk River basin in northeast Montana. The Milk River flows to the east through Malta to Nashua before entering the Missouri River near Fort Peck. The county names are in black and the town names are in red.

averaging more than 10 C° (18 F°) below normal the first 10 days of the month. The rest of November featured alternating periods of warmer and colder than normal temperatures. Snowfall was above normal, and ranged from about 13 to 25 cm (5 to 10 in) across most of the Missouri and Milk River Basins. Due to combination of frequent episodes of snow and cold temperatures, snow remained on the ground most of the month.

The following month, December, was milder than average with infrequent intrusions of arctic air and little snowfall until late in the month when a major winter storm affected all of northeast Montana. The storm produced up to 76 cm (30 in) of snowfall, eclipsing many snowfall records. Some of the highest snowfall totals were recorded in Phillips, Western Valley, Northern Petroleum, and Western Garfield counties where 45 to 76 cm (18 to 30 in) amounts were common. Lesser amounts were found across Roosevelt and Sheridan counties where amounts were generally 20 cm (8 in) or less. Arctic air entered the region in the wake of the storm until end the month. Most of the area across the Milk and Missouri River basins ended the month of December with 30 to 60 cm (1 to 2 ft) of snow on the ground. Temperatures were unusually mild during the storm which led to high water contents.

January was a much colder than average month with intrusions of arctic air during the first and last weeks of the month. Warm and moist pacific air overran an arctic boundary during the last week of the month and produced 30 to 90 cm (1 to 3 ft) of snow across the Milk and Missouri River Basin. The heaviest snowfall occurred in Valley County. The snowfall was accompanied by strong wind at times which produced considerable blowing and drifting snow. The winds, during the last week of January, affected the measurement of liquid equivalent precipitation. For instance, Glasgow reported an increase of 9.4 cm (3.7 inch) in snow water equivalent from 23 January to 30 January while reporting 1.9 cm (0.78 inch) of liquid equivalent precipitation. The snow on the ground on 23 January was reported as 25 cm (10 inch) deep with 5.8 cm (2.3 inch) of water equivalent. On 30 January, the snow depth was reported as 61 cm (24 inch) with 15 cm (6.0 inch) of SWE. The SWE measurements were supported by the National Operational Hydrologic Remote Sensing Center's (NOHRSC) Airborne Gamma Snow Survey (NOHRSC 2004) from early February.

Little additional snow fell in February, when snowfall was generally below average, although a blizzard affected the area on 10 February. Although the blizzard only produced a few centimeters of snow, strong wind produced considerable blowing and drifting of the record deep snow pack that was on the ground. February was a colder than average month mainly due to an arctic airmass that lingered into the first week of the month.

3. REVIEW OF SPRING 2004

March generally had near normal temperatures until the last week of the month when temperatures averaged 5 to 10 C° (10 to 20 F°) above normal. Snowfall was generally light, with almost all of the snowfall occurring during the first two weeks of the month. Combination of daytime temperatures above freezing and nighttime lows below freezing much of the month allowed a gradual melting of the deep snow pack, especially in areas north of the Milk River.

Significant runoff due to the snow melt began in the second week of March. Areas west and south of Glasgow with less snow had somewhat higher temperatures leading to significant runoff. River gages in the region were affected by ice, so it was difficult to distinguish between river rises due to increased flow and ice in the channel. Less flow was measured than the stages would indicate, based on the stage/discharge rating at a few locations, but significant runoff was occurring west of Glasgow where the SWE was lower. The initial snowmelt, south of the Milk River, pushed the river to 7.7 m (flood stage is 7.6 m) on 20 March 2004, see Fig. 2a. The streams to the south of the river had all been bank full or flooding for about 3 days earlier. The river began to recede as the streams south of the Milk also receded.

The extensive snow pack north of the Milk River, mainly in Valley County, kept the temperatures lower there for a longer period. The runoff west of Glasgow led to the expectations of significant runoff from the north and the Milk River would rise to above flood stage. It was clear by 25 March that the expected near record flood at Glasgow and Nashua would not occur because the melt and runoff from upstream and the southern tributaries had already passed. Although significant snow pack remained north and east of Glasgow, river flooding was not reported in the spring of 2004.

Another factor contributing to the decreased runoff from the north included several farmers and ranchers constructing small dams to divert water prior to its reaching the Milk River. This was observed in a number of locations; but, exact dimensions of the dams or volumetric measurements of the diverted water were not determined.

4. COMPARISON OF 2003-04 TO 1951-52

The fall of 1951 was colder and wetter than the fall of 2003. September and October of 1951 had 2.5 cm (1 inch) of liquid equivalent precipitation more than the same two months in 2003. The first snowfall, in 1951, occurred during the last week of September; but the snow melted in early October. The weather turned cold again in second half of October with frequent light snowfalls. Similar to 2003, the average temperature in November was below normal in 1951 [the average temperature was -2.7 °C (27.2 °F)], which is just below the normal average temperature (-2.3 °C or 27.9 °F). However, November 2003 was a much colder month (-6.5 °C or 20.3 °F) than average. In 1951 at the end of November, only a trace to a couple of centimeters (about an inch) of snow was on the ground in much of northeast Montana.

The winter of 1951-52 had temperatures below -18 C (zero F) everyday from 14 to 31 December 1951 in Glasgow and many other locations across northeast Montana (U.S. Dept. of Commerce 1952). Snowfall was frequent, and by the last day of December the snow pack was a few centimeters deep. January 1952 was a much colder than normal, with above average snowfall. Snow depths of over 30 cm (1 ft) were common by mid-late January, but a warm snap the last few days of the month caused snow depths to be reduced to 8 - 18 cm (3 - 7 in) across the Milk River basin by the last day of the month. February was the first month since May of 1951 to have

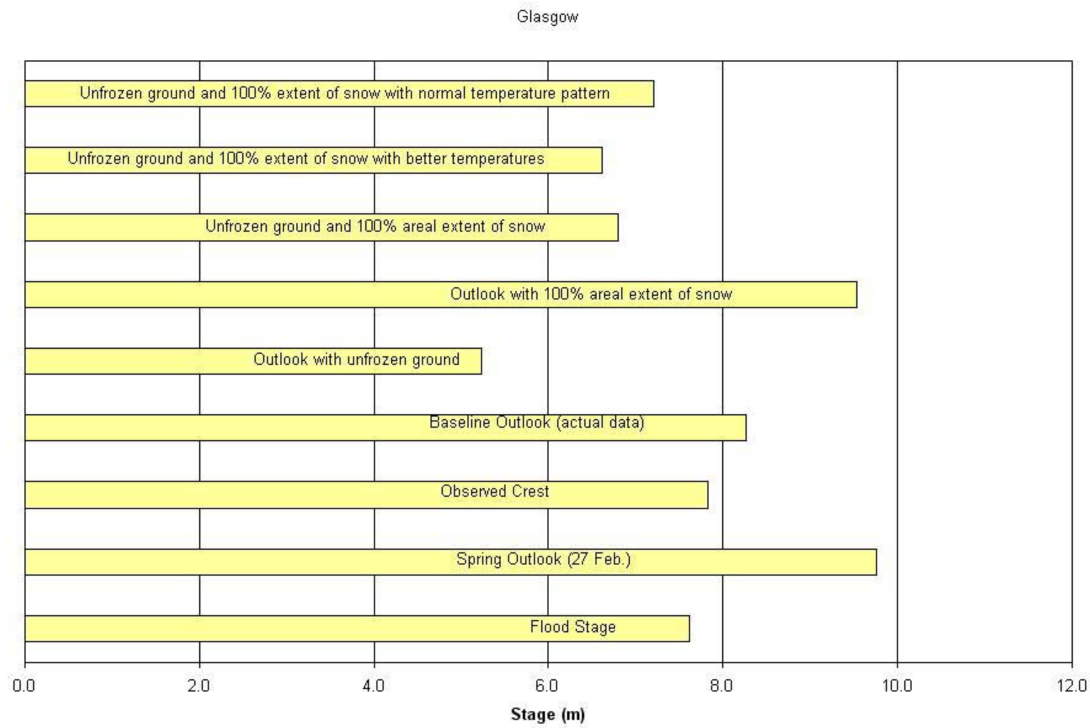

Figure 2a. Graphs showing the Flood Stage in meters, Spring Flood Outlook from 27 February, the observed crest of the Milk River, and the crest of the six different scenarios of the hydrologic model at Glasgow.

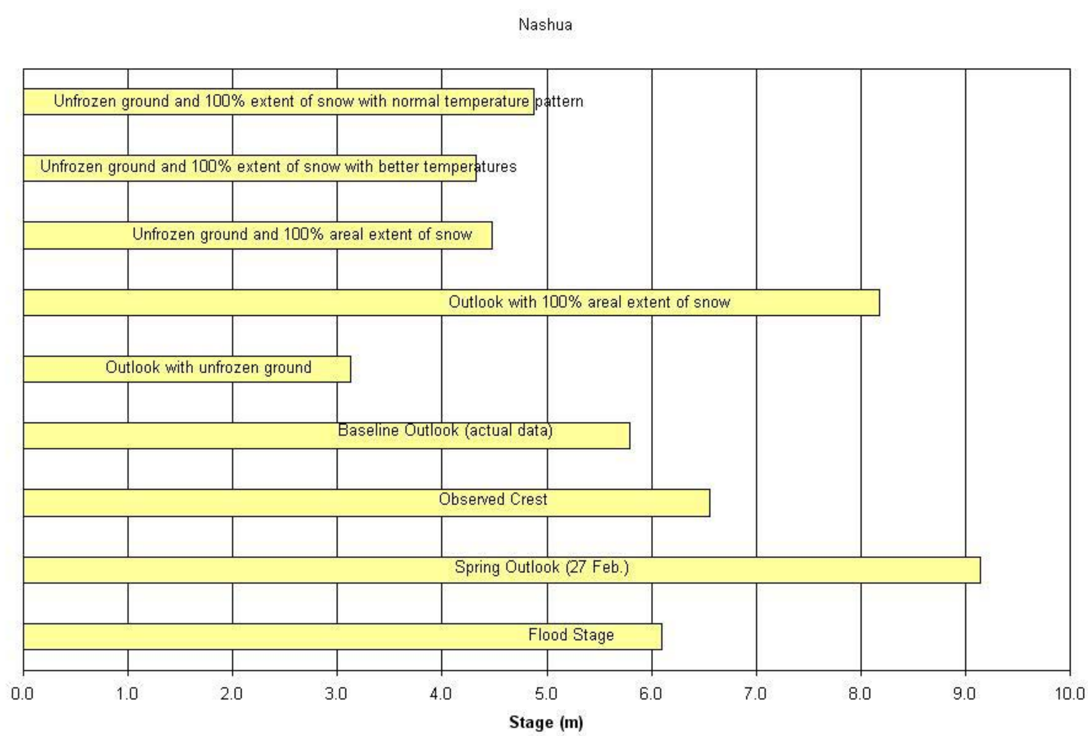

Figure 2b. Same as Fig. 2a except at Nashua.

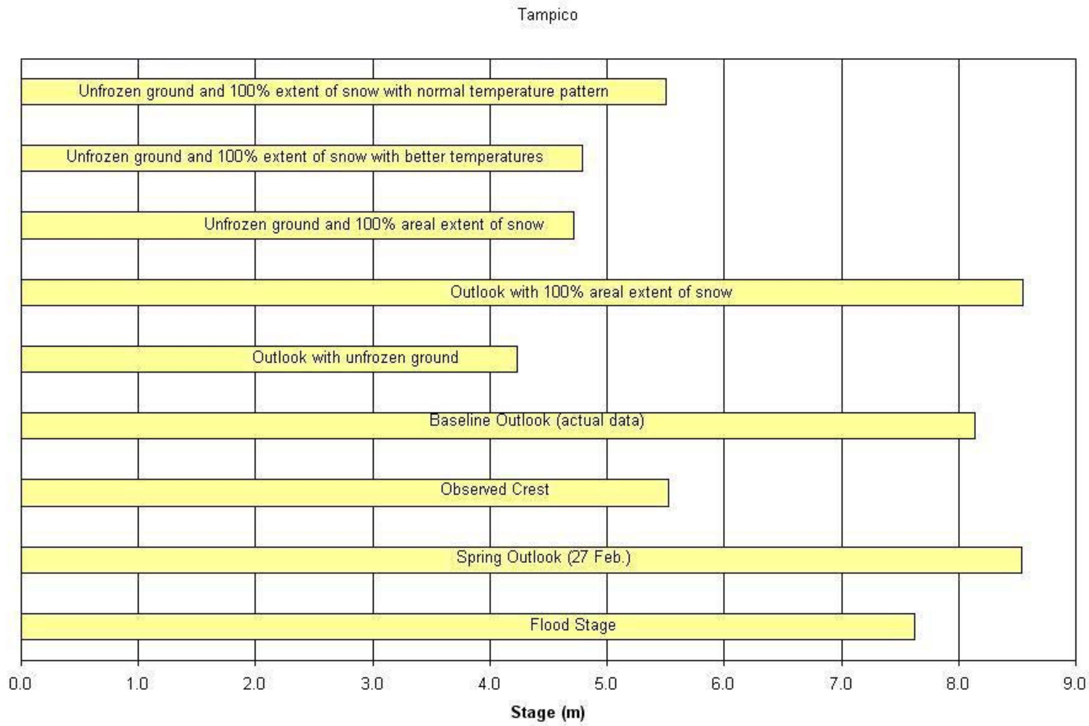

Figure 2c. Same as Fig. 2a except at Tampico.

above average temperatures across the area. Colder weather did return the second half of the month. Snowfall was above average across the basin, with a snow pack of up to 30 cm (1 ft) by the end of the month.

In March 1952, deep snow covered the entire Milk River Basin. In 2004, the deep snow cover was limited to northeast Montana and southern Saskatchewan. Central Montana and Alberta had little or no snow cover. Northeast Montana, the peak snow cover in March was much more in 2004 than it was in 1952 for many locations.

For most locations, snow melted more quickly in 1952 than it did in 2004. In areas south of the Milk River in Phillips County, snow melted in 8 days in 1952 while it took 14 days in 2004. In Valley County along and south of the Milk River, it took about 10 days for the snow to melt in 1952 while it took 15 to 20 days in 2004. For Valley County north of the Milk River, the snow melt occurred in 12 to 17 days in 1952 and 25 to 29 days in 2004. For example, Fig. 3 illustrates the rate of snow melt in Glasgow in 1952 and 2004. The Port of Morgan in Northern Phillips County was the exception with 19 days to melt the snow in 1952 versus 13 days in 2004. However, nearby Val Marie, Saskatchewan with much deeper snow cover, required 33 days to melt the snow in 2004.

While length of time to melt snow and the total seasonal snowfall are important factors in determining the possibility of flooding, timing of snow melt over the area also plays an important role in whether or not flooding will occur. The snow melt both north and south of the Milk River in Phillips County occurred almost simultaneously in both 1952 and 2004. In Valley County, the snow melt in 1952 occurred almost simultaneously north and south of the Milk River. However, in 2004, areas south of the Milk River had a significantly earlier snow melt than areas north of the Milk River.

5. REAL-TIME SNOW MELT OUTLOOK

In early February 2004, the hydrologic model indicated the entire Milk River basin was very dry due to antecedent conditions from the previous summer and fall, and the scarcity of observations in northeast Montana. However, the SWE measurements necessitated the increase of the snow water equivalents in the hydrologic model. With the highest observed SWE in the Lower Milk basin, and significantly higher than those measured in 1952, flooding seemed likely.

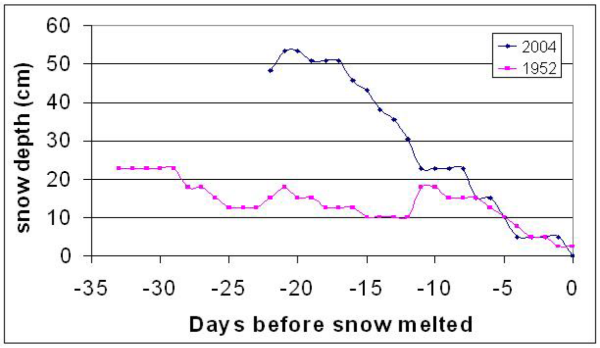

Figure 3. Snow depth for Glasgow from the spring of 1952 (purple squares) versus the spring 2004 (blue diamonds). The snow depth is in centimeters. The snow depths are shown as days before snow melted; thus "-30" is 30 days before snow melted.

However, the hydrologic model run with no frozen ground and dry soils, was not predicting significant flooding. Some of the snow surveys done in February by the Glasgow office reported frozen ground. Thus, the frozen ground condition was invoked in the hydrologic model. In addition, the basin soil moisture was increased slightly. Adding the frozen ground and wetting the soil caused the model to produce near record floods.

Although the ground may not have been frozen in all areas, record flooding was possible due to ice effects, additional rain or snow, or a rapid temperature increase. Therefore, the outlooks released in late February predicted the possibility of record or near record floods at Glasgow and Nashua (see Fig. 2).

The Glasgow office and the Corps of Engineers took additional snow surveys the second week of March; the snow surveys measured the SWE and snow depth across northeast Montana. The agencies worked together to ensure consistent measurements. At the same time, NOHRSC performed a second Airborne Gamma Snow Survey. Again, the SWE from both observation agreed and the mean aerial SWEs were adjusted in the model based on these measurements. The mean aerial SWEs were not significantly different in the area around Glasgow than those used in the late February model runs. Some reductions in SWE were evident west of Glasgow. Model runs for the March 11 outlook indicated somewhat lower flows and stages than in late February. Since the snow water conditions had not changed significantly from late February, the outlook was not changed. There was still a large area north and east of Glasgow that had 12 to 20 cm (5 to 8 inch) of SWE and the soil moisture and frozen ground conditions were not defined well enough to assume that significant runoff would not occur. In addition, there was still a threat that possible ice conditions, a rapid temperature increase, or additional rain or the snow would increase flooding potential.

6. ANALYSIS AND DISCUSSION

To understand why the expected runoff did not occur, the River Forecast Center re-ran the hydrologic model with various scenarios to isolate whether the lower runoff was due to unfrozen ground, different snow water equivalents, different soil moisture conditions, insufficient temperature observations within the high snow pack area, or the observed temperature pattern was different than the temperature pattern used in the spring snowmelt outlook.

Specifically, the simulated scenarios of the hydrologic model included: (1) A baseline simulation using the soil moisture and SWE set to the best-known values of 10 March, frozen ground, and the observed precipitation and temperatures after 10 March. (2) The same as the baseline simulation, (1), with the ground unfrozen. (3) The same as the baseline simulation, (1), with 100% of area covered with snow. (4) A simulation with unfrozen ground and the 100% areal extent of snow. (5) The same simulations as 4 except with additional temperature stations in the high snow pack areas north and east of Glasgow. (The additional sites report maximum and minimum temperatures at 0000 UTC; the temperatures were adjusted to reports similar to 1200 UTC reports for use in the hydrologic model.) (6) The same simulations as 4 except a climatological temperature pattern was used.

In Fig. 2, the scenario results are shown compared to the observed crest value, the spring outlook forecast from February 27, and the flood stage at Glasgow (Fig. 2a), Nashua (Fig. 2b), and Tampico (Fig. 2c).

Analysis of scenario results indicated that the best simulation of runoff between Saco and Nashua would have occurred with no frozen ground and nearly 100% areal extent of snow cover (scenario 6). All scenarios with frozen ground computed too much runoff between Saco and Nashua. None of the scenarios, even with frozen ground, computed enough flow upstream of Saco without wetting the soil or increasing the snow water equivalent.

Based on previous events with less snow pack than the record SWE amounts observed in March 2004, river stages near record flood levels appeared possible, especially if a rapid temperature warm-up, additional rain or snow, or ice jamming would have occurred. Model states were adjusted somewhat and frozen ground added in order to produce large amounts of runoff. Crest forecasts were altered from model results to account for the above possible factors. However, frozen ground and rapid increase in temperatures that occurred during the record flood of 1952 did not occur in 2004.

The frozen ground was less prevalent than assumed and ice had little affect on stages from Tampico on downstream on the mainstem Milk River. In addition, the actual observed temperature pattern was conducive to slow melt unlike the temperature pattern of 1952, which stayed colder than normal until early April and had a very rapid warm-up. In addition, the 2004 snow depth varied across basin, slowing the melt rate. The rate of snowmelt in the model was very sensitive to the aerial extent of snow cover. Finally, although the extent of diversions from the river to flood fields is not known, a contribution to the lower observed stages was likely.

The large volume of water on the ground in the form of SWE may have caused a major flood if conditions would have been slightly different. Fortunately, the ground was not frozen extensively, there was little additional rain or snow, and the diurnal and areal temperature characteristics prevented major flooding.

7. SUMMARY

The winter of 2003-2004 produced record snowfall with high SWE in many areas along and north of the Milk River in northeast Montana. Only minor flooding was observed along the lower Milk River in Glasgow, which was not expected given the historically high probability of significant flooding in years when above average snowfall is observed. The winter of 1951-1952 along with other winters with lesser but still above average snowfall have produced significant flooding.

There are many factors that affect the threat and severity of flooding even during years with above average snowfall in the Milk River basin. A rapid temperature warm-up, additional rain or snow, frozen ground, ice jams, variations in the snow depth and SWE, and diversions from the river to flood fields all play an important role in the hydrologic outcome.

Because rainfall, snow depth, and SWE reports are sparse in this area, it is hoped that an improved mesonet and more frequent observations of soils will help the hydrological model better depict runoff and the subsequent flooding potential.

8. ACKNOWLEDGEMENTS

The authors wish to thank the following individuals for their help during the spring melt season, and for their assistance with completing this paper: Larry Black, Hydrologist in Charge of the Missouri River Basin Forecast Center; Bob Cox, Development and Operations Hydrologist at the Missouri River Basin Forecast Center; Charles Ross, Service Hydrologist at the Spokane, WA, National Weather Service Forecast Office; Jim Rea, Meteorologist in Charge (retired) of the National Weather Service Office in Glasgow, MT; US Army Corps of Engineers in Omaha, NE; Mike Dailey, Hydrologist at the Department of Natural Resources and Conservation Office in Glasgow, MT; John French and Art Thomas, of the US Geological Survey in Fort Peck, MT.

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