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A HYDROMETEOROLOGICAL LOOK AT A UTAH FLASH FLOOD

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Introduction

On Friday, July 24, 1992, a flash flood occurred on the Grand Wash in south central Utah and continued into Capitol Reef National Park on the Fremont River (Map 1). July 24th is a state holiday, with peak visitor attendance in the state's national parks. During this period, the Grand Wash is normally dry and only experiences flows during very heavy runoff. On the morning of the flash flood, the wash was dry, but quickly rose and became a flash flood by early afternoon. Many visitors were swimming in the Fremont River at the park during the early afternoon hours, and left just minutes before the flooding would have reached them. Other recreationalists were stranded in and near the area due to the rising water in both the Grand Wash and the Fremont River.

Meteorological Discussion

The flash flood was caused by a single thunderstorm cell that developed in a typical synoptic weather pattern for July in Utah. A number of meteorological factors considered favorable for thunderstorm development existed, but flash flood potential was minimal.

At 1200 UTC 24 July, a positive-tilt trough was present over the western United States, with the axis extending from the Washington/Idaho border, across Oregon, and over the Pacific Ocean. At 250 mb (Fig. 1), the Great Basin was under a strong southwesterly jet ahead of the trough, with southern Utah positioned under the favorable right-rear quadrant of the jet maximum. At 500 mb (Fig. 2), minor disturbances were embedded within the southwest flow upstream from Utah, initially located near the southwest Utah/Nevada border and near the southwest Nevada/California border.

At lower levels, most meteorological factors were not very favorable for strong thunderstorm development. Average relative humidity in the 850 mb to 650 mb layer (Fig. 3) was 20 to 30 percent at 1200 UTC. This, combined with the 700 mb wind field (Fig. 4), did not indicate significant moisture advection into south central Utah during the next six hours. Low-level (700 mb) forcing due to convergence was not apparent at this time, as the streamlines revealed a diffluent flow regime. The 700 mb equivalent potential temperature (Θ_e) analysis (Fig. 5) indicated a moderate gradient over most of Utah, with a Θ_e ridge located over northern Utah. Through personal observation, this type of Θ_e pattern is fairly common in the Great Basin during the summer convective season. Observed and forecast lifted indices for the day ranged from zero to +2, and 1200 UTC observed precipitable water was near or below one half inch.

At the surface (Fig. 6), a weak pressure trough extended from southwest Wyoming across Utah into southern Nevada. The boundary separated air with very low dew points (<40°F) to the west and higher dew points (40-55°F) to the east. The dew point discontinuity was a very important feature of the surface boundary, which remained stationary throughout the day.

A cross-section of NGM absolute vorticity advection and winds extending across central Utah from Ely, Nevada (ELY) to Grand Junction, Colorado (GJT)is shown in Fig. 7 (valid at 1200 UTC). Although little positive vorticity advection (PVA) is present at 500 mb and negative advection (NVA) is seen at lower levels, the vorticity advection does increase with height. According to the Quasi-Geostrophic (QG) Omega equation, this positive differential vorticity advection, combined with slight warm temperature advection (not shown), indicates a favorable atmosphere for upward QG vertical motion over central Utah at this time.

As daytime heating progressed, convection began to form over northern Arizona and southeast Utah in the region of greatest moisture and instability. The 1731 UTC Infrared satellite photo (Fig. 8) shows the area of convection, with the arrow indicating an isolated cell on the northwest edge of the area near Capitol Reef. This cell produced the localized heavy rainfall over Miner's Mountain between 1800 and 1900 UTC (noon and 1300 MDT), which led to the flash flood.

Little change (other than heating) occurred in the environment over southern Utah between 1200 and 1800 UTC. The following discussion focuses on six hour NGM forecasts of the parameters described earlier, valid at 1800 UTC. South central Utah was forecast to remain under the right-rear quadrant of the 250 mb jet maximum (Fig. 9), with the strongest speeds shifting east over Wyoming. At 500 mb (Fig. 10), both of the shortwave disturbances described above were forecast to weaken as they moved northeast, with only one of them identified over west central Utah. A vorticity center was forecast over eastern Arizona with weak PVA into southeast Utah, and this corresponded well with the main area of convection on the satellite photo. Relative humidity (Fig. 11) was forecast to remain almost identical to the initial analysis over the southern half of Utah. The 700 mb wind field (Fig. 12) was forecast to change over the six hour period, where confluence became evident over southern Utah. Also, the Θ_e pattern (Fig. 13) was forecast to advect to the northeast during the period, leaving a weak Θ_e ridge near the southern border of Utah.

The 1500 and the 2100 UTC surface analyses (2100 UTC shown, Fig. 14) indicated that the surface boundary and associated dew-point discontinuity, initially described at 1200 UTC, remained nearly stationary in a position on the northwest edge of the main area of convection. The cross-section of differential vorticity advection (Fig. 15) for 1800 UTC implies little forcing for upward Q-G vertical motion, especially when compared to six hours earlier.

Although the air mass over south central Utah was relatively dry with marginal instability, a flash-flood producing storm developed. Normally, Utah flash floods form in a strong monsoonal surge, where the air mass contains deep moisture. This type of air mass was not present over Utah in this case. Low Θe values and little 500 mb support (in the form of vorticity advection) also did not indicate favorable conditions for flash flooding at the time. However, lower-level RH values of around 50 percent were sufficient to sustain convection over southeast Utah. The storm that caused the flooding formed on the northwest edge of this area, in the region of strongest moisture gradient in the vicinity of the surface boundary. The position of the boundary, where daytime heating was able to act on a more moist air mass just east of the main area of cloudiness, may have been a key factor in focusing the locally strong storm in the vicinity of Miners Mountain. The convergent flow at lower levels (shown by the 700 mb streamlines) acted on this air mass to initiate convection, which may have been assisted by local topographical forcing as well. The convection was then sustained by favorable jet dynamics (right-rear quadrant and upper-level divergence), quickly dropping localized very heavy rain over terrain that is conducive to flash flooding.

Hydrologic Discussion

The Fremont River flows toward the east through Capitol Reef National Park, located near Torrey, Utah. Natural flows for the river are minimal. The closest gages to the site are the Fremont River near Bicknell and the Fremont River near Cainville. The Bicknell gage lies about 13 miles upstream, the Cainville gage about 8 miles downstream. Monthly mean flow for July is 73.1 CFS (cubic feet per second) and 50.6 CFS, respectively.

The river parallels Utah State Highway 24 flowing in a west to east direction through the park. Prior to entering the park, the river is bordered by a steep canyon area near Boulder and Miners Mountains to the south, and Thousand Lake Mountain to the north (Map 2). The base of Miners Mountain forms a very steep canyon, which the Grand Wash and Fremont River descend. At one point, the river elevation is 6000 ft., while the canyon rim is 7200 ft. (Map 3).

The surface horizons of Boulder Mountain, Thousand Lake Mountain, and Miners Mountain are composed of red sandstone. Little or no topsoil exists on the faces of these mountains. Red sandstone is mostly impermeable and has virtually no infiltration capacity. Precipitation falling on these areas will evaporate or runoff.

Between 1800 and 1900 UTC 24 July 1992, very heavy rain fell on the northeast aspect of Boulder and Miners Mountains. Runoff from these aspects will flow in a northeasterly direction towards the Grand Wash and the Fremont River. In addition, the storm system also moved in a northeasterly direction increasing the volume of water moving towards the park. The storm produced only 0.19" at the visitors center/headquarters of Capitol Reef National Park. However, the size of the flood would suggest a much larger volume of precipitation. The main runoff from Miners Mountain flowed into the Grand Wash and traveled east into the Fremont River. The drainage basin encompasses approximately a 20 square mile area. Residents in the area say that most of the flooding in Capitol Reef National Park involves runoff from the northern aspect of Boulder Mountain, the southern aspect of Thousand Lake Mountain, or Miners Mountain. The runoff from the Boulder/Thousand Lake Mountain area flows into the Fremont River above Grand Wash, near the park's visitors center. Runoff from Miners Mountain will flow into the Grand Wash below the visitors center, resulting in flows similar to the flash flood seen on July 24th. Most likely, runoff from Boulder and Thousand Lake Mountains accompanied the main flood off Miners Mountain and created a very dangerous flash flood.

A visitor to the park videotaped the flood while positioned along Highway 24. The video shows water levels ranging from 4-6 ft. above normal to 20 ft. in some narrow sections of the channel. No one was injured in the flood. However, 50 cars were stranded on Hwy 24, and several hikers were reported stranded in the Grand Wash for up to six hours.

The Dirty Devil River near Hanksville is the closest river gage to record the rise on a real time basis (Map 4). The Fremont River drains into the Dirty Devil River. The gage is situated about 68 miles downstream from the flood area. Normally at this time of the year, the gage at the Dirty Devil near Hanksville records a stage of 4.9 ft. and a volume flow of 12 CFS. Approximately 18 hours from the time of the flash flood, the high flows reached the gage which recorded 9.5 ft. and 2043 CFS at the highest level (Fig. 16). This is a rise of 4.6 ft. and an increased flow of over 2000 CFS, assuming the majority of the rise was due to the Capitol Reef National Park flood. The majority of the high flow did not decline for at least 14 hours. The rise in the Dirty Devil River near Hanksville began at 0000 UTC, Saturday, July 25, and returned to base flow on Tuesday, July 28, at 0000 UTC.

Conclusion

Though there were no injuries due to this flood, it demonstrates the type of situation that can happen in this area during the convective season. Much of the southern two-thirds of Utah has similar topography and soil composition. When this is combined with even marginally favorable meteorological conditions, dangerous flash flooding can occur.

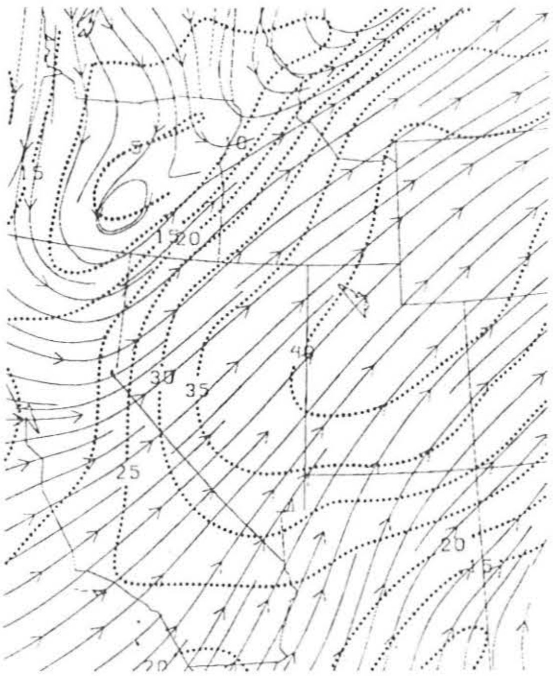


Fig. 1: NGM initialized 250 mb streamlines and wind speed (ms^{-1}) for 1200 UTC. (all figures 24 July 1992)

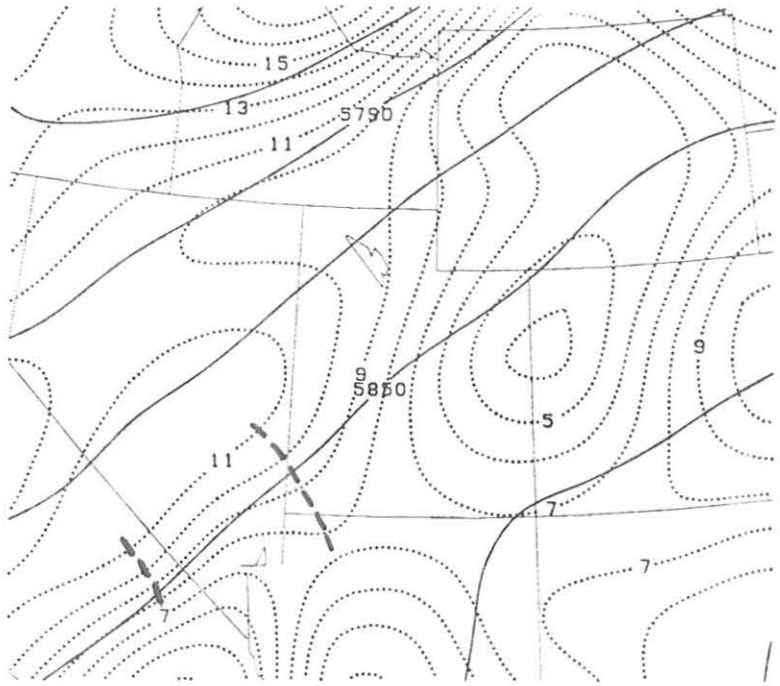


Fig. 2: NGM initialized 500 mb heights (m) and absolute vorticity (sec^{-1} $x10^{-5}$) for 1200 UTC.

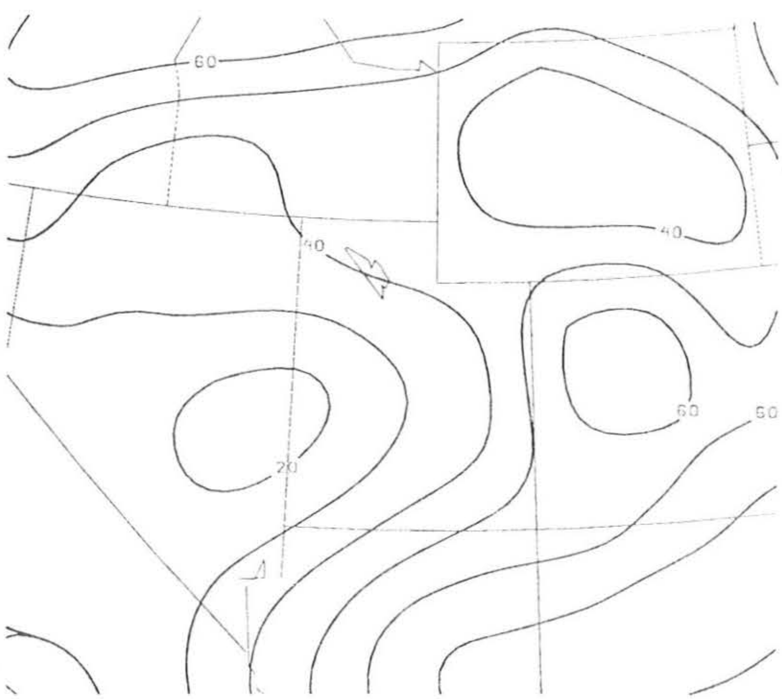


Fig. 3: NGM analyzed relative humidity in 850-650 mb layer for 1200 UTC.

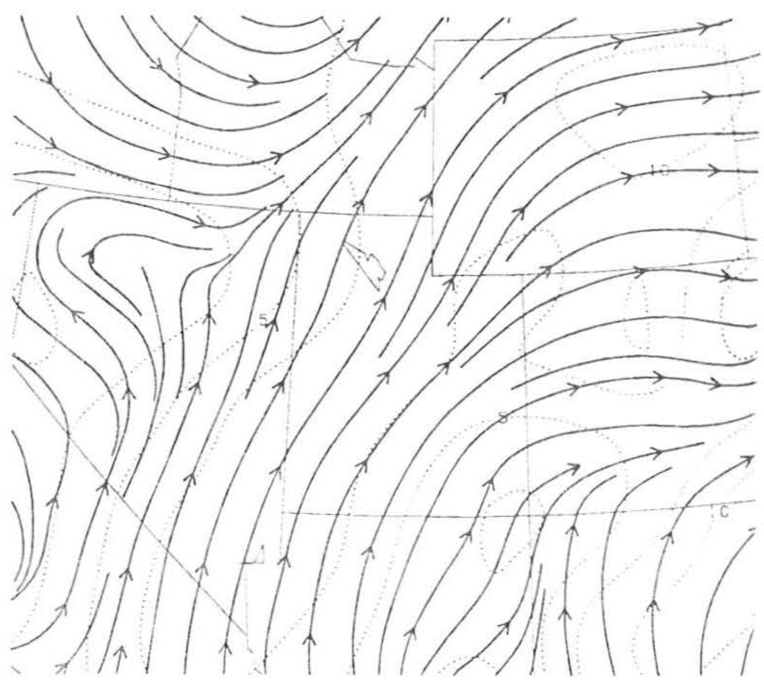


Fig. 4: NGM initialized 700 mb streamlines and wind speed (ms^{-1}) for 1200 UTC.

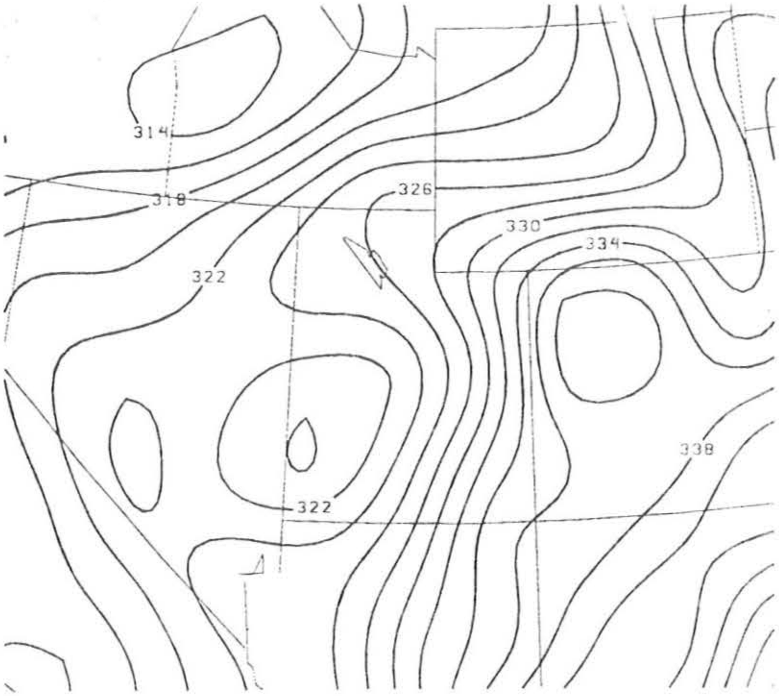


Fig. 5: NGM initialized 700 mb Theta-E (K) for 1200 UTC.

Fig. 7: NGM initialized absolute vorticity advection (s^{-1} x10^{-9}) and wind barbs (ms^{-1}) for cross-section from Ely to Grand Junction.

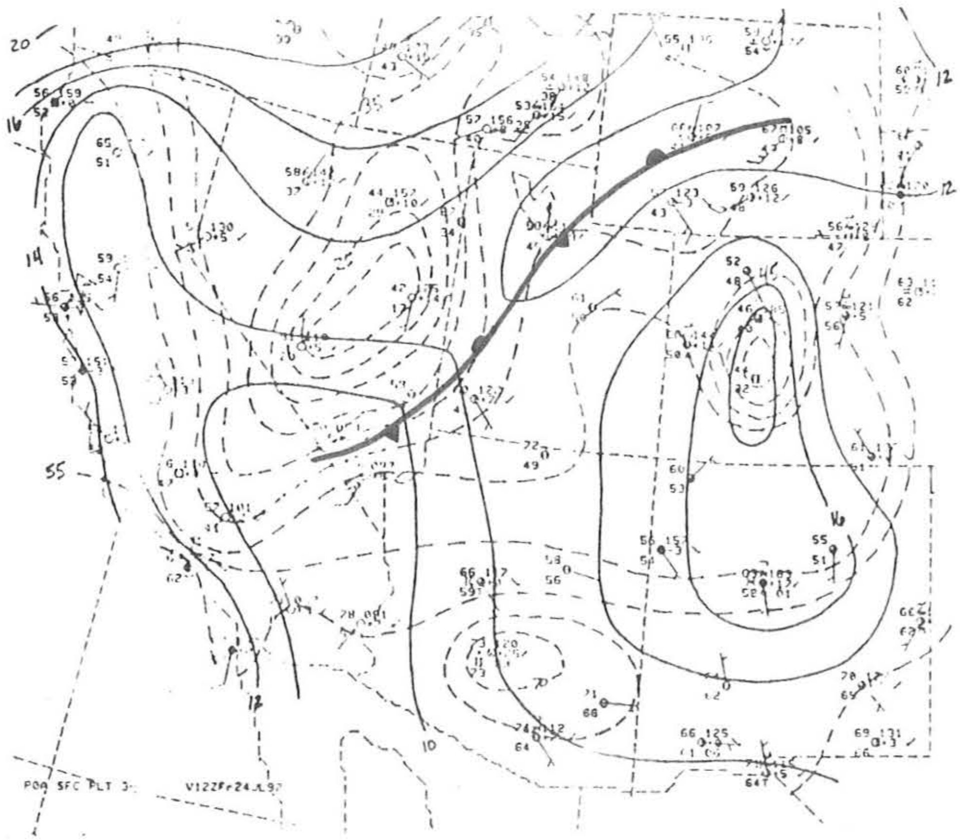


Fig. 6: 1200 UTC surface analysis. Solid= pressure (mb). Dashed=dewpoint (F).

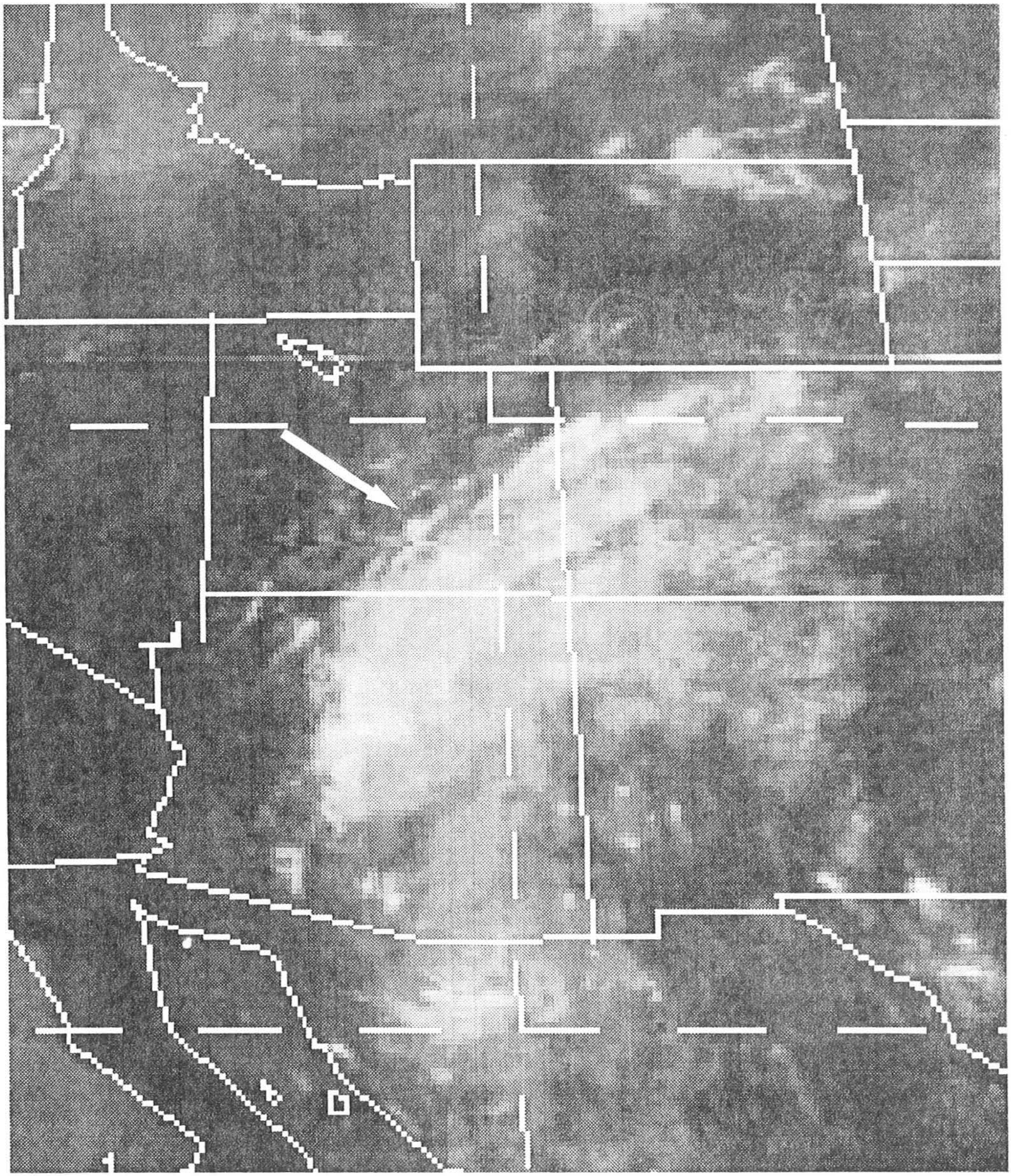


Fig. 8: 1731 UTC IR Satellite Photo. Storm cell highlighted by arrow.

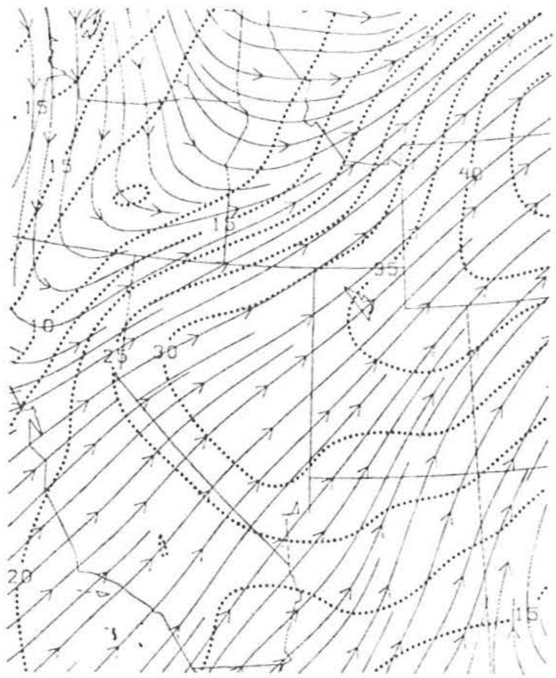


Fig. 9: NGM 250 mb streamlines and wind speed (ms^{-1}). 6 hour forecast valid 1800 UTC.

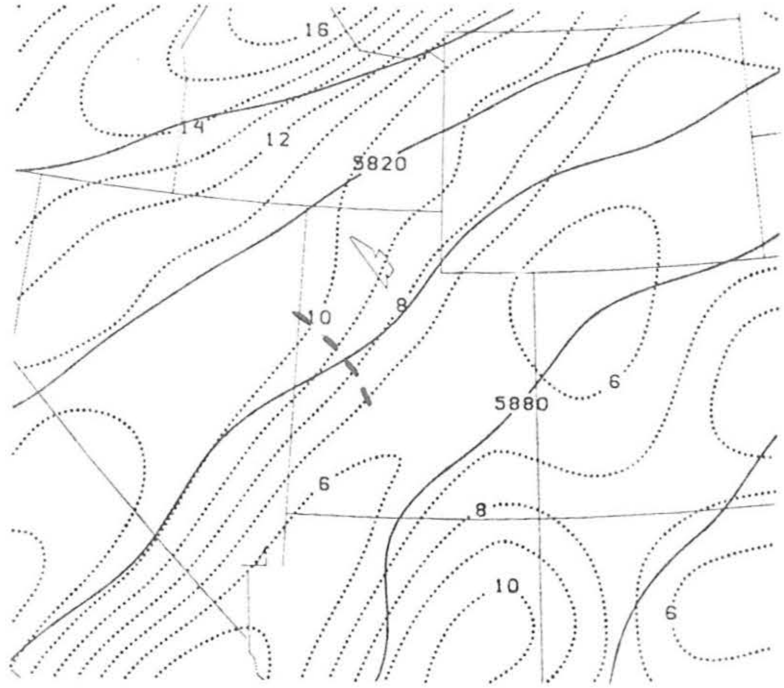


Fig. 10: NGM 500 mb heights (m) and absolute vorticity (sec^{-1} $x10^{-5}$). 6 hour fcst valid 1800 UTC.

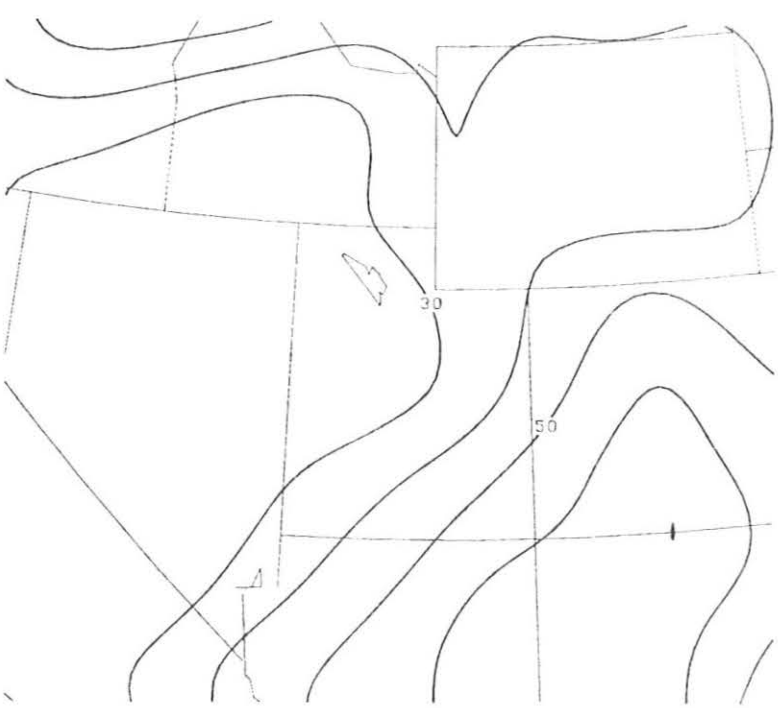


Fig. 11: NGM relative humidity for 850-650 mb layer. 6 hr fcst valid 1800 UTC.

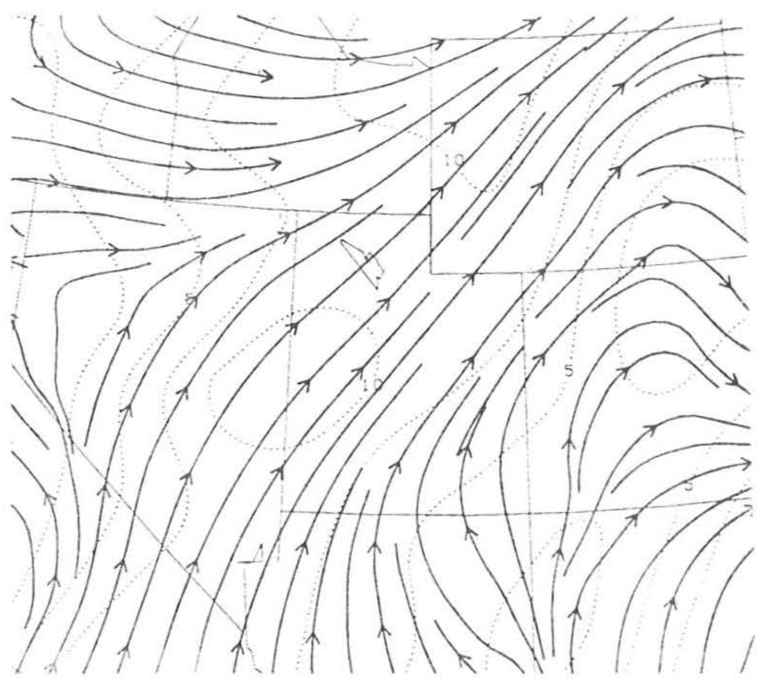


Fig. 12: NGM 700 mb streamlines and wind speed (ms^{-1}). 6 hr fcst valid 1800 UTC.

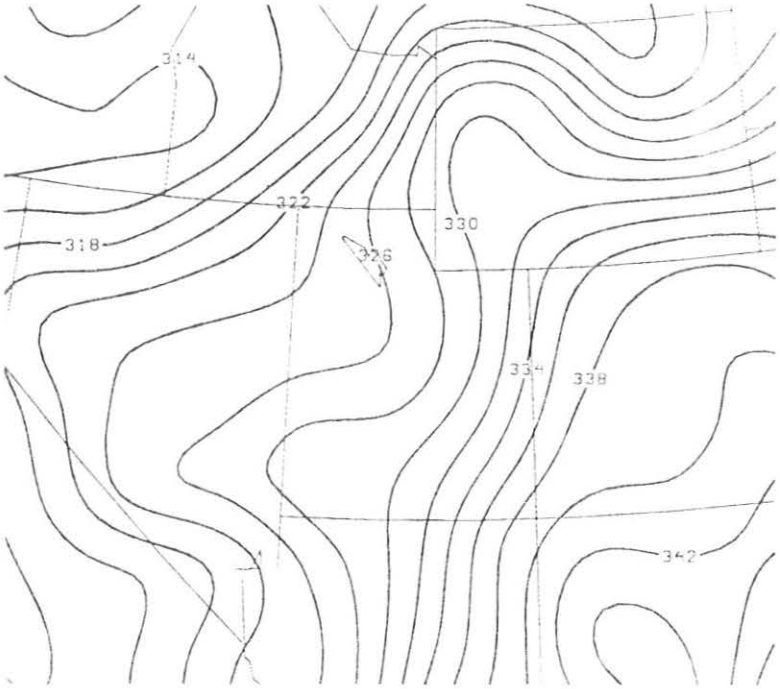


Fig. 13: NGM 700 mb Theta-E (K).
6 hr fcst valid 1800 UTC.

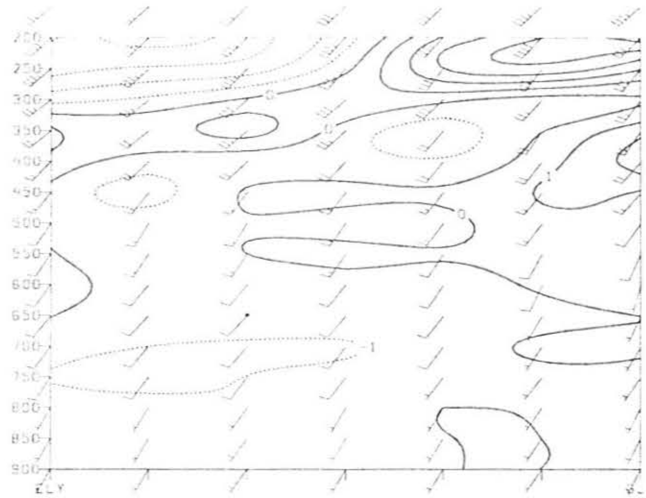


Fig. 15: NGM absolute vorticity advection (as in Fig. 7). 6 hr fcst valid 1800 UTC.

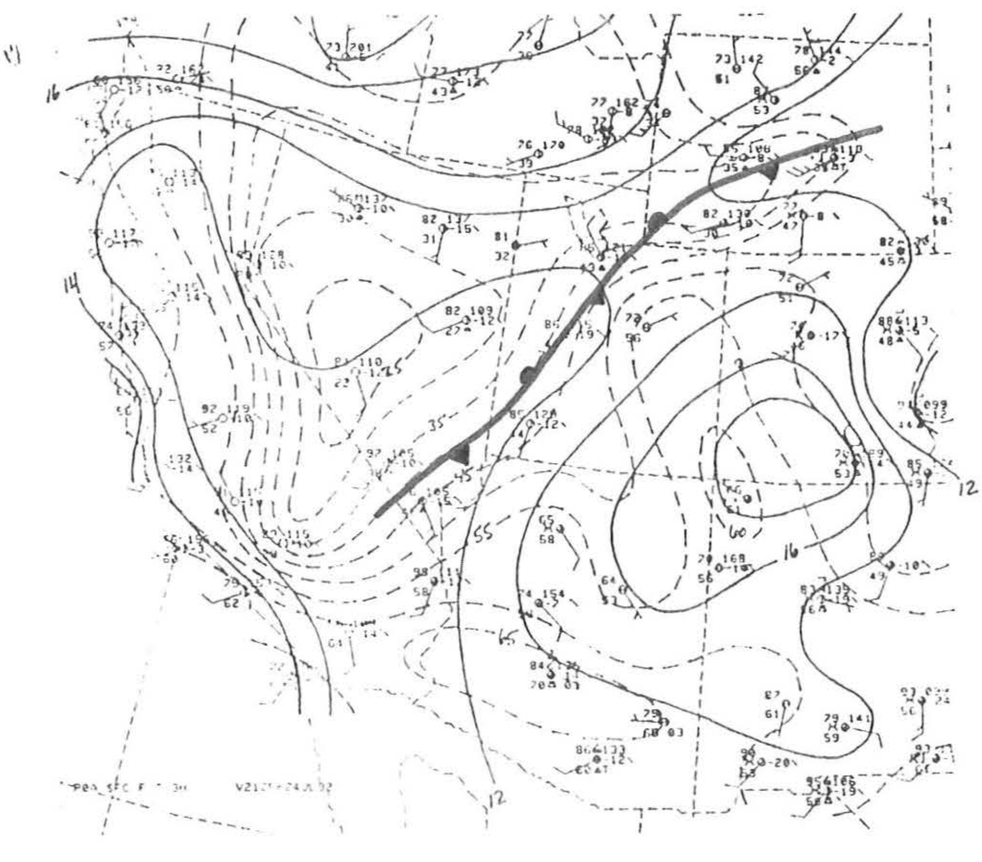


Fig. 14: 2100 UTC surface analysis, as in Fig. 6.

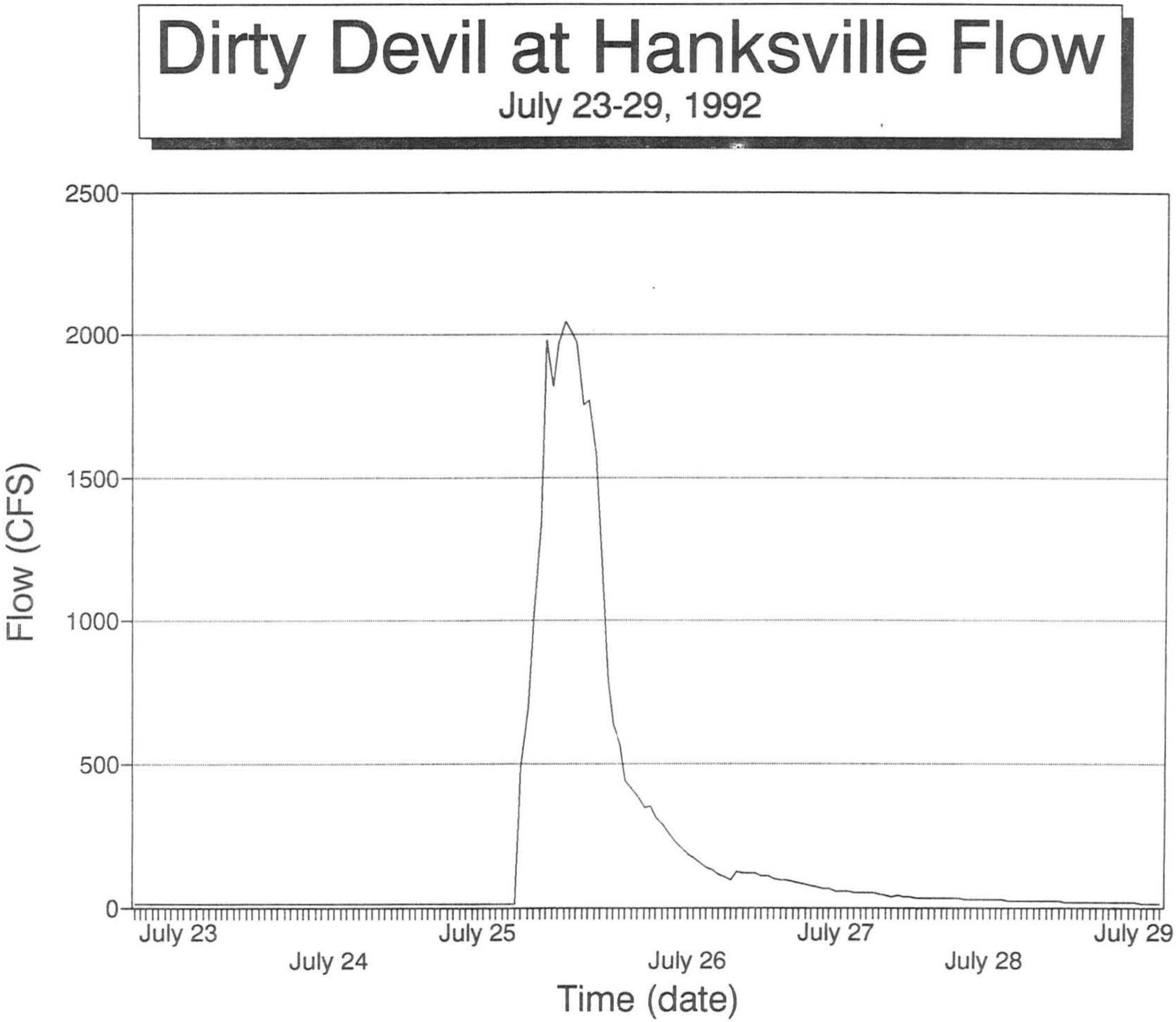
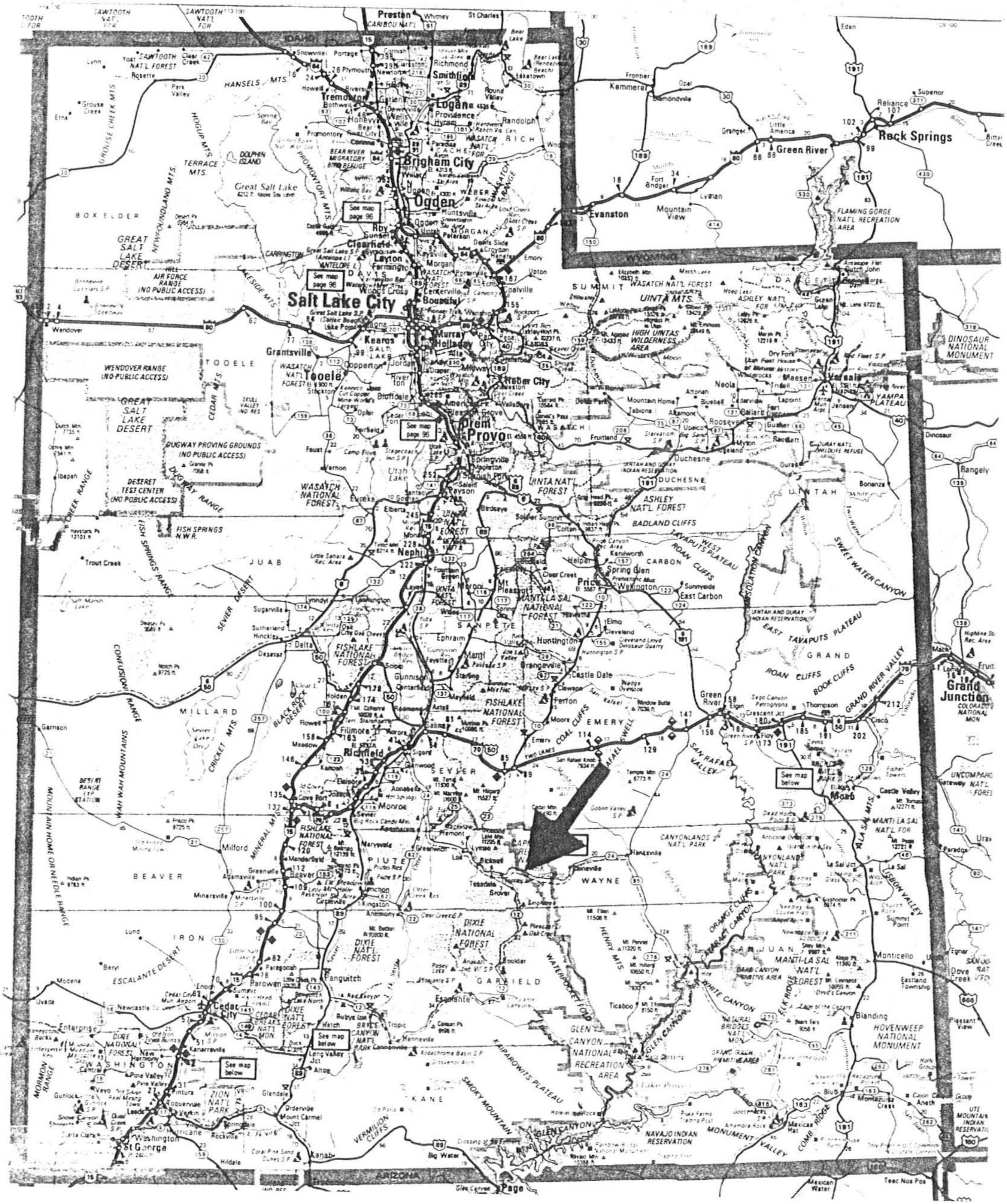
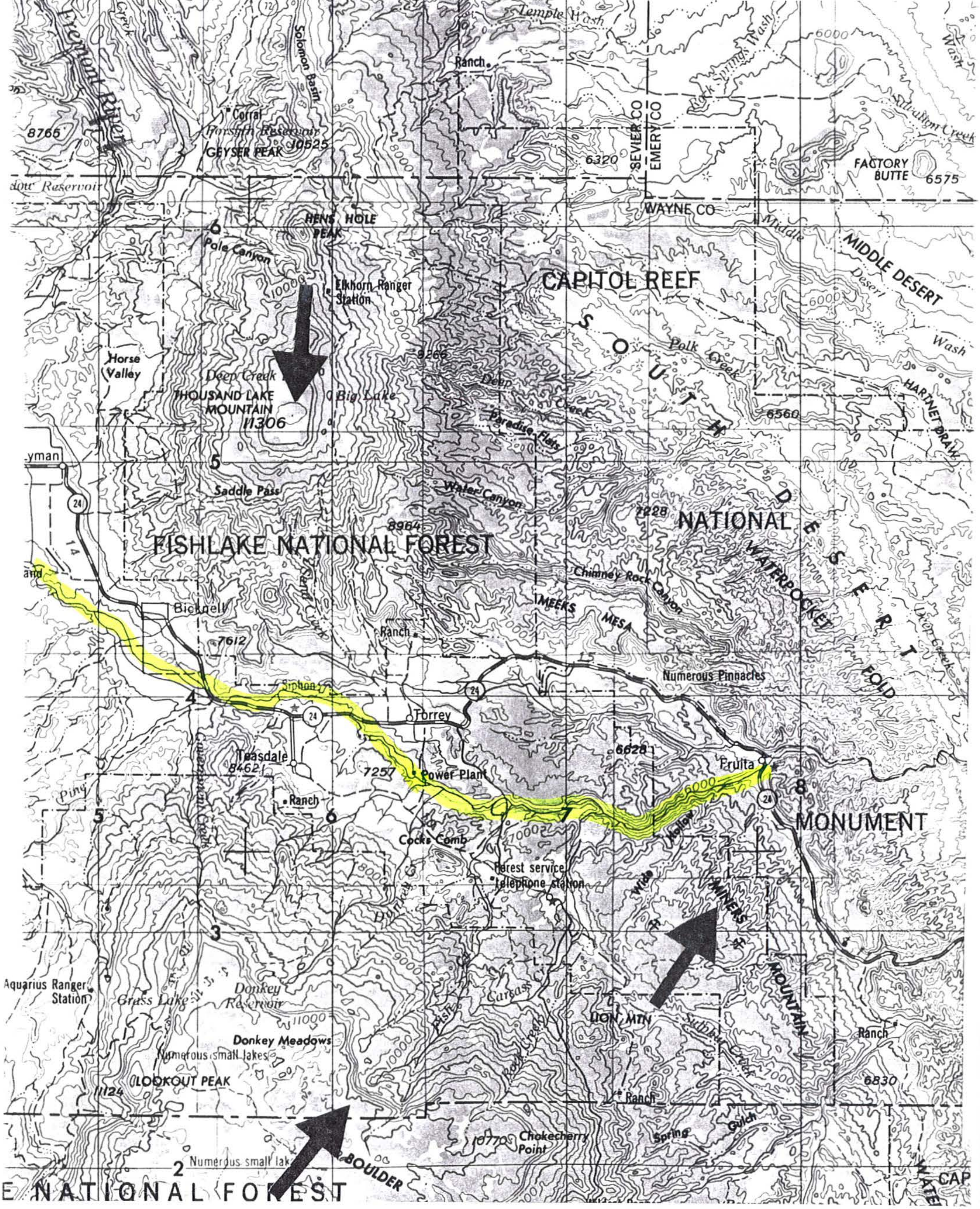


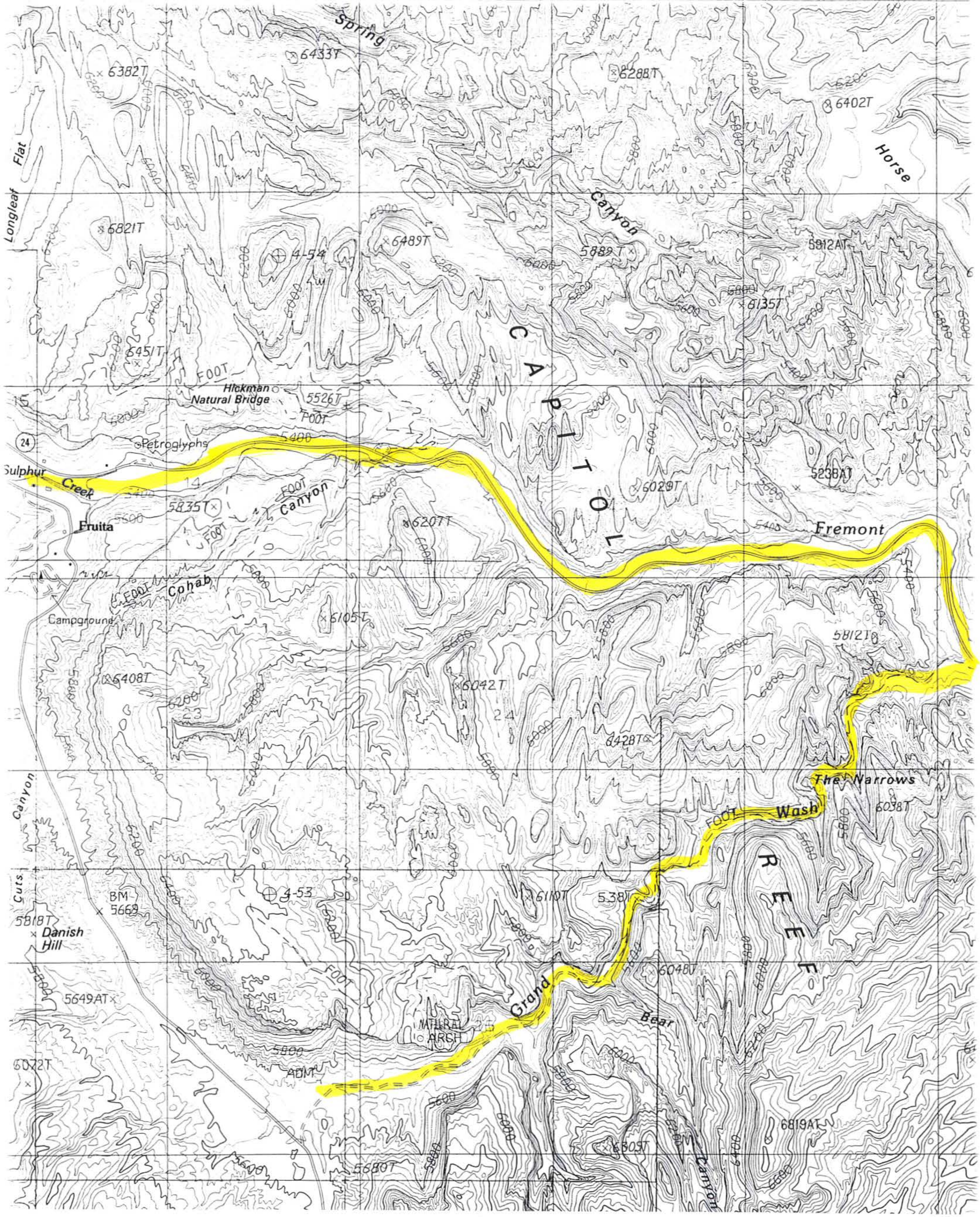
Fig. 16 River flow versus time of Dirty Devil River at Kanksville.



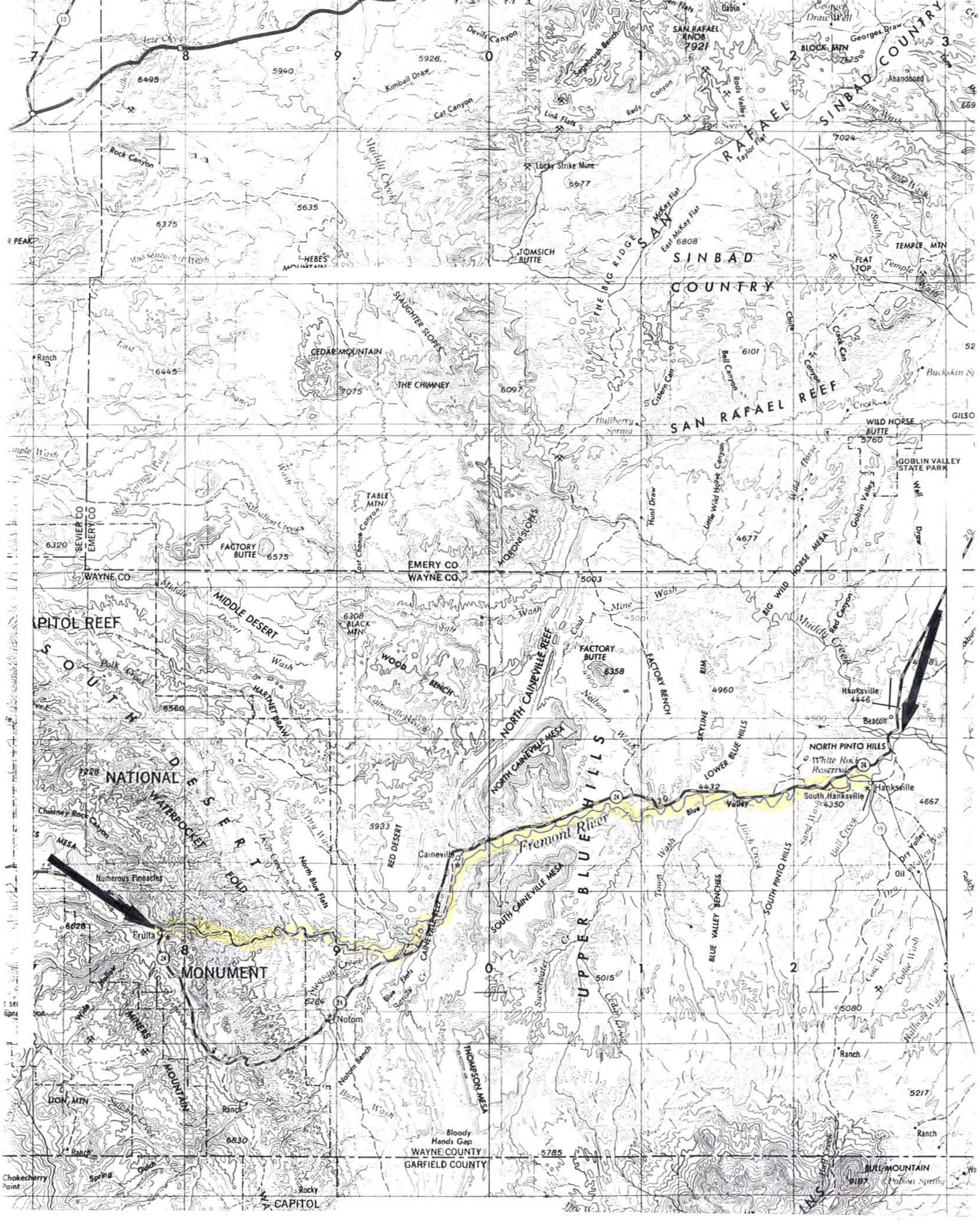
Map 1: Capitol Reef National Park, located south central Utah.



Map 2: Boulder and Miners Mtns. to the south, Thousand Lake Mtn. to the north.



Map 3: Topography of river elevation, and canyon rim elevation.



Map 4: Dirty Devil at Hanksville river gage in relation to Capitol Reef N.P..