Natural Disaster Survey Report

WESTERN WASHINGTON FLOODS

NOVEMBER 21-26, 1990

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Weather Service, Western Region
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Table of Contents

List of Figures

List of Figures (Contd.)

P R E F A C E

The National Oceanic and Atmospheric Administration's (NOAA) National Weather Service, Western Region Headquarters, assembled a Regional Survey Team following the record flooding in western Washington State that occurred during November 21-26, 1990. The purpose of the survey was to review the quality of services provided by the NWS prior to and during this record breaking event and to examine ways, if any, that services can be improved. The floods of western Washington were a significant hydrometeorological event and had a major impact on those in the flood area. When a significant event such as this occurs, it is NWS policy to conduct a review to ensure the best possible service. The team consisted of Robert M. Tibi, Regional Hydrologist (Survey Team leader); Lee P. Krogh, Deputy Regional Hydrologist, Hydrologic Services Division (HSD), Western Region Headquarters (WRH); David Toronto, Marine and Dissemination Meteorologist, Meteorological Services Division (MSD), WRH; Lawrence B. Dunn, Meteorologist, Scientific Services Division (SSD), WRH; and Mark A. Mollner, Lead Forecaster, Weather Service Forecast Office (WSFO), Boise, Idaho.

Most of the team met at Western Region Headquarters on November 26, 1990, to plan its survey strategy and review the event. On November 27, the full team met at WSFO Seattle to discuss the event with members of the WSFO staff, tour portions of the flood affected area, and interview officials of Snohomish County Department of Emergency Management and KING TV, NBC affiliate.

On November 28 and 29, the team split into groups for the purpose of conducting internal reviews of forecast and guidance products, warning products, dissemination systems and preparedness activities, and external reviews of user response, and site surveys of damage.

On the afternoon of November 29, an outgoing briefing was given to the Area Manager/Meteorologist in Charge (AM/MIC) at WSFO Seattle and the team dispersed to their respective duty locations, except for Mr. Tibi, who proceeded on to the Northwest River Forecast Center (NWRFC), Portland, Oregon. On November 30, reviews of RFC activities and RFC/WSFO interactions were conducted with the RFC staff. RFC products and procedures were also reviewed.

The team wishes to express its appreciation to the staffs of WSFO Seattle and the NWRFC for their cooperation and support during an active meteorological and hydrological period while the survey team was on site, and for their assistance in preparing and providing necessary information for the survey.

This survey covers the record flooding of November 21-26, 1990. However, much of the analysis in this report will also discuss the flood events of November 8-14 in the same areas, since the antecedent conditions and damages of both events are significantly linked.

EXECUTIVE SUMMARY

During the period November 20-24, 1990, warm, moist air flowed up the Cascades and Olympic Mountains ahead of a slow moving cold front dropping heavy amounts of rain over an area extending from the central Oregon coast, across western Washington and northward across the Canadian border over British Columbia. Heavy precipitation also spilled across the Cascade Mountains into eastern Washington, northwestern Montana and northern Idaho. Precipitation intensities were as high as 1.5-2.5 inches in 6 hours (maximum of 2.5 inches at Skykomish), and 4-8 inches in 24 hours were recorded at numerous mountain stations (maximum 8 inches at Skykomish). Storm totals for the event were as high as 16 inches in the western King County area of Washington.

The area affected by this event included parts of Washington that had experienced major flooding two weeks earlier as a result of 12-16-inch storm totals over a five-day period. In addition to the very moist soil conditions, runoff included melting snow. All of this combined to cause major-to-record flooding on 18 rivers and numerous tributaries over western Washington and in several river basins in eastern Washington east of the Cascades.

Less serious flooding also occurred in the Wilson and Nehalem River basins in northwest Oregon, and on rivers and streams in northern Idaho and northwestern Montana.

Flooding was most severe in western Washington. There were two human deaths, over 450 cattle perished, and there were over 2,000 evacuations. In addition, severe damage was done to farms, homes, roads, bridges, and utilities. Several levees and dikes were breached, recreational areas (campgrounds and boat launches) were destroyed, and fish and wildlife environments severely impacted. In addition, the flood flows caused severe bank erosion. Dollar estimates of damage are expected to exceed 100 million dollars. The loss of life and property damage very likely would have been much higher had it not been for the highly effective warnings which were issued by the NWS.

The potential for heavy rains and possible flooding was recognized as early as Monday, November 19, for flood problems expected on Thursday, November 22, and Friday, November 23. The WSFO Seattle issued a special weather statement alerting the public and emergency services agencies to this developing situation.

Quantitative Precipitation Forecasts (QPF) issued by WSFO Seattle on Tuesday, November 20, indicated 3.5 to 4 inches of rain for Thursday, November 22, 1990, in the Washington Cascades area.

A contingency forecast was made by the NWRFC based on this QPF and coordinated with the U.S. Army Corps of Engineers (USCE) and county emergency service agencies. On the following day, the WSFO Seattle QPF amounts were reduced but the hydrologic forecasts produced by the NWRFC still indicated a flood event for Thanksgiving Day.

A decision was made by the RFC and WSFO to release the flood forecasts to the public even though these were based entirely upon a QPF. The reason for this decision was based on the need to inform people as early as possible of the potential before they left on the extended holiday break.

Rainfall, accompanied by melting snow, developed and by Thanksgiving Day several streams reached flood stage, but then the rain amounts diminished and headwater streams began to recede. The QPF issued by WSFO Seattle on Friday morning had fairly light amounts and NWRFC forecasts, based on this QPF, kept most headwater streams below flood stage. However, as heavy rainfall again developed, the QPF was updated several times on Friday to reflect the excessive rainfall amounts. These updated QPFs, and the continuous interaction between the WSFO and RFC, resulted in the RFC producing some outstanding flood forecasts, and the WSFO issuing timely and accurate flood warnings to the public.

Overall, the forecast and warning service during this event was outstanding and the cooperation between the NWRFC, WSFO Seattle, and field offices was impressive. Critical hydrologic information was disseminated in a timely fashion over NOAA Weather Wire Service, NOAA Weather Radio, NAWAS, TELEFAX, telephone and by many media outlets serving the affected area. Coordination with hydrologic users and emergency management officials also worked well. All media and emergency management agencies contacted were highly complimentary of the NWS services they received.

Although the NWS does not normally recommend evacuations in their flood warnings, an extremely dangerous situation was identified when the NWRFC forecast model indicated that levees would be over topped on the Snohomish River. After coordination between the RFC and the WSFO, a special flood warning was issued urging immediate evacuation. The Snohomish County Department of Emergency Management indicated that, based on this warning, they were able to evacuate persons in the forecast area that if they had not been evacuated would have later been trapped and possibly have lost their lives.

It should be noted that during these events, the WSFO did not have a dedicated Service Hydrologist assigned. The previous Service Hydrologist had transferred to a new position in October. However, this did not impair the WSFO staff's ability to respond

to this record event due to the WSFO's integrated hydrometeorological concept of operations. The Seattle WSFO management has made it a practice to cross-train and cross-utilize all forecasters and interns in the Hydrology Program.

The Survey Team believes that the following findings and recommendations can serve as a means to highlight the strengths of the forecast and warning system and identify areas where improvements are still possible.

FINDINGS AND RECOMMENDATIONS

1. **Finding:**

   Overall, the forecast and warning services provided by WSFO Seattle and the Northwest RFC were excellent. Emergency service officials, the media (television, radio, and newspapers), and the public were kept well informed with timely and accurate forecasts, warnings, and statements which were frequently updated.

2. **Finding:**

   Three products have been identified as decisive in providing this effective forecast and warning service: 1) Special Weather Statement issued Monday, November 19, mentioning possible flooding problems Thursday and Friday. 2) QPF issued Friday night changing direction of forecast trend. 3) Saturday morning RFC forecast and WSFO Flood Warning calling for immediate evacuations due to levees being topped in Snohomish County.

3. **Finding:**

   WSFO Seattle forecasters did an excellent job issuing QPFs for input to the RFC forecast model. Although QPFs were somewhat lighter than actual rainfall amounts, they generally reflected a large improvement over guidance. Updates of QPFs were timely and relatively accurate, given the nature of the event.

4. **Finding:**

   During this flood event and the one earlier in the month, some of the accumulating rain gages filled during the storm and important precipitation information was lost.

Recommendation:

In advance of an anticipated major storm, every effort should be made to empty the critical buckets. The WSFO should develop a checklist of preliminary activities to implement at the first indications of a flood situation to ensure that reporting equipment is polled at appropriate intervals and that critical gages are emptied.

5. **Finding:**

Problems were experienced with the Skagit River gage near Mt. Vernon and the Cedar River gage at Renton.

Recommendation:

The NWRFC and WSFO Seattle need to work with the Seattle Corps of Engineers, Seattle District and U.S. Geological Survey (USGS) to resolve gage problems.

6. **Finding:**

Information from Chester Morse Lake was very limited during the Cedar River flood event. At one point, the NWRFC was told that water would have to be released and that the NWS would be notified before the spill. Information was never received on an increased spill, but the hydrograph indicated a probable spill.

Recommendation:

Northwest RFC and WSFO Seattle should work on establishing a working relationship with Chester Morse Lake operations to obtain information during major events.

7. **Finding:**

With the widespread flooding, it was necessary to issue separate bulletins for different areas of the state. This was good for emergency management but confusing to the media and the public.

Recommendation:

When it becomes necessary to separate flood information, provide a complete summary containing all rivers and forecast points every six to twelve hours. These should be timed to coincide with major news broadcast times. Also, a sentence in each flood bulletin should indicate that information about other rivers will be issued in later bulletins.

8. **Finding:**

To ease forecaster workload, flood-warning headlines were not placed in the zone forecasts.

Recommendation:

Need for the inclusion of all flood-warning headlines in zone forecasts should be reviewed by Regional Headquarters. A ROML should be issued with specific instructions detailing when headlines may be excluded in flood events.

9. **Finding:**

The term "rising to" was used often in the forecast portion of the bulletins instead of a crest forecast beyond 12 hours. The use of this term was well received by emergency management and the USCE.

Recommendation:

"Rising to" should be used in all flood bulletins when the river is not expected to crest within the next 12 hours. All RFC forecasts should have a forecast period of at least 12 hours beyond the forecast issue time, and all critical activities (above flood stage, crest, below flood stage) within this time period should be indicated. Emergency management should be kept informed of expected crest times and heights forecast beyond 12 hours.

10. **Finding:**

User confusion developed when river levels remained the same but flow (CFS) increased at forecast points when flood waters were forecast to flow over the dikes.

Recommendation:

In these cases, a statement is needed in the flood-warning bulletin explaining why the river level will not rise but the flow will increase.

11. **Finding:**

Several corrections were made to flood bulletins during the episode. Although the corrected bulletins were timely, in some cases the users had to look carefully through both the original and the corrected bulletins to determine what had been corrected.

Recommendation:

When bulletins are corrected, a statement at the beginning of the bulletin should instruct the user where and what to look for to make finding the correction simple.

12. **Finding:**

Emergency management, the media, and the public receive NWS flood bulletins and other information through a variety of dissemination systems. All were generally satisfied with the dissemination of NWS products through these systems.

13. **Finding:**

NWWS dissemination was effective and efficient for those subscribing. Many emergency management and media organizations in western Washington do not subscribe to NWWS.

Recommendation:

WSFO management and staff should strongly encourage receipt of NWS products by NWWS.

14. **Finding:**

The computerized NWR console was easy to use and saved recording time. However, its ease of use and essentially limitless number of products that could be broadcast occasionally caused long-cycle times.

Recommendation:

Products and cycle time should be evaluated occasionally during weather events to determine what products could be eliminated from the cycle to shorten the broadcast.

15. **Finding:**

During the flood event, the telephone facsimile recorder was used to transmit flood bulletins to media organizations.

Recommendation:

Every effort must be made by the WSFO to expand NWWS subscribers to include as many media organizations as possible, and conform to the new WR ROML concerning the use of telephone facsimile recorders.

16. **Finding:**

The WSFO was overburdened by calls from the media and public during the flood event. The public line had to be turned off for several hours on Friday, November 23. The media telephone number has been obtained by many who should not be using it. Many of the calls on the media line asked for updates on the flood forecast when no new information was available.

Recommendation:

The media number should be changed. To eliminate some calls, the media should be made aware, through preparedness efforts, of our limitations due to the frequency of guidance from meteorological models. Other calls could be eliminated by providing more information in the flood bulletins themselves, such as when the next statement or bulletin will be issued.

17. **Finding:**

Occasional AFOS crashes and unexplained loss of products took a toll on the efficiency of the warning program. Occasionally there was competition for AFOS consoles.

Recommendation:

A partial solution to this problem is to connect the hydrology computer directly to AFOS. In the long term, a local area network could help solve these AFOS problems.

18. **Finding:**

The primary hardware for monitoring hydrological data is a NOVA 4X. The NOVA is ported into AFOS; however, public products cannot be prepared at the NOVA and transmitted to AFOS for further dissemination. Public products must either be prepared on AFOS, which is extremely cumbersome due to the poor word processing software, or on another office PC which is ported to AFOS. Thus, the preparation and dissemination of flood warning products is hampered by the system.

Recommendation:

Development work, already in progress at the WSFO to replace the NOVA with a 386 PC, will be a step toward solving the problem. The 386 PC will include word processing capability for product generation and when connected to AFOS will provide much improved product dissemination.

19. **Finding:**

Cross-utilization and training of forecasters in the Hydrology Program have been very effective at WSFO Seattle. Forecasters have a good understanding and a sensitivity for the program and are sufficiently trained to perform hydrologic operations. The actions within the WSFO and between the WSFO and RFC were an impressive demonstration of the concept of integrated hydrometeorology.

20. **Finding:**

Some local emergency management organizations depend too heavily on telephone calls from the NWS for flood information. Special contact with these organizations is not always possible.

Recommendation:

Local emergency management organizations should be contacted concerning the advantages of subscribing to the NWWS. Every effort should be made to reduce unnecessary telephone contact.

PART I
DESCRIPTION AND IMPACT OF THE FLOOD EVENT

Overview

There were two major flood episodes in November of 1990. The first was on the Veteran's Day weekend and the second was during the week of Thanksgiving.

The first episode mainly affected the northernmost counties of western Washington, with the heaviest precipitation occurring in northeast Whatcom County and in southern British Columbia (Figure 1). Five counties of Washington were declared disaster areas.

During the second episode, there were strong westerly winds aloft which carried some of the precipitation across the Cascade Mountain crest and caused some heavy runoff in three counties of eastern Washington. The heaviest precipitation amounts fell in the central Washington Cascades and caused more widespread flooding than the earlier episode (Figure 2). In all, 19 counties were declared disaster areas.

Flooding occurred on the Elwha, Cedar, White, Skykomish, Snoqualmie, Snohomish, Stillaguamish, Skagit, Nooksack, Cowlitz, Skookumchuck, Chehalis, Satsop, Yakima, Naches, Puyallup, and Wenatchee Rivers. Major and record flooding occurred in the western drainages with moderate to record flooding on the eastern drainages. This report will cover the record flooding in the western drainages. Appendixes A and B summarize the observed stages and flows. Please see Figures 24 and 25 for geographic locations of rivers and counties. Other geographic landmarks can be seen on Figure 11.

The western slopes of the Cascade Mountain range in Washington are primarily drained by the Cedar, Skykomish, Snoqualmie, Snohomish, Stillaguamish, Skagit, and Nooksack Rivers. With topography of the area defined mainly by mountain ridges, forested foothills, and river valleys, the affected area is subject to floods from November through late spring.

Hydrometeorological Discussion

1. Antecedent Conditions

The hydrometeorological conditions through October and early November were a significant factor in the Thanksgiving weekend flooding. Very wet weather with significantly above-normal precipitation had occurred throughout western Washington nearly continuously during the seven weeks prior to the event.

The month of October was unusually wet throughout western Washington. Seattle reported 5.79 inches of precipitation for the month. This is 170 percent of normal and ranks as the third wettest October in the last 30 years. Similarly, Olympia and Quillayute reported 135 and 150 percent of normal precipitation. In the Cascade Mountains, Stampede Pass (just above 4,000 feet in elevation) reported 16.83 inches of precipitation during October, which is 217 percent of normal.

October was wet but November was even wetter. A series of weather disturbances moved through the area during the first half of November. Seattle reported precipitation on all but two of the 22 days prior to the start of the flooding on Thanksgiving Day. Similarly, Stampede Pass reported precipitation on all but five days.

A major precipitation event took place over the Veterans Day weekend from November 8 through 14. Storm totals in the Cascades included 12.6 inches at Diablo Dam in the Skagit River basin, 9.8 inches in the Skykomish River basin, and 9.9 inches in the Snoqualmie River basin. Widespread flooding occurred with numerous rivers reaching near-record levels. Considerable damage was reported, particularly near the mouth of the Skagit River where a levee failed and evacuations were necessary. Please see Figure 1 for precipitation contour map for this storm.

In the period between the Veterans Day flooding and the Thanksgiving flooding, wet weather continued but it was relatively cool and snow levels lowered to near 1,000 feet. A warm front moved northward along the West Coast on November 21, bringing heavy snow to the Cascades. Paradise Ranger Station at the 5,000-foot level on Mt. Rainier reported 51 inches of snow on the ground on the morning of November 22. By the morning of the 22nd there were 15 inches of snow on the ground at Snoqualmie Pass at 3,000 feet, and 20 inches at Stampede Pass. Throughout the Cascades there were generally 6 inches of snow between 1,000-2,000 feet, 12 inches between 2,000-3,000 feet, and 12-18 inches of snow between 3,000-4,000 feet. Snow/water ratios in this snow were generally 10:1 or higher.

2. Description of Meteorological Features

At 500 mb, northwest flow gave way to westerly flow during the day on the 21st as a flat ridge moved into the Pacific Northwest. Over the northeast Pacific, a strengthening baroclinic zone was forming as a broad trough moved southeast from the Aleutian Islands while, at the same time, an upper-level disturbance north of Hawaii pushed moist tropical air northward into the baroclinic zone

(Figure 3). Strong, slightly anticyclonic westerly flow at 500 mb continued over western Washington from the afternoon of the 21st through the 25th. Numerous embedded short-wave disturbances moved over the state in this flow, with a vorticity trough moving through the area at least every 12 hours.

At the surface, a warm front moved northward through western Washington on Wednesday, November 21. Heavy snow preceded the front in the mountains. Snow changed to rain at Snoqualmie Pass by Wednesday evening as the freezing level rose. Snow levels which had been near 1,000 feet early in the week, rose to 7,000-8,000 feet in the southern Cascades and to near 5,500 feet in the northern Cascades by Thanksgiving morning. Heavy precipitation was reported throughout Thanksgiving Day while western Washington was in the warm sector. By Thursday evening, the cold front was along the northern tip of Vancouver Island and moving slowly south as a series of surface waves propagated along the front. Over the next 24 hours, the front moved very slowly south and by late Friday afternoon, it was near the southern end of Vancouver Island. Western Washington continued to receive moderate to heavy rain Thursday night and during the day, Friday, although not quite as heavy as on Thursday. Freezing levels remained high into Friday afternoon ahead of the cold front.

During the next 24 hours, the front became virtually stationary. Frontal analyses placed the front at various locations across northwest Washington. Extremely heavy rain was reported from Friday afternoon through early Saturday evening ahead of and coincident with the cold front. Freezing levels remained high until Saturday evening. The cold front moved through western Washington late Saturday, and was just east of the Washington Cascades by Sunday morning. Freezing levels dropped and precipitation diminished after midnight Saturday.

Flow at mountaintop level was nearly perpendicular to the Cascades throughout the entire event. Winds reported from an automatic gage at 5,530 feet near Snoqualmie Pass, from Friday afternoon through Saturday afternoon, showed hourly averages of 40 to 50 mph from near 260 degrees. Peak gusts at this gage were over 90 mph for 17 of this 24 hours, and over 100 mph for 10 hours. Clearly, orographic lift was substantial ahead of the cold front.

3. Summary of Precipitation

Heavy precipitation fell for most of the five-day period from November 21, 00z, through November 26, 00z. The heaviest precipitation fell during two periods, from Wednesday afternoon through early Thursday evening, and then again from Friday afternoon through Saturday evening (Figures 1 and 2). This second

period was the heaviest at most locations. Five-day rainfall totals were generally quite uniform with 12-16 inches at most mountain locations, while 4-8 inches was reported at most low-elevation sites. The greatest five-day total was from the Alpental Ski Area near Snoqualmie Pass, where 16.54 inches of precipitation was reported. Nearly all of this was in the form of rain. Please see Figure 12.

Virtually all snow on the ground below 4,000 feet had melted by Friday morning during the first period of heavy rain. Precipitation amounts in the Cascades during the first period of heavy rain were 3 to 5 inches in 24 hours. The greatest amount during this period was 4.92 inches at Alpental. Six-hour precipitation was generally between 0.5-1.5 inches during this period. The greatest 6-hour amount was 1.64 inches at Alpental for the period ending at 18z on November 22.

The second period of heavy rain saw generally between 4 and 8 inches of rain at mountain stations in 24 hours. The largest 24-hour report was 8 inches at Skykomish, while numerous other stations reported over 7 inches. Six-hour precipitation totals were generally between 1.5-2.5 inches, with numerous stations over 2 inches in 6 hours. The maximum 6-hour precipitation was 2.5 inches at Skykomish for the period ending at 12z on November 24. Please see Figure 12.

Description of the Damages

Heavy flooding and flood-related damage was widespread in 16 counties of western Washington and 3 counties east of the Cascades as creeks, streams and rivers reached record stages between November 8 and 14, 1990, and again between November 21 and 26, 1990. Puget Sound lowland rivers overran channels to reoccupy their natural flood plains, causing severe bank erosion and, in some cases, cutting new channels.

While loss of human life was limited to two -- during the later event -- damage to farms, homes, roads, bridges and utilities was severe and extensive during both floods. Flood waters required the evacuation of numerous people.

Levees and dikes on the lower reaches of the Skagit and Snohomish Rivers were overtopped and breached. Fir Island, with 8,000 acres of farmland and 167 homes dependent upon flood protection by a system of levees and dikes, was completely inundated after the levee system was breached.

Flooding on the Nooksack River transported and redeposited tons of gravel, rocks, and other debris in its lowland reach. The river's high velocity discharge over heavy gravel deposits at Everson topped and ruptured the dike, flooding the area and extending damage by flood water to Sumas and over the Canadian border.

Damage and destruction also occurred with levee failure on the Skykomish River at Gold Bar and Monroe. In the Snohomish Valley, levees failed or were overtopped. They were designed to protect thousands of acres of farmland, as well as residential and commercial development. Ebey Island, just east of Everett, was completely submerged, requiring the evacuation of all residents.

The Snoqualmie River above the falls reclaimed its flood plain. This required temporary evacuation of most of the residents in the town of Snoqualmie. Damage occurred to residential, commercial and institutional property.

Many homes suffered damage along Issaquah Creek and along the Cedar River in Maple Valley, where the river's stage exceeded all previous elevations.

Flood and storm damage also occurred in the upper reaches of the state's rivers and streams, much of it affecting recreation areas in the national forests and parks, where bridges, forest roads, trails, campgrounds, and boat launches were affected. Restoration is expected to cost $12 million.

Damage caused by the flood was not limited to man-made structures. The fish and wildlife environment were also severely impacted. In addition to actual fish and wildlife loss, the very heavy flood flows caused bed-load movement, channel changes, channel scouring, and bank erosion, resulting in the complete destruction of fish and wildlife habitat, the effects of which will be felt for many years.

Specific damages reported in each county are summarized as follows:

November 8-14 Event

Damages were in King, Whatcom, Skagit, Snohomish and Grays Harbor Counties. Total damage was: 48 homes (mobile homes or apartment units) destroyed, 254 units sustained major damage, and 239 units had minor damage. The Red Cross provided temporary shelter to 899 people and provided additional assistance to 172 families. The State Governor places the losses at approximately

$41.8 million. Of this amount $14 million was damage to homes in Snohomish, Skagit, and Whatcom Counties. Damage to roads, bridges, sewer systems, parks, dikes, and levees was $23.5 million. Agricultural losses are estimated at $4 million in Skagit County.

Skagit County had losses of approximately $8.5 million, including damage to 248 homes, of which 137 on Fir Island received major damage. One hundred ninety residences (450 people) were evacuated from Fir Island where almost all of the 8,000 acres were inundated. The losses for Fir Island alone were approximately $5.48 million. The USCE spent $400,000 for emergency repair to the levee.

Whatcom County had losses of approximately $4.3 million and damage to 109 homes.

King County had 1 unit with major damage and 10 units with minor damage.

November 21-26 Event

State-wide damages are estimated at $100 million. This includes 42 homes destroyed, 600 with major damage and 800 with minor damage.

King County:

One man drove around two barriers to bring about his own death. Another man died due to a kayaking accident on the Green River which was experiencing ten times the normal flow. At Maple Valley, along the Cedar River, 300 homes were flooded, 50 were homes in a mobile home park which was inundated. On the upper White River near Greenwater, roads and bridges were washed out and several homes were damaged. In North Bend a 100-bed nursing home had to be evacuated. There was a $1 million initial estimate of road damage. Approximately 450 cows drowned or died of exposure in the Duval area.

Whatcom County:

The entire population of Sumas (approximately 700) was evacuated.

Skagit County:

Fir Island was inundated for the second time this month. Also, along the Skagit River, a levy was overtopped near Burlington, damaging a rail line. One thousand people were told to evacuate their homes.

Snohomish County:

The Burlington Northern Rail line, between Everett and Wenatchee, had washouts in 15 to 20 places. Eighty-five people had to be rescued by helicopter or boat. Ebey Island levees broke or were overtopped, forcing 100 people to be evacuated. One-hundred-ninety residents were evacuated from a senior center in Stanwood.

Pierce County:

A total of 500 people were evacuated.

Thurston County:

Four families were evacuated from near Bucoda.

Kitsap County:

Thirty-eight families were evacuated because of mud slide threats.

Mason County:

Twenty-five people were evacuated from along Skokomish Valley Road.

Yakima County:

Forty families were evacuated from the Buena area.

Kittitas County:

Fifty people left their homes along the Yakima River.

Wahkiakum County:

Localized but significant flooding was reported in the Grays River area.

Benton County:

Thirty-five people were evacuated from their homes in Benton City and west Richland.

Pacific County:

Six families were evacuated from a trailer court in Ilwaco.

PART II
SUMMARY OF WARNING AND FORECAST SERVICES

Overview

Overall, the forecast and warning service during this event was outstanding. Forecast and subsequent warnings are a team effort between the Seattle WSFO and the Northwest RFC. WSFO Seattle produces quantitative precipitation forecasts (QPF) and freezing level forecasts used by the NWRFC in their river model to produce forecasts which are then used by the WSFO to issue flood bulletins to the public. Precipitation and stage observations are also collected by the various field offices for input to the RFC model. This total process is an impressive demonstration of cooperation and interaction between the NWRFC and WSFO Seattle.

To provide a complete picture of the activities and process during the event to produce the forecasts and warnings, the survey team looked at internal and external products used to produce QPFs, freezing level forecasts, RFC forecasts, and WSFO flood bulletins. This section will provide an analysis of the numerical guidance available for producing WSFO forecasts, an analysis of the QPFs produced, a general summary of warning services, and finally a detailed chronology of the RFC/WSFO interactions. Note, a summary of all public products issued are contained in Appendix C.

Analysis of Numerical Guidance

The overall quality of the numerical guidance was quite good with respect to the synoptic-scale pattern. The development of a flat ridge over the area, with a moist baroclinic zone stretching from near Hawaii to the Cascades, was well advertised in the NMC progs. The movement of the warm front northward on Wednesday and the subsequent rise in freezing levels was quite accurate. A complete archive of NGM QPF data was not available, but, in general, the NGM QPF guidance showed precipitation maxima in western Washington. Amounts were underforecast by as much as a factor of 4 or 5 on the mountain precipitation. Even at lower elevation sites, the forecast precipitation was much too low. Please see Figures 13 and 14 for accompanying charts.

Manually generated QPFs from NMC showed a significant improvement over the numerical guidance. Twenty-four-hour totals for the first period of heavy rain, which began near 00z, November 22, were in the 1-2-inch range with an area of greater than 2 inches in the northern Cascades. Six-hour manual QPFs during this period were near .5 inch in the Cascades. During the second period

of heavy rain, which began near 00z, November 24, 24-hour totals of 3 inches were indicated for the Cascades. Six-hour QPFs showed generally 1 inch in the Cascades, with 2-inch maximums indicated. Please see Figures 15 and 16 for accompanying charts.

The single biggest deficiency in the numerical guidance was in the movement of the cold front. All model runs up through the 12z, November 23, guidance consistently moved the cold front through western Washington Friday night, and showed much lower thickness values into the area Saturday, indicating low freezing levels. The corresponding numerical QPF guidance showed little or no precipitation in western Washington after 12z, November 24, behind the front. The 12z, November 23, NGM run-thickness forecast verified 60 meters too low at 24 hours, and 120 meters too low at 36 hours, as it moved the front through the area too quickly. In reality, the front stalled. The result was high freezing levels continued through most of Saturday, with the heaviest rain of the entire event falling; whereas the 12z, November 23 run had little or no precipitation predicted for this period.

The 00z, November 24 model runs held the front back correctly and increased both the thickness values and the precipitation forecast over western Washington.

Discussion products issued by NMC highlighted the heavy rain potential in the days prior to the event. However, there was no indication in the products issued November 23 that the numerical guidance was incorrect in moving the front south through the area too quickly in the next 24 hours. Discussion products issued after the 00z, November 24, model runs noted the slower frontal speed and thus the continued threat of heavy precipitation. Please see Figures 17-22 for accompanying charts.

Locally Generated QPFs

The QPFs issued by WSFO Seattle are valid for 6-hour periods out through 48 hours, with a day-3, 24-hour amount. These forecasts are for internal use only and are not disseminated to the public. They are routinely made once each day and sent to the NWRFC for inclusion in numerical river basin models run by the RFC. During a significant event, they are produced twice each 24 hours and are amended more frequently if needed. Each QPF consists of predictions at 10 locations in Washington. There are three forecast points in the Cascades from Stampede Pass northward where most of the worst flooding took place. Typically, each QPF sent to the RFC results in a new set of river forecasts being returned to the WSFO. Thus, these internal forecasts are a critical element to successful prediction of flooding.

During the Thanksgiving weekend event, the QPFs were produced twice a day. The accuracy of the forecasts was truly outstanding during the first period of heavy rain. For example, the Stampede Pass forecast of 3.30 inches in the 24 hours ending at 00z, November 23, verified with 3.47 inches. The combination of heavy rain, rapid snowmelt, and the antecedent conditions brought most of the rivers on the west side of the Cascades to near flood stage on Thanksgiving Day.

Precipitation forecasts for the second period of heavy rain were initially not as good. They were based on the premise, as indicated in the numerical guidance, that the cold front would move through the area Friday evening and conditions behind the front would be showery. The forecasts issued during the day shift on November 23, that were based on the 12z run, indicated approximately 12 hours of heavy rain associated with the frontal passage, then decreasing rainfall. The 24-hour amount forecast for Stampede Pass, issued at 00z, November 24, predicted 2.10 inches. At 06z, this forecast was amended to include 1.75 inch in the six hours ending at 12z, November 24, and a total of 2.55 inches in the remaining 18 hours. This, combined with the 1.55 inch that fell between 00z-06z, November 24, indicated a 24-hour total of 4.10 inches. The QPF was again issued at 12z, November 24. The forecast for the first 12 hours was 2.70 inches. This, combined with the previous 12-hour precipitation of 3.15 inches, indicated a 24-hour total of 5.85 inches. The actual 24-hour total ending at 00z, November 25, was 7.56 inches at Stampede Pass. Forecasters indicated the updates were based primarily on the lack of movement of the back edge of the frontal band in the satellite imagery, as well as the gage reports of heavy rain.

The initial QPFs were based on the incorrect model solutions. The evening shift amended the forecasts 6 hours after the initial QPFs were issued, with significant precipitation predicted. This update had a dramatic effect on the river forecasts. The next shift similarly updated the forecast with continued very heavy rain. This, again, had a large impact on the river forecasts. The updates were timely and relatively accurate, given the nature of the event. Please see Figure 23 for accompanying chart.

General Summary of Warning Services

Overall, the warning services provided by WSFO Seattle were excellent. Both emergency service officials and the media (television, radio, and newspapers) were kept well informed and updated with forecasts and statements. Three products have been identified as decisive in providing this effective warning service.

1. The Special Weather Statement issued at 3 a.m., PST, on Monday, November 19, 1990, heightened awareness of a "potentially serious situation" on Thursday and Friday. Emergency management and the media reacted positively to this statement in preparing the public for possible flooding. Mention of this flood potential was also made in subsequent statements through Wednesday morning. The first flood bulletin was issued around noon on Wednesday, November 21.

2. An unscheduled Quantitative Precipitation Forecast (QPF), made around 10:30 p.m., Friday night, reversed the expected receding trend of the river forecasts. This QPF was made before the meteorological models showed the significant slowdown of the weather system. The update was based on satellite and observational data. The flood forecast, based on this update, gave emergency managers and the public over 12 hours lead time to prepare for increased flow and flooding.

3. The leading paragraph of Flood Bulletin No. 16, issued at 4:10 a.m., PST, on Saturday, November 24, 1990, urged persons on the Skykomish, Snoqualmie, and Snohomish Rivers to evacuate immediately. Near-record flows and river levels, higher than those of the last flood, were forecast. The WSFO was unable to coordinate this issuance with Snohomish County Emergency Management before the bulletin was released, but was able to contact them shortly after the forecast was disseminated. Snohomish County officials stated that this product aided immensely in their efforts to evacuate those in the flood area. Residents who would not have otherwise evacuated, left because of this call to action.

Based on river forecasts provided by the NWRFC in Portland, 79 Flood Bulletins were issued to the public by the Seattle WSFO from noon Wednesday, November 21, 1990, through Wednesday afternoon, November 28, 1990.

Prior to the issuance of Flood Bulletin No. 6, all river stages and forecast stages were contained in a single bulletin. Because of the expansion of flood conditions, the bulletins were broken up in distinct areas. Each area coincided with that of an RFC river stage and flow forecast model. The emergency management officials were happy to see the river information in three separate segments. This made it easy for them to extract the information they needed. On the other hand, some confusion developed in the media community when certain rivers were not included in every bulletin. After some explanatory phone conversations, however, the media adjusted well to this procedure.

At the beginning of this event, the Area Manager/Meteorologist in Charge (AM/MIC) at WSFO Seattle made a decision that flood warnings were not to be mentioned in the zone forecasts. Updating zone forecasts each time a new flood forecast was updated would have caused the forecaster workload to increase significantly. It was determined that the flood bulletins themselves would be sufficient to call emergency management and the general public, through the media and NWR, to appropriate action. This, indeed, was the case.

Overall, the products themselves were understood by the users and gave sufficient information. The term "rising to" was often used in the forecast portion of the flood warning bulletins. This indicated a rise in the near term (12 hours or less) but not necessarily a crest. Using this term avoided the need to include an uncertain crest (level and time) forecast beyond 12 hours. Emergency management officials were pleased with this wording because it gave them more flexibility in managing evacuation. People in potential flood areas will often use a dubious crest forecast to base their decisions on rather than the recommendations of emergency management officials. When the "rising to" term was used, a statement was included to explain that the crest would most likely occur at a later time. In these cases, crest information was available to emergency management officials through direct contact with the service hydrologist and forecasters at the WSFO.

Product users experienced some confusion with the meaning of the forecast when river levels were not forecast to rise because of water flowing over the dikes and the use of flow forecasts (CFS) in these situations. Explanations over the telephone seemed to satisfy the users.

Several corrections were made to flood bulletins during the episode. Although the corrected bulletins were timely, in some cases the users had to look carefully through both the original and the corrected bulletins to determine what had been corrected.

Detailed Forecast and Warning Chronology

NOVEMBER 21-26

QPF on November 20 indicated that third-day QPF could be 3.5-4.0 inches in the Cascade headwaters on Thanksgiving Day. NWRFC ran the river model and provided guidance that those rain amounts would produce major flooding on western Washington streams. County Departments of Emergency Services officials and Seattle Corps of Engineers were contacted to discuss rain/runoff potential.

QPF on November 21, 4 a.m., was considerably lighter than the previous day, but the NWRFC forecasts, with this QPF included, did indicate that several rivers would rise above flood stage: Cedar (Landsburg and Renton), White below Mud Mountain Dam, Nooksack, Skagit, Stilliguamish, Skykomish, Snoqualmie, and Snohomish. At 12:45 p.m., WSFO Seattle used this guidance to issue a flood warning for all mentioned streams to reach flood stage on Thursday.

Forecast updates at 6 p.m. on November 21 still indicated that all mentioned streams would reach levels near flood stage late Thursday. The NWRFC update at midnight continued the same guidance and warnings for Thursday.

QPF issued on November 23 at 6 a.m. indicated 2 to 3 inches in the headwater areas, which produced NWRFC guidance of rises to major flood levels on the Skagit, Snoqualmie, and Snohomish Rivers. Flood forecasts continued on all other rivers. WSFO Seattle flood warning, issued at 9:30 a.m., included mention of rise to major flood stage levels. Updated NWRFC guidance at 1 p.m., Thursday, continued flood forecasts on all north Cascade rivers, including potential for rise to major flood levels based upon QPF.

The evening update from NWRFC on Thursday, 6 p.m., indicated a rise to near flood stage on most north Cascade rivers Thursday evening, and then headwater areas dropping before more rain on Friday brought rivers to flood stage again late Friday. Downstream points on the Skagit and Snohomish Rivers were projected to continue to rise to 2-3 feet above flood stage by late Friday evening. On the Cedar River the forecast was revised to keep Landsburg and Renton below flood stage. WSFO Seattle's 7:30 p.m. release reflected this guidance. Forecast update at 11 a.m., Thursday, continued the same guidance.

Seattle's QPF guidance, issued on Friday, November 23 at 5:40 a.m., indicated 1-2-inch amounts in the Cascade headwaters but, more importantly, freezing levels which were at 5-7 thousand feet on Friday morning were projected to drop to 3-4 thousand feet. This meteorological guidance produced lower-crest forecasts for rivers, so that the Nooksack, Stillaguamish, Skykomish, and Snoqualmie (near Snoqualmie), and Cedar Rivers were expected to remain below flood stage. The forecast for the lower Skagit and lower Snohomish Rivers indicated a continued above-flood-stage condition. The WSFO release at 8:30 a.m., Friday, dropped flood warnings on the Snoqualmie River at Snoqualmie, Stillaguamish River, and Skykomish River. The update at noon indicated the next rain event would be of short duration, turning to showers late Friday and Saturday. Flood warnings continued on the Nooksack, Skagit, Snoqualmie near Carnation, Snohomish, and White Rivers.

QPF update issued at 5 p.m., Friday, increased the QPF for 4 p.m.-4 a.m., with 1.5-2.0 inches in the mountains and freezing levels remaining above 5,000 feet through Saturday, 4 a.m., then dropping to 3-4 thousand feet later Saturday. This updated QPF produced rises to above flood stage in all western Washington rivers. At 6 p.m., NWRFC issued guidance that all western Washington rivers would be going above flood stage early Saturday and continuing to rise. WSFO Seattle issued flood warnings for all northwestern Washington rivers except the Elwha and Cedar.

At about 7 p.m., WSFO Seattle contacted Jim Mathison at the NWRFC indicating very heavy rain in the Olympics with the Elwha River already at 20.6 feet (flood stage 20.0). Jim Mathison gave them a forecast for rise to 23 feet by 10 p.m., Friday, on the Elwha River. WSFO Seattle issued an Elwha River flood warning at 7:25 p.m. At 9:40 p.m., Jim Mathison raised the Elwha River forecast at McDonald Bridge to 25 feet by 11 p.m.

At 11 p.m., all western Washington river forecasts were updated. The updates reflected the heavy rain falling in the north Cascades and the updated QPF from WSFO Seattle, which indicated another 1.5 to 1.75 inches by 4 a.m., and then lighter amounts of .50 or less for the period 4 a.m. to 10 a.m., with freezing levels dropping 3-4 thousand feet on Saturday. This QPF update produced NWRFC guidance for all western Washington rivers that indicated a rise to major flood levels during the next 6 to 12 hours and rises to flood stage at Landsburg and Renton by Saturday mid-day. New flood warnings were issued by WSFO Seattle at 11 p.m.

At 1 a.m., Saturday, the NWRFC recognized that heavy rain was also causing rapid rises on the east slopes of the Cascades. A flood watch was issued for the upper Yakima River at 3 a.m., Saturday. A flood warning for Cle Elum River at Cle Elum was issued at 4:30 a.m. Flood guidance for the Yakima River was released at 8 a.m. by the NWRFC. WSFO Seattle issued a flood warning for the Yakima River at 10:50 a.m., Saturday.

The NWRFC thought that the Wenatchee River would also be rising rapidly. However, the Bonneville Power Administration (BPA) gage was out and no information was available. At 10 a.m., Friday, the NWRFC issued a flood forecast for the Wenatchee River. At about noon a visual reading was received for the Wenatchee River at Peshastin and indicated a stage of 13.8 feet, .8 feet above flood stage. With that information and some observer reports of very high flows in the headwaters, the NWRFC issued a crest forecast of 17 feet for Sunday morning (which would have been a record flood event). Actual peak was 18 feet. At 4 a.m., Sunday, Yakima River forecasts were raised to major flood proportions near Parker and at Kiona.

The NWRFC forecasts for western Washington streams were updated at 3:15 a.m., Saturday, to reflect excessive precipitation between 10 p.m. Friday and 4 a.m. Saturday. Several stations reported 2.5 to 3 inches in that 6-hour time frame. The updated forecasts indicated rises to major flood levels on all western Washington streams and record flow potential on the lower Snohomish River system. NWRFC coordinated with WSFO Seattle on the need to issue a call to action for very dangerous conditions on the Snohomish and lower Skagit Rivers. At 4:10 a.m., WSFO Seattle issued a warning for record flooding, urging evacuations. At 4:10 a.m., a warning was issued for major record flooding on all rivers and streams from the Nooksack to the Snohomish area.

At 5:34 a.m., Saturday, a forecast was issued by the NWRFC for the Satsop River to go over flood stage. At 6:46 a.m., a forecast for the Cedar River, near Landsburg and Renton, to also reach major flood levels was issued. At 8 a.m., WSFO Seattle issued flood warnings for rises to major flood levels on the Cedar and White Rivers.

At 8:15 a.m., Saturday, the NWRFC issued a forecast for the Snohomish levee overtopping with extremely dangerous flooding and urging major evacuation. The Skykomish River near Goldbar and the Snohomish River near Monroe were also forecast to peak at new record levels. At 9 a.m., Saturday, WSFO Seattle issued a special update for the Snohomish River to rise well above levee levels with major flooding imminent and major evacuation urgently needed.

Heavy rain continued from 4 a.m., Saturday, to 10 a.m., Saturday, with 2 to 2-1/2 inches in several locations. This caused an upward revision on several forecasts, notably the Skagit River at Concrete, to crest at 40.5 feet (12.5 feet over flood stage); the Skagit River near Mt. Vernon to crest at 36.0 feet (8 feet over flood stage); and Snoqualmie River near Snoqualmie to peak at a new record flow of 60,000 cfs. Near Carnation, the river was forecast to crest at a record level of 60.5 feet. This increased the record flow at Snohomish to above 150,000 cfs. WSFO Seattle's updated release issued at 6:45 p.m. had showed these increases.

At 6:45 p.m., an updated forecast on the Cedar River was issued by the NWRFC calling for an 8.5-foot crest near Landsburg and a 15.5-foot crest near Renton. Telephone coordination with WSFO Seattle revised the Landsburg forecast to a 9.5 foot crest.

The NWRFC updated a forecast on the Skagit River near Mt. Vernon based upon apparent cresting at gage. Predicted peak was lowered to 34.5 feet. WSFO Seattle's release on Sunday at 9 a.m. included this guidance. It was later learned that the Mt. Vernon

gage was inaccurate and the original predicted crest of 36-37 feet was probably correct. At 2 p.m., Sunday, the Mt. Vernon gage reported 38.3 feet. This was an impossible reading, as the whole city of Mt. Vernon would be under water at this level.

Note: A summary of WSFO staffing is contained in Appendix D and a summary of staffing and experience for the NWRFC is contained in Appendix E.

Chronology on the Cowlitz and Chehalis Rivers

NOVEMBER 24-25, 1990

On Saturday morning the heavy rain began moving farther south getting into the Nisqually, Upper Cowlitz, and Chehalis River basins. Rainfall rates were excessive - Olympia had 3 inches on Saturday and Sunday, and Ohanepecosh Ranger Station had 4.5 inches of rain from 4 a.m. on Saturday to 4 a.m. on Sunday.

At 5:30 a.m., the NWRFC issued a flood forecast for the Upper Cowlitz River at Packwood. The forecast was for a crest of 3 feet over flood stage by late Saturday. At 6 a.m. WSFO Seattle issued a flood warning for the Cowlitz River at Packwood.

At 7 a.m., November 24, the first forecast for the Chehalis River to rise above flood stage was issued by NWRFC. The Chehalis River at Chehalis was forecast to rise to flood stage by 8 p.m., Saturday, and to 69 feet by 4 p.m., Sunday. The Skookumchuck River was forecast to rise to flood stage (85 feet) by 10 a.m., Sunday. The WSFO issued a flood warning for the Nisqually, Skookumchuck and Chehalis Rivers at 8:55 a.m.

At 6:20 a.m., Saturday, the NWRFC issued a flood forecast for the entire Cowlitz River. The Kalama River near Kalama and the Cowlitz River near Randle, at Castle Rock and at Kelso, were expected to exceed flood stage. The RVF product for the Cowlitz River was resent at 11:30 a.m., Saturday, since WSFO Seattle's AFOS was down and they didn't receive the original flood forecast.

The NWRFC revised the Cowlitz River forecasts at noon Saturday to reflect observed rain through the morning. This update removed the Kalama River from the flood warning forecast. The WSFO issued a flood warning for the Cowlitz River forecast points below Packwood at noon Saturday.

When the Cowlitz River at Castle Rock is forecast to rise above flood stage, the NWRFC is obligated to coordinate with Tacoma City Light schedulers and the U.S. Army Corps of Engineers

Reservoir Control Center so that coordination can be done on Mossyrock Dam regulation. These contacts were made at 6:45 a.m., Saturday.

The delayed release of the Cowlitz River flood warning near Randle at Castle Rock and at Kelso, because of an AFOS outage, caused some consternation for the local warning center. They were aware of NWRFC discussions with Tacoma City Light about potential flooding but had received no public flood warning.

The Cowlitz River forecasts were updated after the 4 p.m. observed precipitation to show Randle cresting 4 feet above flood stage Sunday, and Castle Rock cresting 2.5 feet above flood stage Sunday morning.

At 4 p.m., Saturday, NWRFC put the observed precipitation from 10 a.m. to 4 p.m. into the model and updated the Chehalis River forecasts. Extremely heavy rain had fallen during this period over most of the basin. The revised forecasts issued at 4 p.m., Saturday, indicated that Chehalis River at Centralia would crest at 72 feet (7 feet over flood stage) at 6 p.m., Sunday, and the Skookumchuck River would crest at 86 feet on noon Sunday. These forecasts were released to the public by WSFO Seattle at 4:30 p.m.

These forecasts remained unchanged until midnight Saturday when the Skookumchuck River forecast was raised to crest at 87.0 feet at 10 a.m., Sunday. This was released by WSFO Seattle at 3 a.m., Sunday.

PART III
DISSEMINATION

Emergency management, the media, and the public received NWS flood bulletins and other information through a variety of dissemination systems. All were satisfied with the dissemination of NWS products through these systems.

NWWS - All public flood warning products and statements were uplinked directly from the WSFO to the NOAA Weather Wire Service (NWWS). No outages of the system occurred during the event. There are currently twelve NWWS subscribers in Washington State (see Appendix F). All are located in the area of the flood event. Those using NWS flood warnings and statements directly are the State of Washington Department of Emergency Management, Snohomish County Department of Emergency Management, City of Tacoma, U.S. Army Corps of Engineers, KIRO TV, KGNW-AM radio, and KMPS-AM/FM radio. Many of the local law enforcement agencies and emergency management offices receive a relay of NWS bulletins through the law enforcement teletype network from the State of Washington Emergency Management office. Other media organizations receive NWS bulletins through other wire services such as WSID or AP. There did not appear to be any significant delays of products through these alternate systems.

Weather Radio (NWR) - The computerized digital storage device, used as the NWR console for both the Seattle and Neah Bay broadcasts, performed without problems. All who used the system to broadcast flood bulletins and information were pleased with its ease of use and the recording time saved over that required of the AMPRO system. However, the advantages of the system may also present potential problems to the NWR program itself. Because it is so easy to program and there is essentially no limit on the number of products that can be in the broadcast cycle, NWS broadcasters paid little attention to the need to limit the number of products being broadcast. The NWR broadcast was occasionally longer than advisable. The limitations of a tape-driven system would have forced a reduction of products in the cycle.

NAWAS - The NAWAS system remains the only means of alert that some of the emergency management agencies have for watch and warning messages. Most agencies that have hard-copy capability rely on NAWAS as the initial alert for watch/warning products. The main complaint about the system came from the WSFO staff regarding its demand on staff time to broadcast information. In general, NAWAS procedures and formats were followed by the WSFO staff. On one occasion, when information relayed over NAWAS was abbreviated due to time constraints, the WSFO received calls asking for more information. Given user reliance on NAWAS, it is unlikely that the demand on WSFO staff time will change in the near future.

TELEFAX - Several times during the flood event, the telephone facsimile recorder was used to transmit flood bulletins to media organizations. A new ROML (not issued before this flood) regarding the use of telephone facsimile recorders states that they may not be used to disseminate NWS products available on NWWS or NWR to the media except when these means of receipt are out of service. Every effort must be made by the WSFO to expand NWWS subscribers to include these media organizations.

TELEPHONE - Media and public telephone lines became saturated during the flood event. Even with extra help to answer calls, the public line had to be turned off for several hours on Friday, November 23. The media telephone number evidently has been obtained by many nonmedia persons, accounting for the increase on this line. Many of the calls on the media line were for updates of the flood forecast when no new information was available. To eliminate some calls, the media should be made aware, through preparedness efforts, of our limitations due to the frequency of guidance from meteorological models. Other calls could be eliminated by providing more information in the flood bulletins themselves, such as when the next statement or bulletin will be issued.

AFOS/PCs - there were no major AFOS problems during the flood event. However, occasional crashes and unexplained loss of products took a toll on the efficiency of the warning program. Occasionally there was competition for AFOS/PC consoles and the hydrologist had to run back and forth from the hydrologist's area to the forecast area to issue products. A major improvement would be to connect the hydrology computer directly to AFOS. As an interim solution, the public forecaster's ABT could be turned around into the hydrologist's area for exclusive use in major flooding situations. Forecasters can use the AFOS console for their products. The Page Five Append program can be used to accommodate the zones. In the long term, a local area network could help solve many of these AFOS problems.

PART IV
PREPAREDNESS ACTIVITIES

The most recent hydrology exercise was given to the WSFO Seattle staff in June 1990. The exercise included questions about proper hydrologic product headers, guidance materials, instructions and where they are found, as well as SHEF format decoding.

The acting Service Hydrologist during this event, Robert Jackson, received two weeks of one-on-one training from the Service Hydrologist, Lee Krogh, before Lee moved to his new position in Western Region Headquarters in October. Mr. Jackson had also been given occasional opportunities in the past to perform hydrology duties. In addition, Mr. Jackson participated in flood awareness meetings in the cities of Auburn and Issaquah.

The Seattle WSFO management has made it a practice to cross-utilize and cross-train all forecasters and interns in the Hydrology Program. During this flood event, several forecasters and interns performed hydrologic duties. Along with the ability to work the "hydro desk", this cross-training gives the forecasters a better understanding of how hydrology and meteorology interrelate. A sensitivity of forecasters to the needs of the Service Hydrologist, the RFC, and the Hydrology Program in general, has been developed in Seattle.

Preparedness activities between the service hydrologist and other staff members and the user community have led to understanding of NWS operations and effective cooperation. This was evident in our discussions with emergency management and media officials, as well as with the Corps of Engineers.

Some emergency management officials depend entirely on telephone calls from the NWS or some other organization for flood warning information. The King County Flood Warning Center was disappointed that more calls and coordination did not come from the NWS, as has been the case in the past. However, few flood events involving King County have been as extensive as this, so special contact with King County was not possible. Subscription to the NWWS was discussed with the King County flood coordinator. WSFO management should follow up with King County regarding NWWS. If NWWS is not feasible for the King County Flood Warning Center, then some other arrangements to meet their needs for information during flood events should be developed.

PART V
USER RESPONSE

Overall, all users surveyed were pleased with the quality and timeliness of the warning and forecast services provided by the NWS prior to and during the event, and felt the NWS did a good job. Following are summaries of persons contacted and their comments:

1. Rich Marriott, Channel 5, KING TV (full time), and meteorologist (part-time) at the Northwest Avalanche Center.

Mr. Marriott is a meteorologist and has worked closely with the NWS for many years at WSFO Seattle as an avalanche meteorologist and now is with KING TV. KING TV gets their weather information through WSID, who receives the information from the family of services. There appears to be about a 10-minute delay. The overall perception at the TV station was that "people were well warned." This was a big story for the Pacific Northwest, with lots of resources used to bring in the stories, and viewership was very high.

Mr. Marriott suggested that a composite list of all rivers flooding be made from time-to-time. (WSFO Seattle grouped the rivers into several different groups and then issued warnings for a group at a time.) "Rip-and-read" people had difficulty seeing the big picture.

2. Mike Razey, Acting Director of Snohomish County Department of Emergency Management (DEM):

Mr. Razey has worked closely with the NWS for about 8 years in Snohomish County in the capacity of Coordinator in the Department. The county is a subscriber to the NOAA Weather Wire Service (provided under contract by Contel). Warnings are received via NAWAS at SnoPac (which is the 911 center), then relayed to the Emergency Operations Center (EOC) or to a duty officer (after normal duty hours). Once the EOC is aware of a flood warning, they activate a call to about 12 agencies within the county.

Mr. Razey said that on the morning of Saturday, November 24, they were busy in the EOC with an attitude of "business as usual for high flooding." Then, at 9 a.m., they received Flood Warning No. 21 which urged EVACUATION of the flood plain for the Snohomish River because the river would rise well above levee levels. Knowing that the Weather Service "never urges evacuation", he knew it was serious and started all the wheels moving to evacuate the several hundred or more people from the flood plain. He stated that this gave them a 12-hour lead time, and the only people who later required rescuing were those who refused to leave their homes when advised.

Mr. Razey also stated that they were not sure what the following information meant in Flood Warning No. 23 ... 9 a.m. reading 32.4 feet, forecast 32.4 feet (levee top with flow of 92,000 cfs) at 1 p.m. today and flow continue to increase to 145,000 cfs at 1 a.m. Sunday morning ... They immediately called WSFO Seattle and were advised that while the flow would continue to increase, the gage height would not continue to rise because the excess flow would go over the levees and inundate the area behind the levees.

3. Skagit County Citizen:

Prior to our meeting with the Skagit County DEM, we stopped along a flooded road and talked with an elderly couple. Their home is next to a dike in the lower Skagit system and leakage through the dike had isolated them from their home. They seemed quite knowledgeable about the river and stated that they had 24-hour notice of the major rise. Being farmers, they pay close attention to the weather at all times. They receive their weather information from the local radio stations in Mt. Vernon. KBRC is one of the radio stations. KBRC receives its weather and flood information from AP. During the flood, they worked closely with Skagit County DEM. The other radio station is KAPS and they receive their weather and flood information by monitoring the NOAA Weather Radio. During the flooding, they had two reporters in the field and also were working closely with Skagit County DEM.

4. Don Nelson, Head Engineer for Skagit County Department of Public Works:

Mr. Nelson is a knowledgeable person who has worked closely with WSFO Seattle over a long period of time. He felt that the support from WSFO Seattle was good. He liked the initial notice on Monday of potential heavy rain and flooding problems for later in the week. This allowed the county and USCE time to do a fast repair job on the levees for Fir Island, as well as other fast fixes in the county.

Mr. Nelson also commented on the direct service he received from WSFO Seattle. The WSFO would brief him (as they did each county) on the current forecast which was given to the public and on the long-range planning forecast (not disseminated to the public). Mr. Nelson felt that the planning forecasts were great planning tools but agreed that because of the potential for large errors, they should not be given public dissemination.

5. Staff at State of Washington, Division of Emergency Management in Olympia, Washington:

Dave Rider was working at the EOC in Whatcom County during this event. From his perspective, things went well.

Lora Murphy was in the Lewis County EOC during the flooding and she said that the county had "a high level of comfort using NWS flood products."

Gene Bostock was the Duty Officer at the EOC for the State of Washington during much of the flooding. He felt that the NWS did an excellent job but he had the following comments:

A. When a warning is issued over AFOS and the announcement of it is issued over NAWAS, WSFO Seattle should make certain that the Duty Officer at either the Washington Control Point (Washington State Patrol) or at the Washington Alternate Control Point (WA DEM EOC) acknowledges receipt and takes a roll call of the counties involved. If necessary, the Washington Alternate Control Point Duty Officer may have to be paged. The ability to page the Duty Officer was something which had not been coordinated in the past.

B. The ability of WSFO Seattle to do a RING over NAWAS, and thus do their own roll call, was lacking. WA DEM had previously contacted AT&T several times to get this malfunction corrected, to no avail. This problem was corrected in early February 1991.

C. When a product is corrected, it would be very helpful to give some indication as to what the correction is. With many numbers in the warnings, they would have to carefully compare the two messages line-by-line to find what had been corrected.

D. When WSFO Seattle changed their format from listing all rivers on a single warning to grouping the rivers on different warnings, WA DEM EOC was a little confused for a while, but as soon as they realized what was happening, they liked the new arrangement. They found it easier to keep up with the forecasts and post them on their boards.

6. The USCE staff in Seattle, Reservoir Control Section:

The survey team interviewed 7 people in this department, all of whom were very complimentary of the NWS efforts, both those of the NWRFC, with whom they work directly, and WSFO Seattle. They have access to the QPF issued at WSFO Seattle and the river forecasts produced by the NWRFC via the Columbia River Operational Hydromet System (CROHMS). They were impressed by the number of extra QPFs issued and the many river forecast model runs made to keep up with changing situations. The heads-up call, very early in the week from Bob Jackson, allowed them to gain much needed flood control space in several of their projects.

In talking with the USCE about long range river forecasts (second and third day), they want the extended information for in-house use but they don't think it should be given to the public due to the changeable nature of the planning forecasts.

The USCE offered the following suggestions:

When the NWRFC completes a run, the USCE would like a telephone call so they can go to CROHMS and retrieve it.

The USCE and WSFO Seattle need to see if they can establish a closer working relationship with Seattle Water Department. For the first time in many years, Chester Morse Lake filled and the operators opened a large gate on the spillway. This caused a considerable increase in the flow in the Cedar River. Seattle Water Department failed to coordinate this action with the USCE or the NWRFC.

7. Jerry Creek, King County Public Works, Surface Water Division:

Mr. Creek said that the flood warnings were good and there were no major problems. The one point that Mr. Creek made was that they do not receive NWS products in their EOC and they could use a few more coordination calls when products are issued. It was suggested that they contact WSFO Seattle to obtain information about NOAA Weather Wire (Contel).

8. Nick Walker, daytime Weather Caster on KIRO TV in Seattle:

Mr. Walker felt the public was getting the needed information related to the flooding and flood forecasts. He felt as did Rich Marriott of KING TV, that one list which included all river floods should be issued from time-to-time. KIRO is a subscriber to the NOAA Weather Wire.

It was interesting to note that several of the people interviewed use the term "ALERTS" rather than watches, warnings, or statements.

Summary

Overall, the forecast and warning service during this event was outstanding. As noted throughout the report, cooperation among the NWRFC, WSFO Seattle, and field offices was impressive. Critical Hydrologic information was disseminated to the public, hydrologic users, and emergency management agencies in a timely fashion over NOAA Weather Wire Service, NOAA Weather Radio, NAWAS, telephone, and by many media outlets serving the flood-affected areas. All media and emergency management agencies contacted were highly complimentary of the services that they received from the NWS.

WS FORM E-3
(5-71)
(PRES. BY WSOM E-41)

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE

RIVER DISTRICT OFFICE
WSFO, Seattle, Washington

REPORT FOR:
MONTH: November
YEAR: 1990

FLOOD STAGE REPORT

RIVER AND STATION	FLOOD STAGE (Feet)	ABOVE FLOOD STAGES (Dates) FROM	ABOVE FLOOD STAGES (Dates) TO	CREST STAGE (Feet)	CREST DATE
Elwha River at McDonald Bridge	20	11/10	11/10	20.06	11/10
Cedar River nr Landsburg	5	gage outage unkn	unkn	4.64	11/09
Cedar River at Renton	12	11/09	unkn	12.29	11/10
White River below Mud Mountain Dam	4500 cfs	11/09	11/11	5200 cfs	11/10
Skykomish River nr Gold Bar	15	11/09	11/10	21.01	11/10
Snoqualmie River nr Snoqualmie Falls	20000 cfs	11/09	11/10	49100 cfs	11/10
Snoqualmie River nr Carnation	54	11/09	11/12	59.42	11/10
Snohomish River nr Monroe	15	11/09	11/12	21.75	11/10
Snohomish River at Snohomish	25	11/09	11/12	32.72	11/10
Stillaguamish River at Arlington	16	11/09	11/10	19.35	11/10
Skagit River nr Concrete	28	11/09	11/12	40.20	11/10
Skagit River nr Mt. Vernon	28	11/10	11/15	36.60	11/11
Nooksack River at Deming	12	11/09	11/11	15.40	11/10

WS FORM E-3 SUPERSEDES WB FORM E-3 WHICH MAY BE USED

WS FORM E-3
(5-71)
(PRES. BY WSOM E-41)

U.S. DEPARTMENT OF COMMERCE
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REPORT FOR:
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FLOOD STAGE REPORT

RIVER AND STATION	FLOOD STAGE (Feet)	ABOVE FLOOD STAGES (Dates) FROM	TO	CREST STAGE (Feet)	CREST DATE
Nooksack River at Deming	12	11/24	11/25	14.59	11/24
Elwha River at McDonald Bridge	20	11/24	11/25	23.56	11/24
Skagit River nr Concrete	28	11/24	unkn	39.89	11/24
Skagit River nr Mt. Vernon	28	11/24	11/27	37.37	11/25
Skykomish River nr Gold Bar	15	11/24	11/25	22.49	11/24
Snoqualmie River nr Snoqualmie	20000 cfs	11/24	unkn	74300 cfs	11/24
Snoqualmie River nr Carnation	54	11/23	unkn	gage out at 60.59	11/25
Snohomish River nr Monroe	15	11/23	11/26	25.42	11/25
Snohomish River at Snohomish	25	11/23	gage out at unkn	33.50	11/25
Stillaguamish River at Arlington	16	11/24	11/25	19.95	11/24
Cedar River nr Landsburg	5	11/24	11/26	9.08	11/25
Cedar River at Renton	12	11/24	11/26	16.40	11/25
White River below Mud Mountain Dam	4500 cfs	11/22	11/30	9500 cfs	11/24
Cowlitz River at Castle Rock	22	11/24	11/25	25.77	11/24

WS FORM E-3
(5-71)
(PRES. BY WSOM E-41)

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
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REPORT FOR:
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FLOOD STAGE REPORT

RIVER AND STATION	FLOOD STAGE (Feet)	ABOVE FLOOD STAGES (Dates) FROM	TO	CREST STAGE (Feet)	CREST DATE
Cowlitz River at Packwood	10.5	11/24	11/25	12.40	11/25
Cowlitz River nr Randle	18	11/25	11/26	23.6	11/25
Cowlitz River at Kelso	20	11/25	gage outage unkn	unkn	11/25
Skookumchuck River at Centralia	85	11/24	11/26	86.5	11/25
Chehalis River at Centralia	65	11/25	11/26	71.3	11/25
Satsop River nr Satsop	34	11/24	11/25	35.75	11/24
Puyallup River nr Orting	10.5	11/24	11/24	10.5	11/24
Yakima River nr Parker	10	11/24	11/27	14.5	11/26
Yakima River at Cle Elum	6.9	11/24	11/26	9.7	11/25
Yakima River at Ellensburg	34	11/24	11/25	34.3	11/25
Yakima River at Kiona	13	11/27	11/28	15	11/27
Yakima River at Richland	368	11/25	11/29	370.1	11/28
Naches River nr Naches	17	11/24	11/25	17.6	11/25
Naches River nr Cliffdell	31	11/25	11/25	31.8	11/25
Wenatchee River at Peshastin	13	11/25	unkn	17.6	11/25

WS FORM E-3 SUPERSEDES WB FORM E-3 WHICH MAY BE USED

APPENDIX B

US GEOLOGICAL SURVEY, PACIFIC NORTHWEST DISTRICT
FLOOD DATA FOR SELECTED SITES IN WASHINGTON, NOVEMBER 1990
(Provisional Data; subject to revision)
Current as of 12/03/90

WRD station number (1)	Stream and place of determination (2)	Drainage Area (square miles) (3)	Period of known floods (4)	Max flood previously known			Maximum during present flood				
				Date (5)	Stage (feet) (6)	Discharge (cfs) (7)	Date (8)	Stage (feet) (9)	Discharge Cfs (10)	Discharge Cfs per sq mi (11)	Recurrence interval (yrs) (12)
12013500	Willapa River nr. Willapa	130	1948-	01/09/90	24.06	11,700	11/10/90	10.84	2,650	20	<2
							11/24/90	24.21	11,800	91	25
12025700	Skookumchuck River nr Vail	40	1967-	01/20/72	10.93	6,900	11/09/90	6.92	1,600	40	<2
							11/24/90	10.30	5,910	148	25
12027500	Chehalis River nr Grand Mound	895	1928-	01/10/90	19.34	68,700	11/10/90	9.14	7,110	8	<1
							11/24/90	18.12	48,000	54	25
12035000	Satsop River nr Satsop	299	1929-	01/22/35	38.9	46,600	11/10/90	33.78	27,700	93	2
							11/24/90	35.75	38,200	128	10
12040500	Queets River nr Clearwater	445	1930-49 1950-67 1974-	01/22/35	27.0	130,400	11/10/90	24.19	98,900	222	10
							11/24/90				
12045500	Elwha River nr Port Angeles	269	1897-1901 1918-	11/18/ 1897	14.5f	41,600	11/10/90	20.08	19,000	71	5
							11/23/90	23.76	28,800	107	25
12056500	N.F. Skokomish nr Hoodsport	57.2	1924-	11/05/34	14.4	27,000	11/10/90	7.35	6,550	115	2
							11/23/90	8.80	9,980	174	5
12083000	Mineral Creek nr Mineral	75.2	1942-	01/09/90	13.56	13,500	11/09/90	9.80	1,630	22	<1
							11/24/90	12.57	8,770	117	25
12095000	S. Prairie Creek nr S. Prairie	79.5	1949-71 1987-	12/11/55	9.78f	6,850	11/09/90	30.57	2,100	26	<2
							11/24/90	32.45	4,400	55	5
12101500	Puyallup River at Puyallup	948	1914-	12/10/33	31.0	57,000	11/10/90	19.09	18,000	19	<2 a
							11/24/90	26.99	41,200	43	25 a
12114500	Cedar River below Bear Creek	25.4	1945-63 1975-	11/22/59	6.98f	7,620	11/09/90	6.30	2,570	101	5
							11/24/90	6.78	3,190	126	10

12119000	Cedar River at Renton	184	1945-	12/04/75	14.14	8,800	11/10/90	12.29	3,780	21	2 a
							11/25/90	16.4c	8,800c	48	100 a
12134500	Skykomish River nr Gold Bar	535	1928-	12/26/80	21.38	90,400	11/10/90	21.01	86,800	162	25
							11/24/90	22.49	101,600	190	50
12141300	M.F. Snoqualmie River nr Tanner	154	1961-	11/23/59	18.7	49,000	11/09/90	12.76	21,000	136	5
							11/24/90	14.97	30,100	195	50
12144500	Snoqualmie River nr Snoqualmie	375	1958-	11/23/59	19.78	61,000	11/10/90	18.23	49,100	131	10
							11/24/90	21.1	74,300	198	100
12145500	Raging River nr Fall City	30.6	1945-	11/23/86	6.27	5,330	11/09/90	5.72	3,900	127	25
							11/24/90	6.34	5,540	181	100
12150800	Snohomish River nr Monroe	1,537	1963-	12/04/75	22.92	115,000	11/10/90	21.75	101,200	66	25
							11/25/90	25.42	135,500	88	1.20b
12186000	Sauk River nr Darrington	152	1928-	12/26/80	16.03	40,100	11/10/90	11.90	22,000	145	10
							11/24/90	12.56	24,600	162	25
12194000	Skagit River nr Concrete	2,737	1924-	1815	69.3	500,000	11/10/90	40.20	148,800	54	25a
							11/24/90	39.89	146,000	53	25a
12200500	Skagit River nr Mt. Vernon	3,093	1940-	1906	37	180,000	11/11/90	36.6c	142,000	46	50a
							11/25/90	37.37	152,000	50	100a
12210500	Nooksack River nr Deming	584	1935-	02/27/32	16.8	49,300	11/10/90	15.40	40,000 c	68	25
							11/24/90	14.59	35,000 c	60	10
12213100	Nooksack River nr Ferndale	786	1966-	12/03/75	21.97	52,700	11/11/90	23.59	55,000cd	70	100
							11/25/90	22.30	49,000c	62	25
14233400	Cowlitz River nr Randle	1,030	1947-	12/03/77	26.54	89,300	11/10/90	13.42	15,100	15	<2
							11/25/90	23.60	66,200	64	25
12451000	Stehekin River nr Stehekin	321	1910-15 1926-	05/29/48	29.00	18,900	11/10/90	26.61	12,600	39	5
							11/24/90	27.45	14,800	46	10
12457000	Wenatchee River at Plain		1910-79 1989-	05/29/48	12.48	22,700	11/25/90	14.27	31,900	54	1.39b
12462500	Wenatchee River at Monitor	1,301	1962-	12/27/80	27.23	29,600	11/25/90	29.79	43,000	33	1.18b

(a) Regulation

(b) Recurrence interval greater than 100 years. Value shown approximately ratio of discharge to that of a 100-year flood.

(c) Estimated

(d) Tidal backwater effect

(e) Not determined

(f) At different datum

APPENDIX C

List of Applicable Bulletins and Statements

Time (PST)/Date	Product	Comments
300 am/Mon Nov 19	SPS	Contained headline and information regarding flood potential for western Washington rivers. First statement concerning the event.
945 am/Tue Nov 20	SPS	Mention of possible flooding in western Washington. Emphasis on Winter Storm Warning and Snow Advisories.
830 pm/Tue Nov 20	SPS	Mention of possible flood problems. Emphasis on Winter Storm Watch and Snow Advisories.
325 am/Wed Nov 21	SPS	"People living along the flood plains of the rivers from the Nooksack south to the Nisqually should stay tuned for possible Flood Watches or Warnings later in the day."
1215 pm/Wed Nov 21	FLW	Bulletin #1 - Flood stage expected on the Cedar, Nooksack, Skagit, Stillaguamish, Skykomish, Snoqualmie, and Snohomish Rivers Thursday morning through Friday morning.
335 pm/Wed Nov 21	SPS	One of three headlines - "Flooding is expected Thanksgiving Day and Friday along eight major rivers of western Washington."
715 pm/Wed Nov 21	FLS	Bulletin #2 - Forecast adjusted time of flood stage expected on rivers in Bulletin #1 to mid-day Thursday through late Thursday evening.
830 pm/Wed Nov 21	SPS	Same headline as at 3:35 pm.
120 am/Thu Nov 22	FLS	Bulletin #3 - Forecast the same as in Bulletin #2.
530 am/Thu Nov 22	FLS	Bulletin #4 - 18-hour rainfall amounts from western Washington.
930 am/Thu Nov 22	FLW	Bulletin #5 - Flood Warning issued for White River. Update for Cedar, Nooksack, Skagit, Stillaguamish, Skykomish, Snoqualmie, and Snohomish Rivers.
1130 am/Thu Nov 22	FLS	Bulletin #6 - Update for Cedar and White Rivers only. None above flood stage yet.
130 pm/Thu Nov 22	FLS	Bulletin #7 - Updated information on Nooksack, Skagit, Stillaguamish, Skykomish, Snoqualmie

		and Snohomish Rivers. None above flood stage yet.
300 pm/Thu Nov 22	SPS	Along with High Wind Watch and High Wind Warning, discussed river flooding.
730 pm/Thu Nov 22	FLS	Bulletin #8 - Flood Warning cancelled for Cedar River, continued for Nooksack, Skagit, Stillaguamish, Skykomish, Snoqualmie, Snohomish, and White Rivers. Snoqualmie at flood stage, others getting close.
815 pm/Thu Nov 22	FLS	Bulletin #8 - Corrected Snohomish River forecast.
1215 am/Fri Nov 23	FLS	Bulletin #9 - Update on rivers in Bulletin #8. Snoqualmie over flood stage. All others near flood stage.
830 am/Fri Nov 23	FLS	Flood Warning dropped for Stillaguamish, Skykomish and upper Snoqualmie Rivers. Flood stage reached on Skagit, Snohomish, and lower Snoqualmie Rivers.
1100 am/Fri Nov 23	SPS	One of three headlines - "Heavy rain potential continues."
130 pm/Fri Nov 23	FLS	Bulletin #11 - Flood Warning continues on Nooksack, Skagit, Snohomish, lower Snoqualmie and White Rivers.
530 pm/Fri Nov 23	SPS	One of three headlines - "Heavy rain threat expected to end in the west and Cascades by Saturday morning but Flood Warnings continue for some rivers in the west."
630 pm/Fri Nov 23	FLW	Bulletin #12 - Flood Warnings again issued for Stillaguamish, Skykomish, and upper Snoqualmie Rivers.
725 pm/Fri Nov 23	FLW	Bulletin #13 - Flood warning issued for Elwha River.
830 pm/Fri Nov 23	SPS	One of three headlines - "Flood Warnings continue on many western Washington rivers tonight through Saturday."
945 pm/Fri Nov 23	FLW	Bulletin #14 - Update on Elwha River. 3.6 ft. over flood stage at 9 pm.
1100 pm/Fri Nov 23	FLS	Bulletin #15 - Flood Warnings continue for Nooksack, Skagit, Snohomish, Snoqualmie, Skykomish, Stillaguamish, and White Rivers. Crests and flows increased. Sentence in the

		body of the forecast read **"This is a dangerous flood and persons should stay tuned to the latest forecast."**
300 am/Sat Nov 24	FFA	Flood Watch issued for the Yakima and Naches River basins of south central Washington for Saturday.
410 am/Sat Nov 24	FLS	Bulletin #16 - Flood Warning issued for Cedar River. Update for rivers in #15 and Elwha River. **Call to action for immediate evacuation along the Skykomish, Snoqualmie, Snohomish and Skagit Rivers.**
600 am/Sat Nov 24	FLW	Bulletin #17 - Flood Warning issued for the Cowlitz and Satsop Rivers.
630 am/Sat Nov 24	FLW	Bulletin #18 - Flood Warning issued for the Yakima River.
800 am/Sat Nov 24	FLW	Bulletin #19 - Flood Warning issued for the Green and Puyallup Rivers. Updates on Cedar and White Rivers.
845 am/Sat Nov 24	FFS	Urban Flood Statement - local flooding of roadways in the Seattle area.
855 am/Sat Nov 24	FLW	Bulletin #20 - Flood Warning issued for Nisqually, Chehalis and Skookumchuck Rivers. Update on Satsop River.
900 am/Sat Nov 24	FLW	Bulletin #21 - Special update for the Snohomish River - expected to rise well above levee levels with major flooding imminent. Major evacuation urgently needed.
902 am/Sat Nov 24	SPS	From WSO Olympia. Major rivers, small streams, ditches, roadways and low areas are flooding or expected to flood.
930 am/Sat Nov 24	SPS	Urban and small stream flooding as well as major river flooding in western Washington.
950 am/Sat Nov 24	FLW	Bulletin #22 - Flood Warning issued for Naches River. Update on Yakima River.
1000 am/Sat Nov 24	FLW	Bulletin #23 - Flood Warning update for Nooksack, Skagit, Stillaguamish, Skykomish, Snoqualmie, and Snohomish Rivers. All rivers currently over flood stage.
1130 am/Sat Nov 24	FLS	Bulletin #24 - Summary of Flood Warnings for Nooksack, Skagit, Stillaguamish, Skykomish, Snohomish, Snoqualmie, and Elwha Rivers.

1200 pm/Sat Nov 24	FLW	Bulletin #25 - Flood Warning expanded on Cowlitz River.
1220 pm/Sat Nov 24	FLW	Bulletin #26 - Flood Warning update for Cedar, Green, Puyallup, and White Rivers.
1230 pm/Sat Nov 24	FLS	Bulletin #27 - Flood Warning update for Nisqually, Chehalis, Skookumchuck, and Satsop Rivers.
145 pm/Sat Nov 24	FLW	Bulletin #28 - Flood Warning issued for the Wenatchee River. Update on Yakima and Naches Rivers.
330 pm/Sat Nov 24	SPS	Heavy rains..major river flooding..urban and small stream flooding in western Washington.
345 pm/Sat Nov 24	FLS	Bulletin #29 - Update for Nooksack, Skagit, Stillaguamish, Snohomish, Snowqualmie, and Cedar Rivers. All above flood stage. Snohomish over levee top.
430 pm/Sat Nov 24	FLS	Bulletin #30 - Update for Nisqually, Chehalis, Skookumchuck, and Satsop Rivers.
600 pm/Sat Nov 24	FLW	Bulletin #31 - Flood Warning issued for the Kalama River. Update for Cowlitz River.
645 pm/Sat Nov 24	FLS	Bulletin #32 - Update for Rivers in #29 and Elwha River. Nooksack, Stillaguamish, and Elwha Rivers falling.
700 pm/Sat Nov 24	FLW	Bulletin #33 - Update for the Cedar, White, Green, and Puyallup Rivers.
715 pm/Sat Nov 24	FLS	Bulletin #34 - Update for Nisqually, Chehalis, Skookumchuck, Elwha, and Satsop Rivers. Satsop receding slowly.
900 pm/Sat Nov 24	FLS	Bulletin #35 - Update for the Yakima, Wenatchee, and Naches Rivers. All continue to rise. All above flood stage at some locations.
1030 pm/Sat Nov 24	SPS	Major river and small stream flooding continues. Snow level lowering through Sunday.
1045 pm/Sat Nov 24	FLS	Bulletin #36 - Summary of **record breaking floods** on the Cedar, Skykomish, Snoqualmie, Snohomish and Stillaguamish Rivers.
1225 am/Sun Nov 25	FLS	Bulletin #37 - Flood Warning dropped for Kalama River but continued for Cowlitz River.

135 am/Sun Nov 25	FLS	Bulletin #38 - Flood Warnings dropped for Elwha, Nooksack, and Puyallup Rivers. Flood Warnings continue for Skagit, Stillaguamish, Snohomish, Skykomish, Snoqualmie, Cedar, Nisqually, Chehalis, Skookumchuck, and Satsop Rivers.
305 am/Sun Nov 25	FLS	Bulletin #39 - Update for Cedar, Chehalis, and Skookumchuck Rivers. All above flood stage.
530 am/Sun Nov 25	FLS	Bulletin #40 - Update for Yakima, Wenatchee, and Naches Rivers. River levels on Yakima River expected to be higher than those of the December 1977 flood. Freezing level dropping in Cascades.
545 am/Sun Nov 25	FLS	Bulletin #41 - Update statement #40 to include crest times.
555 am/Sun Nov 25	SPS	Cooler, drier air spreading into Washington, turning rain to snow.
740 am/Sun Nov 25	FLS	Bulletin #42 - Update for Cedar and White Rivers. Cedar falling below flood stage today.
740 am/Sun Nov 25	FLS	Bulletin #44 - Update for the Cedar and White Rivers.
800 am/Sun Nov 25	FLS	Bulletin #43 - Flood Warning dropped for Satsop River. Update for Nisqually, Chehalis, and Skookumchuck Rivers.
815 am/Sun Nov 25	FLS	Bulletin #45 - Update for Cowlitz River.
900 am/Sun Nov 25	FLS	Bulletin #46 - Flood Warnings dropped for Stillaguamish River. Update for Snowqualmie, Snohomish, Skykomish, and Skagit Rivers. Snohomish remains over levee tops.
1100 am/Sun Nov 25	SPS	River flooding across western Washington and east slopes of Cascades. Next storm will be more winter-like.
1215 pm/Sun Nov 25	FLS	Bulletin #47 - Update on Yakima, Wenatchee, and Naches Rivers.
215 pm/Sun Nov 25	FLS	Bulletin #48 - Update for #47 of downstream crests and timings.
240 pm/Sun Nov 25	FLS	Bulletin #49 - Flood Warning dropped for the Skykomish River. Update for Snoqualmie, Snohomish, and Skagit Rivers. All have crested and are receding.

300 pm/Sun Nov 25	FLS	Bulletin #50 - Update for Cowlitz River. Crested and receding.
330 pm/Sun Nov 25	FLS	Bulletin #51 - Flood Warning dropped for Nisqually River. Update for Chehalis and Skookumchuck Rivers. Crested and receding.
340 pm/Sun Nov 25	FLS	Bulletin #52 - Update for Cedar and White Rivers. Gradually receding.
645 pm/Sun Nov 25	FLS	Bulletin #53 - Update for Chehalis, Skookumchuck, and Cowlitz Rivers. Crested and receding.
715 pm/Sun Nov 25	FLS	Bulletin #54 - Update for Snoqualmie, Snohomish, and Skagit Rivers. All receding. Snohomish below levee top level.
730 pm/Sun Nov 25	FLS	Bulletin #55 - Update for Yakima, Wenatchee, and Naches Rivers.
745 pm/Sun Nov 25	FLS	Bulletin #56 - Update for Cedar and White Rivers. Gradually receding.
1015 pm/Sun Nov 25	FLS	Bulletin #57 - Issued by WSO Olympia. Chehalis at Oakville over its banks and still rising. Residents evacuated.
1240 am/Mon Nov 26	FLS	Bulletin #58 - Update for Chehalis, Skookumchuck, and Cowlitz Rivers. All crested and receding.
100 am/Mon Nov 26	FLS	Bulletin #59 - Update for Snoqualmie, Snohomish, and Skagit Rivers. All receding.
125 am/Mon Nov 26	FLS	Bulletin #60 - Update for Cedar and White Rivers. Continue to recede slowly.
400 am/Mon Nov 26	FLS	Bulletin #61 - Summary of flooding compared to records. Several records set (see #36).
700 am/Mon Nov 26	FLS	Bulletin #62 - Update for Wenatchee, Yakima, and Naches Rivers. Lower Yakima still rising. Flood warnings dropped for portions of the Naches and Yakima Rivers.
930 am/Mon Nov 26	FLS	Bulletin #63 - Update for Snowqualmie, Snohomish, and Skagit Rivers. Receding.
930 am/Mon Nov 26	FLS	Bulletin #64 - Update for Cedar and White Rivers.
1030 am/Mon Nov 26	FLS	Bulletin #65 - Flood Warning for Skookumchuck River dropped. Update for Chehalis and Cowlitz

		Rivers. Crested and receding.
145 pm/Mon Nov 26	FLS	Bulletin #67 - Update for Chehalis River. Crested and receding.
200 pm/Mon Nov 26	FLS	Bulletin #68 - Update for Cedar and White Rivers.
230 pm/Mon Nov 26	FLS	Bulletin #69 - Update for Snoqualmie, Snohomish, and Skagit Rivers. Flood Warning for a portion of Skagit River dropped.
315 pm/Mon Nov 26	FLS	Bulletin #70 - Flood Warnings for Wenatchee and Naches Rivers dropped. Flood Warnings continued for Yakima River.
720 pm/Mon Nov 26	FLS	Bulletin #71 - Flood Warnings for Snoqualmie and Skagit Rivers dropped. Flood Warnings continue for Snohomish, Cedar, White, Chehalis, and Yakima Rivers.
1040 pm/Mon Nov 26	FLS	Bulletin #72 - Update for Snohomish, Cedar, White, Chehalis, and Yakima Rivers.
800 am/Tue Nov 27	FLS	Bulletin #73 - Flood Warnings dropped for upper portions of Snohomish, Chehalis, and Yakima Rivers. Flood Warnings continue for lower Snohomish, Cedar, White, lower Chehalis and lower Yakima Rivers.
900 am/Tue Nov 27	FLS	Bulletin #74 - Update for Yakima River. Lower Yakima still rising.
200 pm/Tue Nov 27	FLS	Bulletin #75 - Flood Warnings for Snohomish River Dropped. Continue Flood Warnings for Cedar and White Rivers which are affected by flood control.
200 pm/Tue Nov 27	FLS	Bulletin #76 - Update for lower Yakima River. Crest expected this evening.
740 pm/Tue Nov 27	FLS	Bulletin #77 -Update for Cedar and White Rivers. Effected by flood control.
930 am/Wed Nov 28	FLS	Bulletin #78 - Update for Yakima and Cedar Rivers.
230 pm/Wed Nov 28	FLS	Bulletin #79 - Update on Yakima, Cedar, and White Rivers. Yakima to fall below flood stage Thursday morning. Cedar and White Rivers to remain above flood stage due to flood control.

APPENDIX D

Staffing During Thanksgiving Day Flood Event - WSFO SEA

DAY	Forecasters	Hydro Desk	Pub.Serv.U.
Wed. 11/21	Arthur	Jackson	Bauck
	Hooker	Felton	Dearn
	Schneider	Colman	Frange
			Thompson
			Treick
Thu. 11/22	Kierulff	Jackson	Bauck
	Arthur	Felton	Brandow
	Hooker	Schneider	Dearn
	Colman		Herzog
			Palmer
Fri. 11/23	Kierulff	Jackson	Bauck
	Arthur	Renneke	Brandow
	Hooker	Felton	Dearn
			Herzog
			Palmer
Sat. 11/24	Kierulff	Jackson	Brandow
	Schneider	Swift	Herzog
	Hooker	Felton	Thompson
			Trieck
			Palmer
Sun. 11/25	Kierulff	Swift	Brandow
	Schneider	Jackson	Herzog
	Hooker	Felton	Thompson
		Doherty	Trieck
			Palmer
Mon. 11/26	Kierulff	Jackson	Brandow
	Schneider	Felton	Cerniglia
	Arthur		

APPENDIX E

NWRFC Work Schedule
Nov 21 - 26, 1990

Nov 21, 1990

DATA SHIFT	6AM - 2:30PM	RON WININGS
DAY SHIFT	W. WASHINGTON	DAVE WESTNEDGE
LATE SHIFT	NOON - MIDNIGHT	JIM MATHISON

Nov 22, 1990

DATA SHIFT	4AM-NOON	RON WININGS
DAY SHIFT	4AM-NOON	VERN BISSELL
DAY SHIFT	4AM-NOON	RAY FUKUNAGA
LATE SHIFT	NOON-MIDN	JIM MATHISON
LATE SHIFT	4PM-10PM	MARY MELLEMA

NOV 23, 1990

DATA SHIFT	4AM-NOON	RON WININGS
DAY SHIFT	4AM-NOON	KYLE MARTIN
DAY SHIFT	5AM-4PM	CHUCK ORWIG
LATE SHIFT	NOON-MIDN	JIM MATHISON
GRAVEYARD	MIDN-8AM	VERN BISSELL
GRAVEYARD	1AM-7AM	MARY MELLEMA

NOV 24, 1990

DATA SHIFT	4AM-NOON	RON WININGS
DAY SHIFT	4AM-2PM	DAVE WESTNEDGE (E-W WASHINGTON)
DAY SHIFT	4AM-4PM	CHUCK ORWIG (W WASHINGTON)
DAY SHIFT	6AM-2:30PM	KYLE MARTIN (OR COAST/WILLAMETTE)
LATE SHIFT	4PM-MIDN	JIM MATHISON
LATE SHIFT	NOON-8PM	RAY FUKUNAGA
LATE SHIFT	NOON-8PM	TORSTEN DUFFY
GRAVEYARD	MIDN-7AM	VERN BISSELL
GRAVEYARD	MIDN-7AM	MARY MELLEMA

NOV 25, 1990

DAY SHIFT	4AM-NOON	DAVE WESTNEDGE (E. WASHINGTON)
DAY SHIFT	5AM-4PM	CHUCK ORWIG (W. WASHINGTON)
DAY SHIFT	4AM-NOON	KYLE MARTIN (OR COAST/WILLAMETTE)
LATE SHIFT	NOON-8PM	RAY FUKUNAGA
LATE SHIFT	NOON-8PM	TORSTEN DUFFY
LATE SHIFT	4PM-11PM	JIM MATHISON

NOV 26, 1990

DAY SHIFT	4AM-NOON	VERN BISSELL
LATE SHIFT	NOON-10PM	MARY MELLEMA

NAME	TIME AT NWRFC
RON WININGS	16 YEARS
CHUCK ORWIG	24 YEARS
VERN BISSELL	16 YEARS
JIM MATHISON	16 YEARS
DAVE WESTNEDGE	11 MONTHS
MARY MELLEMA	2 YEARS
KYLE MARTIN	1 1/2 YEARS
RAY FUKUNAGA	9 MONTHS
TORSTEN DUFFY	8 MONTHS

APPENDIX F

List of NWWS Users in Washington

USER	CITY
AAA of Washington	Seattle
City of Tacoma	Tacoma
Eastlake Computer Services	Seattle
KGNW-AM	Seattle
KIRO TV	Seattle
KMPS-AM/FM	Seattle
Puget Sound Air Pollution Control	Seattle
Puget Sound Power and Light	Redmond
Snohomish County Emergency Mgmt.	Everett
State of Washington	Seattle
US Army Corps of Engineers	Seattle
Washington Natural Gas Co.	Seattle

FIGURE 1

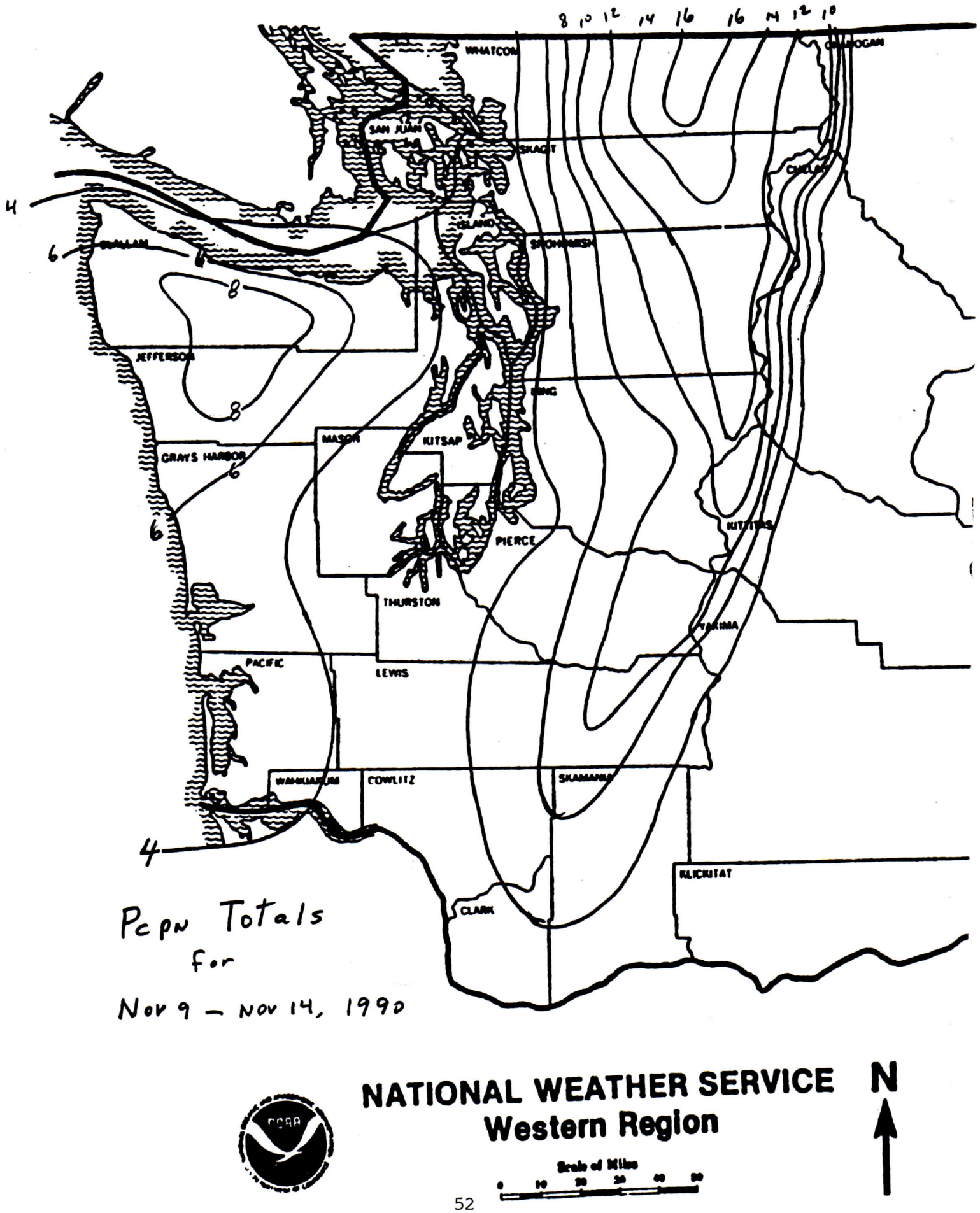
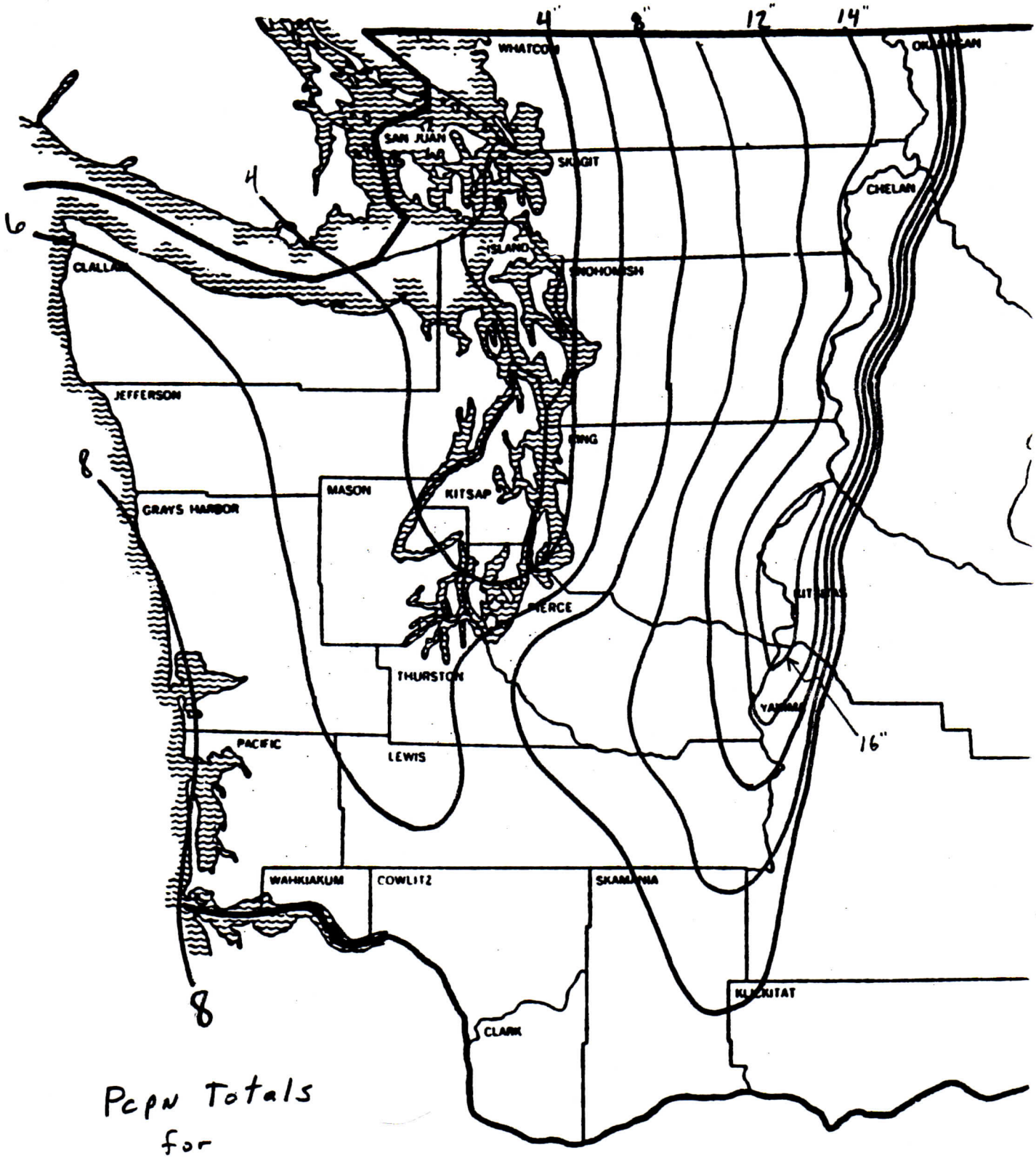

8 10 12 14 16 16 14 12 10
WHATCOM
SAN JUAN
SKAGIT
ISLAND
SNOHOMISH
CHELAN
OKANOGAN
4
6
CLALLAM
8
8
JEFFERSON
KING
MASON
KITSAP
GRAYS HARBOR
6
6
PIERCE
KITTITAS
THURSTON
YAKIMA
PACIFIC
LEWIS
WAHKIAKUM
COWLITZ
SKAMANIA
4
KLICKITAT
CLARK
Pcpn Totals
for
Nov 9 – Nov 14, 1990
NATIONAL WEATHER SERVICE
Western Region
N

FIGURE 2



Pcpn Totals
for
Nov 20 - Nov 24, 1990

NATIONAL WEATHER SERVICE
Western Region

N

Scale of Miles
0 10 20 30 40 50

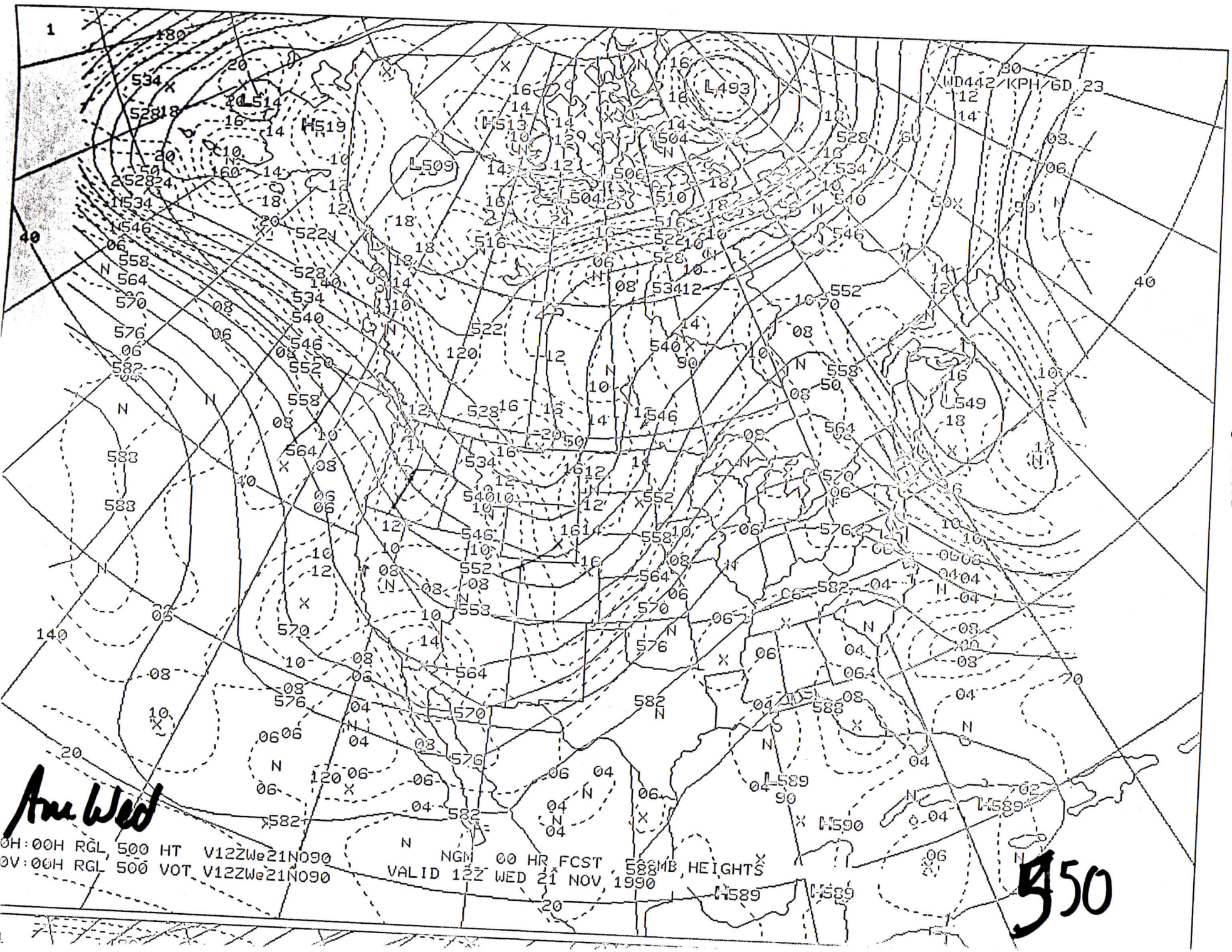

WD442/KPH/6D 23
L493
H513
L509
H519
L514
L549
L589
H589
H590
NGM 00 HR FCST 588MB HEIGHTS
VALID 12Z WED 21 NOV 1990
0H:00H RGL 500 HT V12ZWe21N090
0V:00H RGL 500 VOT V12ZWe21N090
Ave Wed
550

FIGURE 3

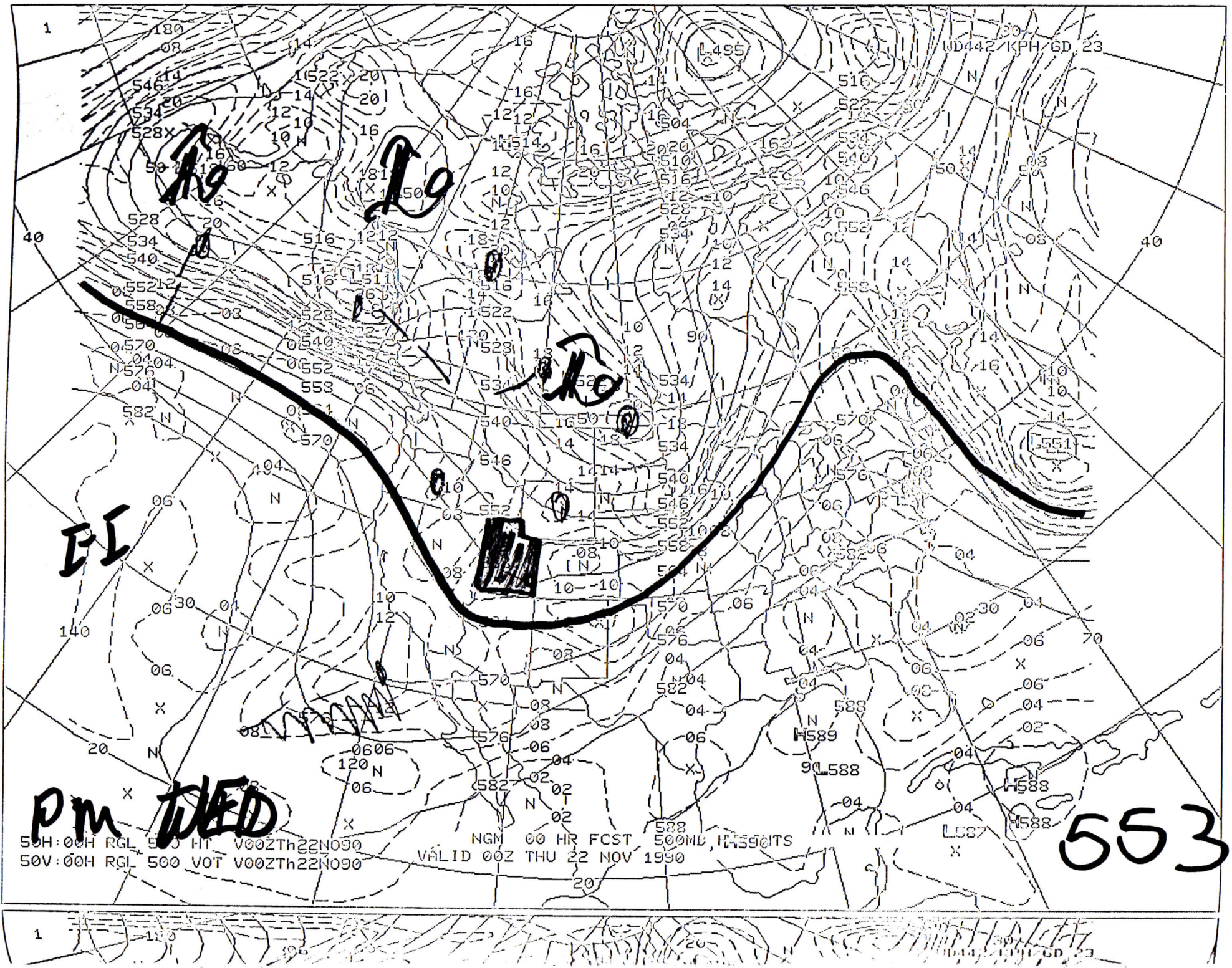

50H:00H RGL 500 HT V00ZTh22N090
50V:00H RGL 500 VOT V00ZTh22N090
NGM 00 HR FCST 500MB HEIGHTS
VALID 00Z THU 22 NOV 1990
PM WED
553

FIGURE 4

FIGURE 5

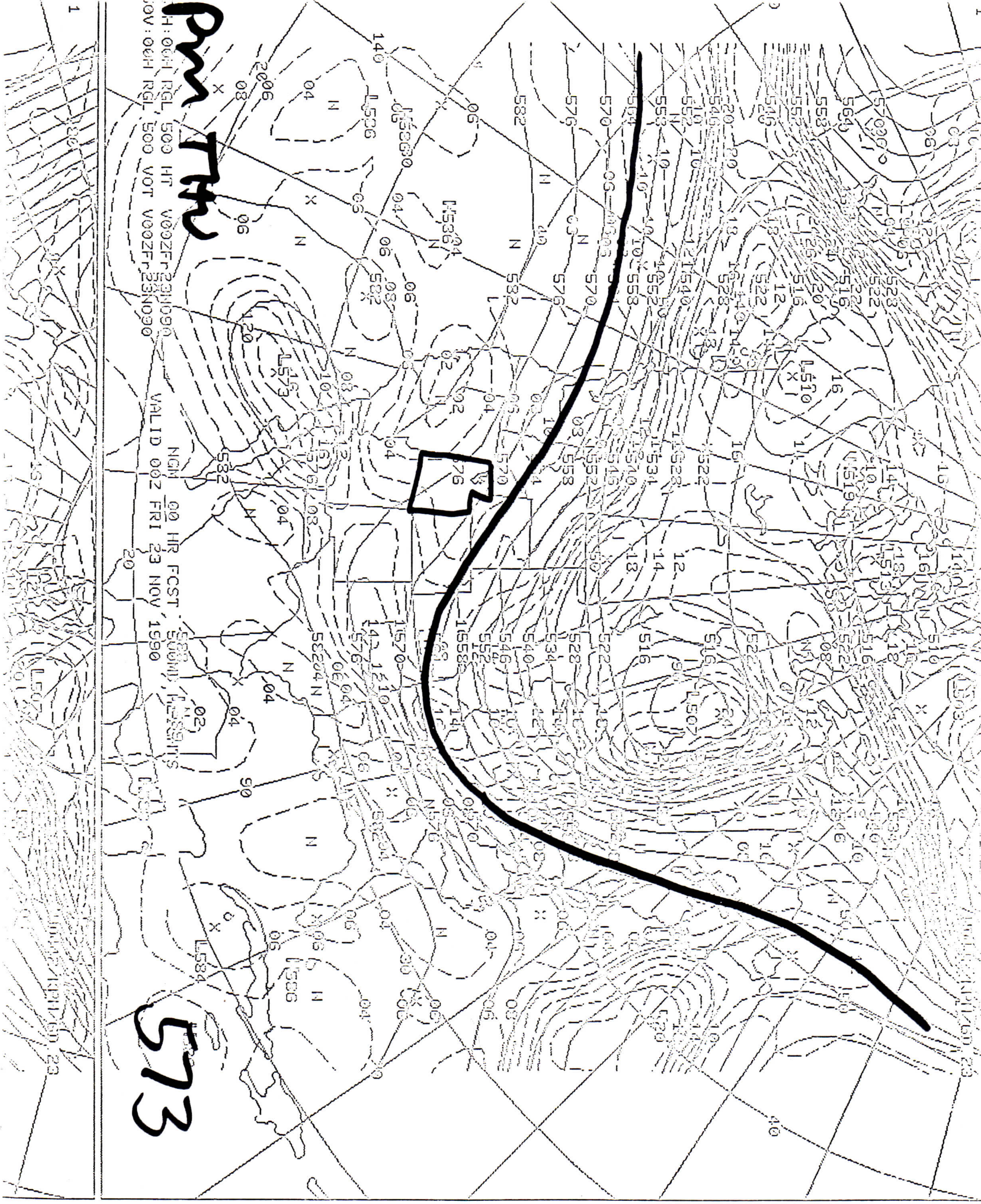

NGM 00 HR FCST 500MB HEIGHTS
VALID 00Z FRI 23 NOV 1990
Pm Thu
573

FIGURE 6

FIGURE 7

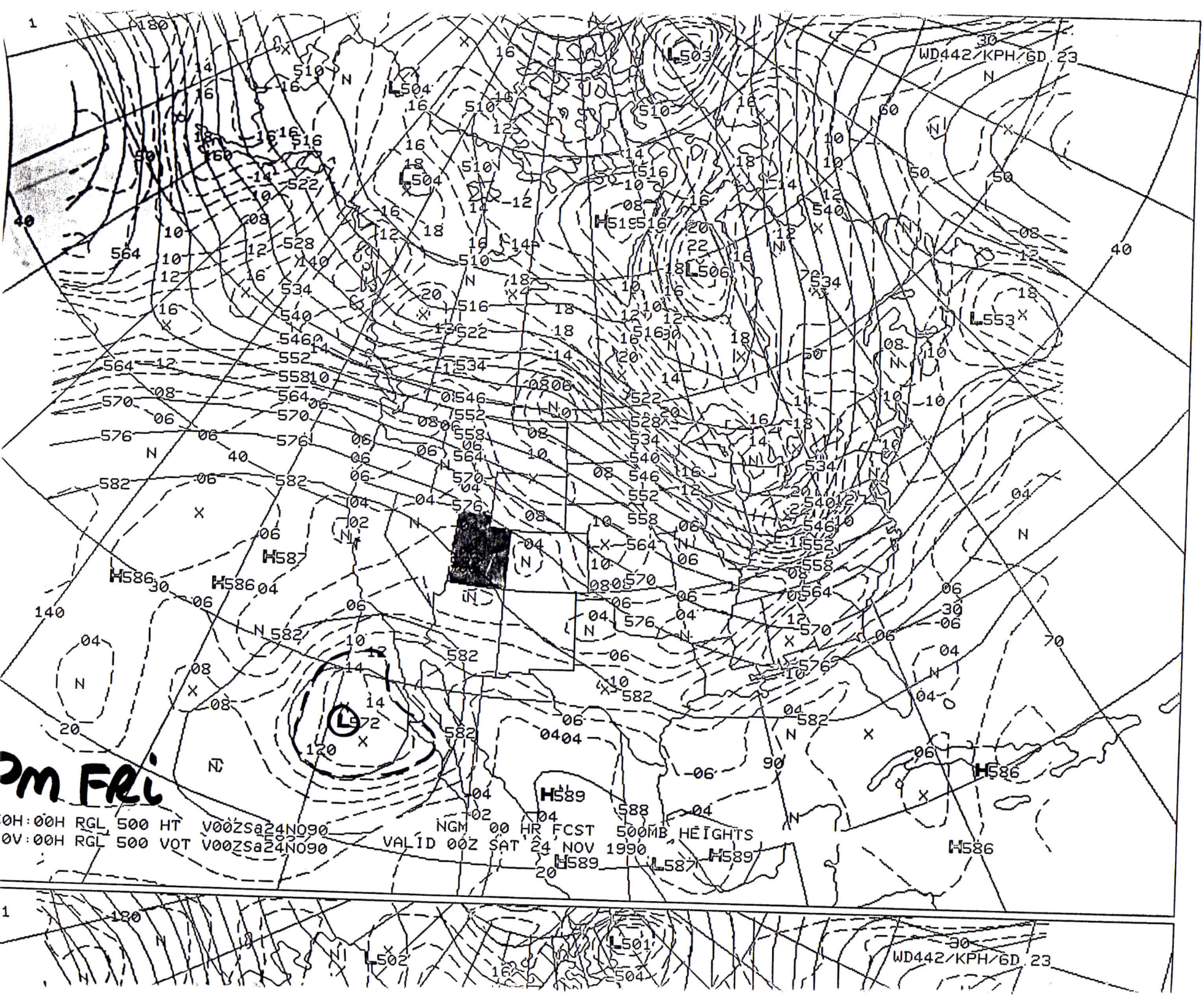

WD442/KPH/GD 23
NGM 00 HR FCST 500MB HEIGHTS
VALID 00Z SAT 24 NOV 1990
00H:00H RGL 500 HT V00Zsa24N090
00V:00H RGL 500 VOT V00Zsa24N090
WD442/KPH/GD 23

FIGURE 8

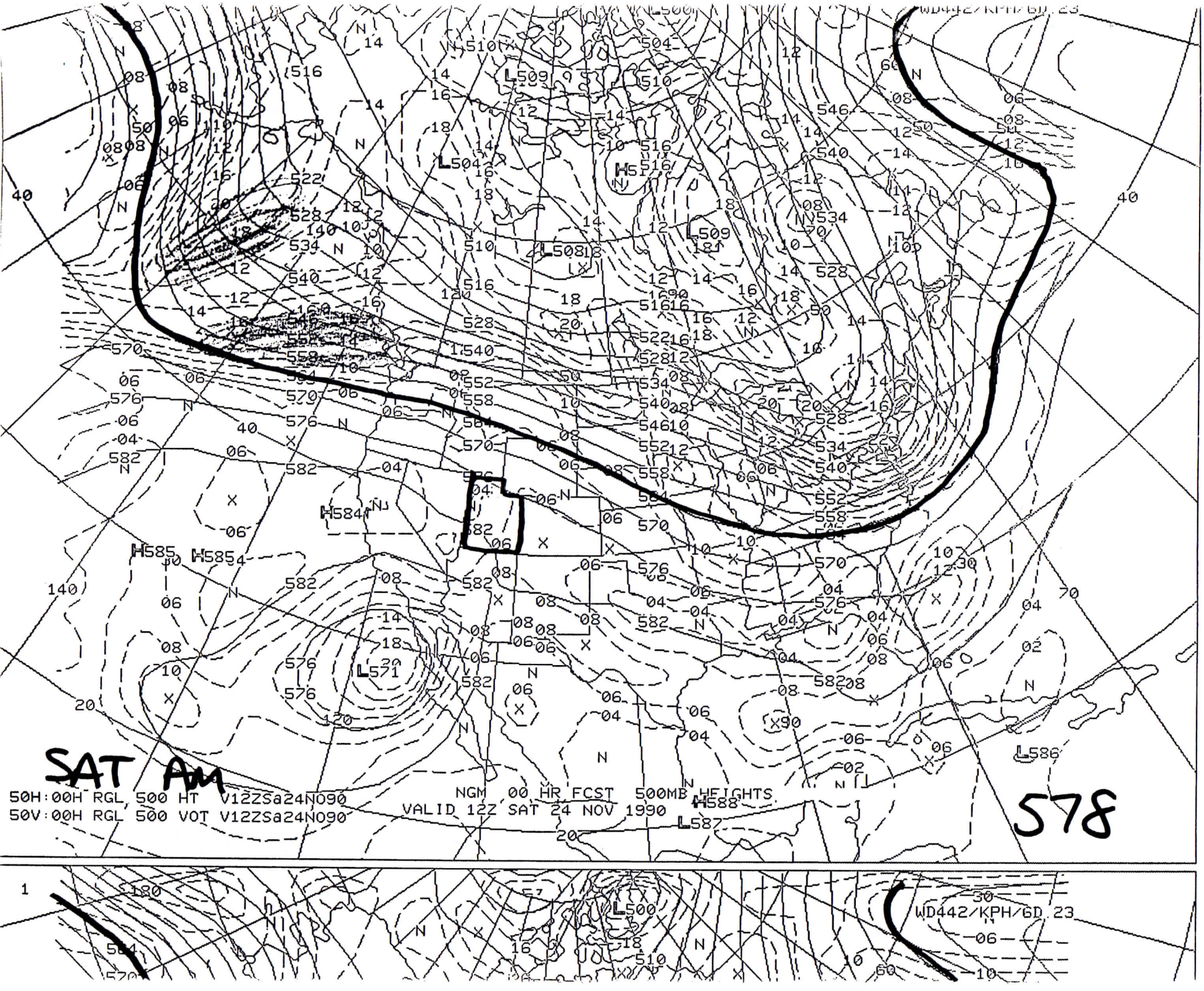

SAT AM
50H:00H RGL 500 HT V12ZSa24NO90
50V:00H RGL 500 VOT V12ZSa24NO90
NGM 00 HR FCST 500MB HEIGHTS
VALID 12Z SAT 24 NOV 1990
578
WD442/KPH/6D 23

FIGURE 9

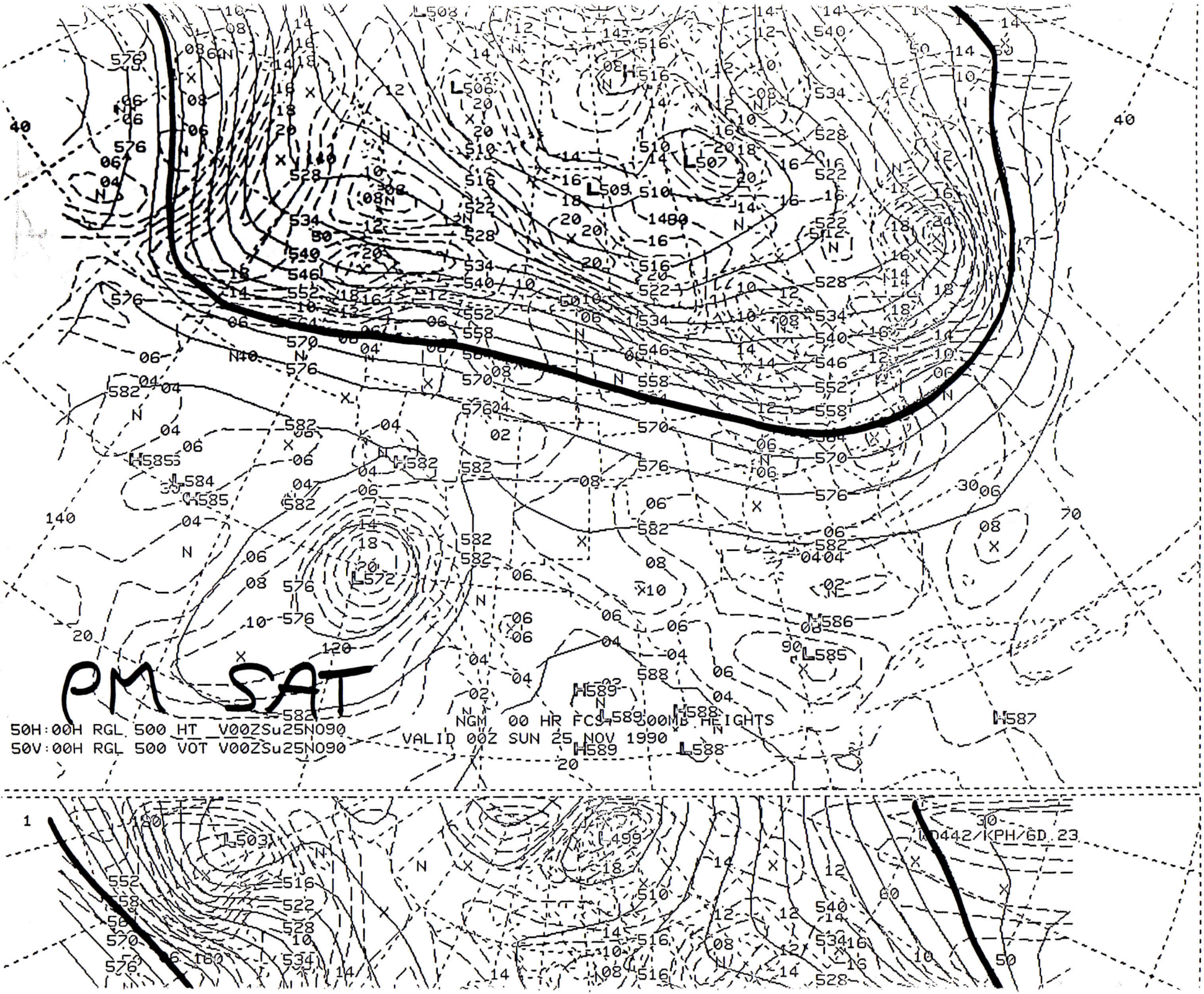

PM SAT
50H:00H RGL 500 HT V00ZSu25N090
50V:00H RGL 500 VOT V00ZSu25N090
NGM 00 HR FCST 500MB HEIGHTS
VALID 00Z SUN 25 NOV 1990

FIGURE 10

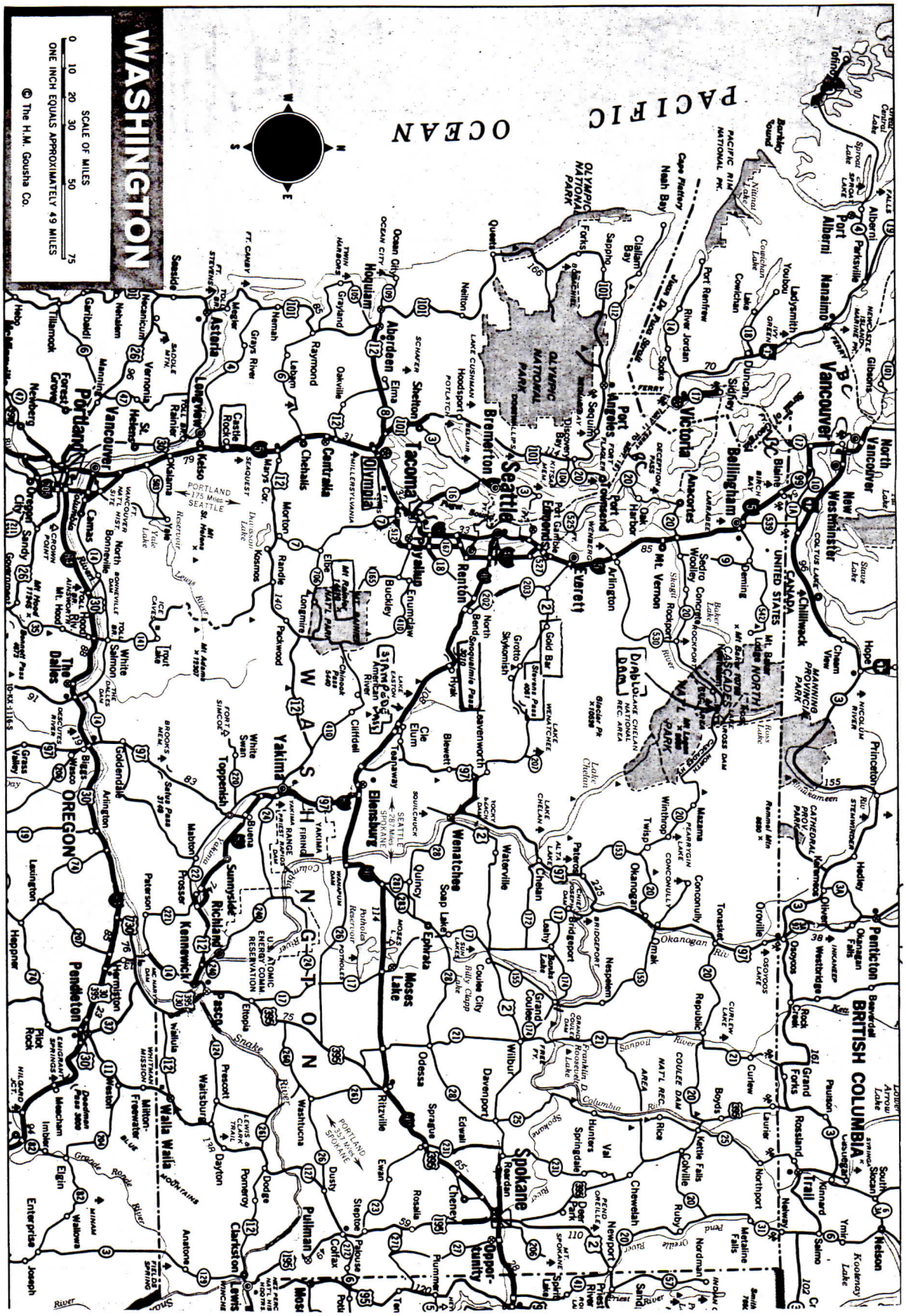
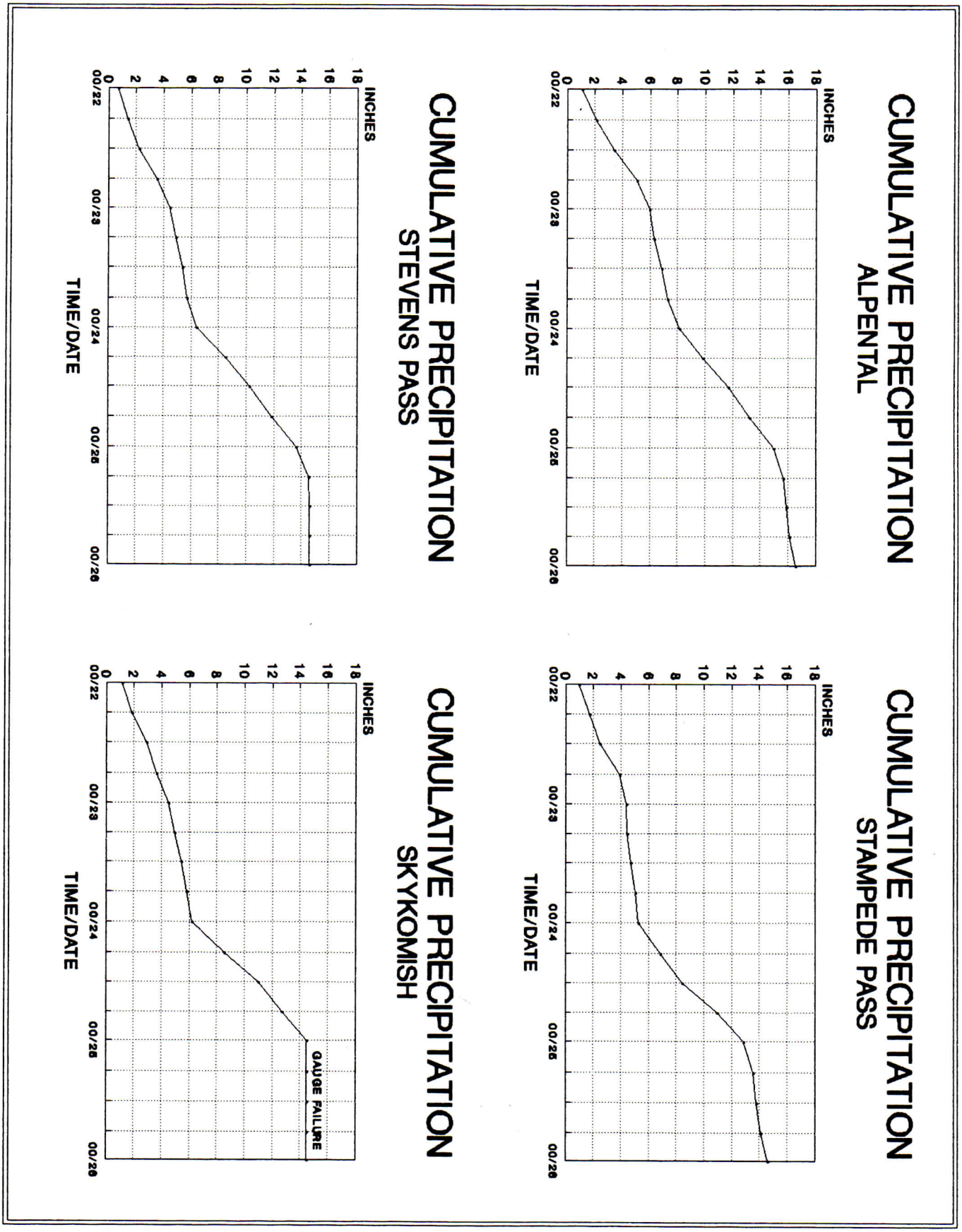

WASHINGTON
SCALE OF MILES
0 10 20 30 50 75
ONE INCH EQUALS APPROXIMATELY 49 MILES
© The H.M. Gousha Co.
PACIFIC OCEAN
BRITISH COLUMBIA
OREGON
Seattle
Spokane
Tacoma
Vancouver
Bellingham
Everett
Olympia
Yakima
Kennewick
Pasco
Richland
Wenatchee
Moses Lake
Pullman
Walla Walla
Pendleton
Portland
Victoria
Nanaimo
Port Alberni
Penticton
Kelowna
Kamloops
Hope
Chilliwack
Abbotsford
New Westminster
North Vancouver
Prince George
Prince Rupert
Dawson Creek
Fort St. John
Fort Nelson
Whitehorse
Yukon Territory
Alaska
Idaho
Montana
Alberta
Saskatchewan
Columbia River
Snake River
Puget Sound
Strait of Juan de Fuca
Strait of Georgia
Queen Charlotte Islands
Vancouver Island
Olympic Peninsula
Cascade Range
Mount Rainier
Mount St. Helens
Mount Adams
Mount Hood
Mount Baker
Glacier Peak
Mount Olympus
Columbia Plateau
Okanogan Highlands
Blue Mountains
Grand Coulee Dam
Chief Joseph Dam
Wanapum Dam
Priest Rapids Dam
Rock Island Dam
Wells Dam
McNary Dam
John Day Dam
The Dalles Dam
Bonneville Dam
Ice Caverns
Lewis and Clark Trail
Oregon Trail
Hanford Atomic Energy Reservation
Yakima Firing Range
Columbia Basin Irrigation Project
Columbia River Gorge
Columbia River Highway
Crown Point
Vista House
Multnomah Falls
Mount Hood Loop
Mount Rainier Scenic Railroad
Portland to Seattle 175 Miles
Portland to Spokane 287 Miles
Seattle to Spokane 287 Miles

FIGURE 11

FIGURE 12


CUMULATIVE PRECIPITATION
ALPENTAL
INCHES
TIME/DATE
CUMULATIVE PRECIPITATION
STAMPEDE PASS
INCHES
TIME/DATE
CUMULATIVE PRECIPITATION
STEVENS PASS
INCHES
TIME/DATE
CUMULATIVE PRECIPITATION
SKYKOMISH
INCHES
GAUGE FAILURE
TIME/DATE

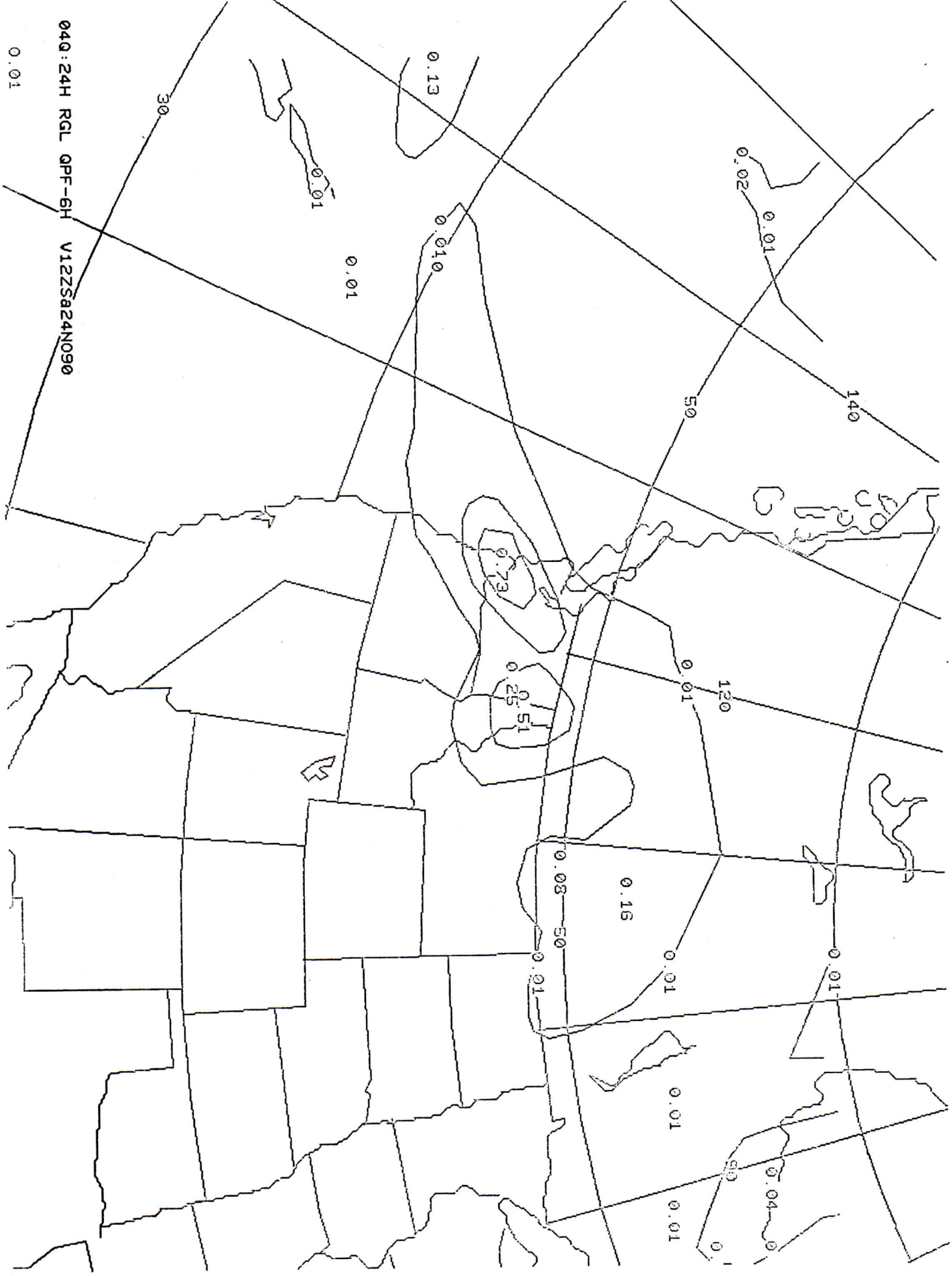
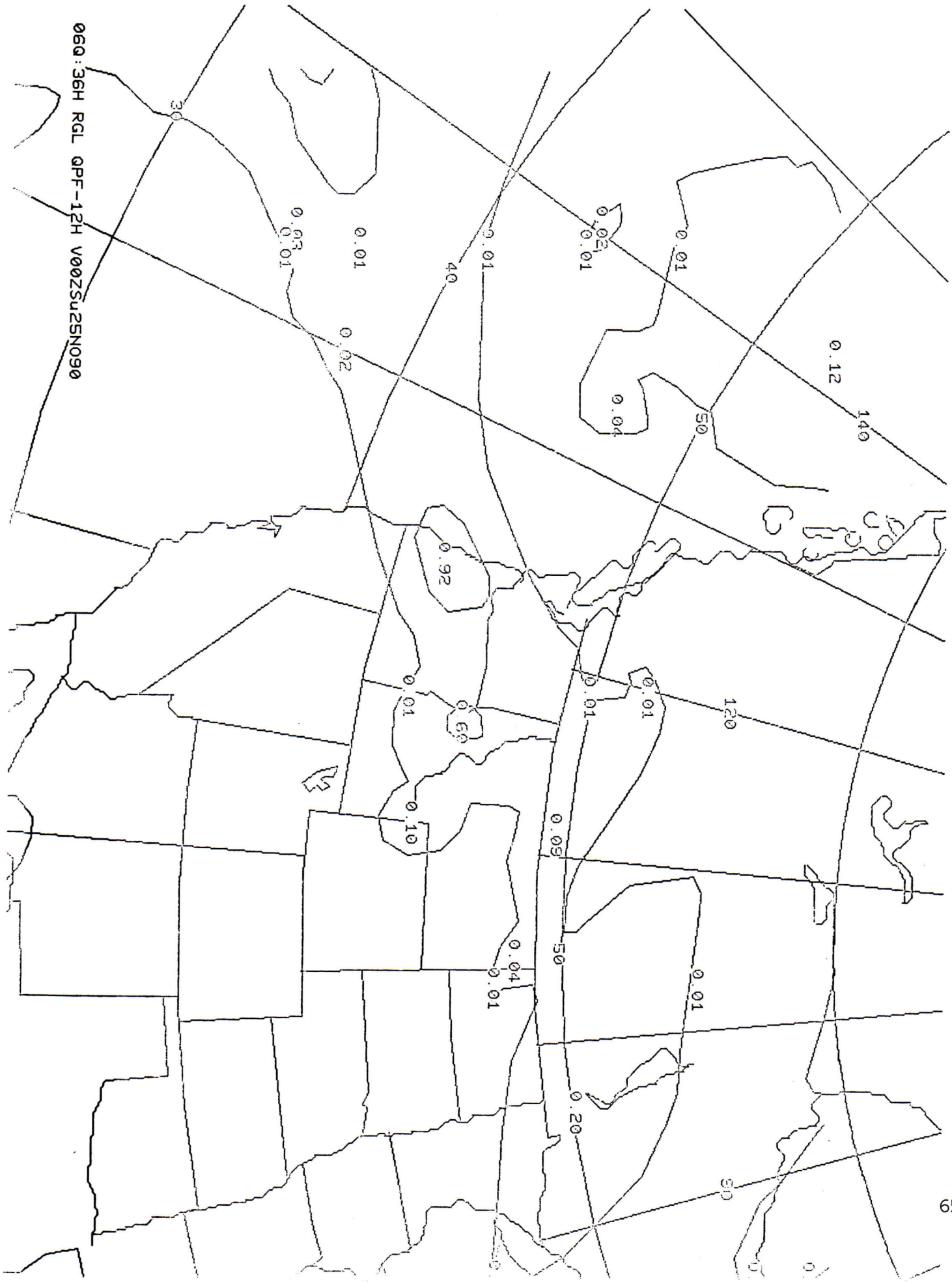

04Q:24H RGL QPF-6H V12ZSa24N090
0.01
30
0.13
0.01
0.01
0.010
0.02
0.01
50
140
0.73
0.25
0.51
0.01
120
0.08
50
0.16
0.01
0.01
0.01
0.01
80
0.04
0.01
0

FIGURE 13

FIGURE 14


060:36H RGL QPF-12H V00ZSu25N090
30
40
50
60
120
140
0.01
0.02
0.04
0.12
0.92
0.10
0.09
0.20

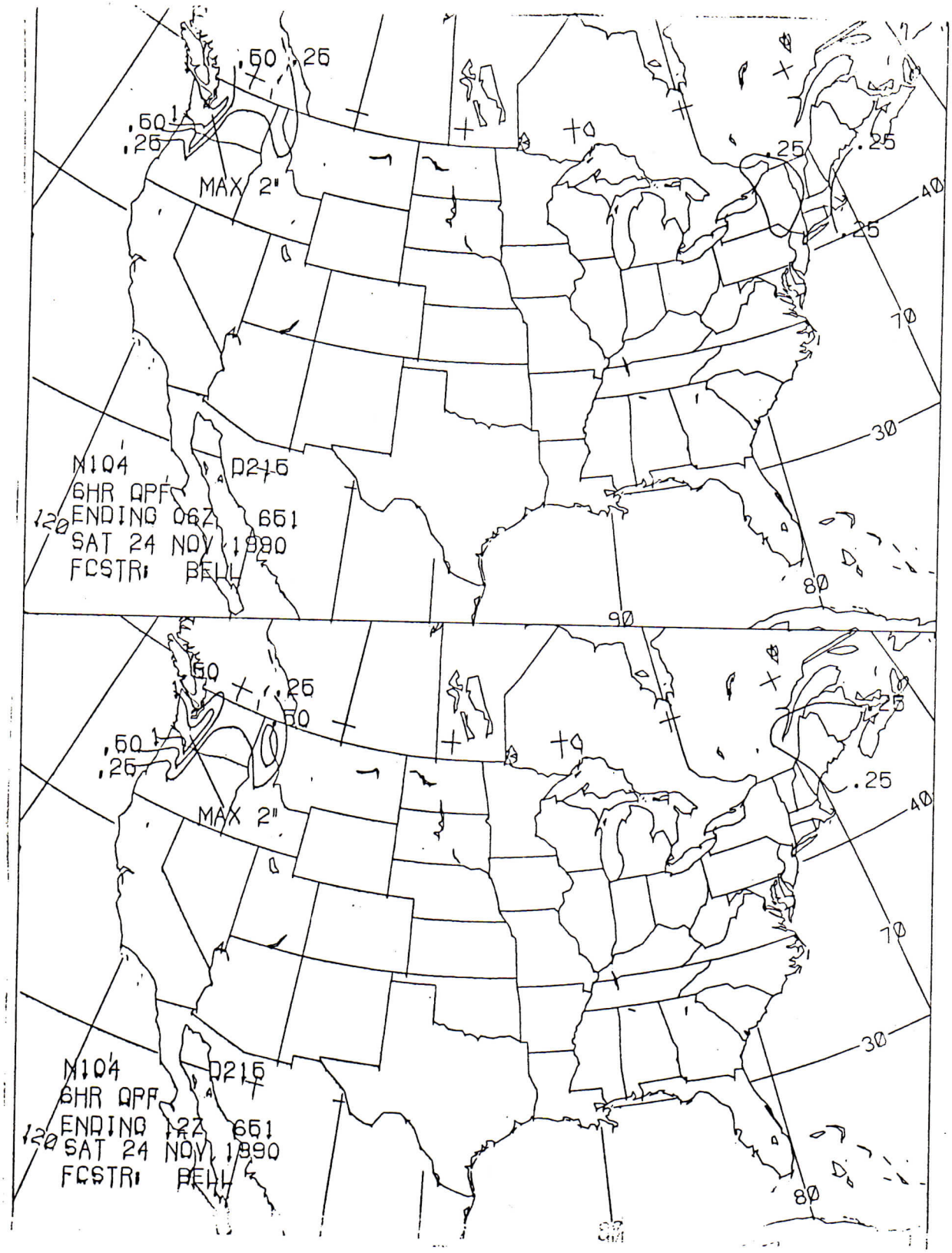

.50
.25
MAX 2"
.25
40
70
30
80
90
N104
6HR QPF
ENDING 06Z
SAT 24 NOV 1990
FCSTR: BELL
120
D215
651
.50
.25
MAX 2"
.25
40
70
30
80
N104
6HR QPF
ENDING 12Z
SAT 24 NOV 1990
FCSTR: BELL
120
D215
651

FIGURE 15

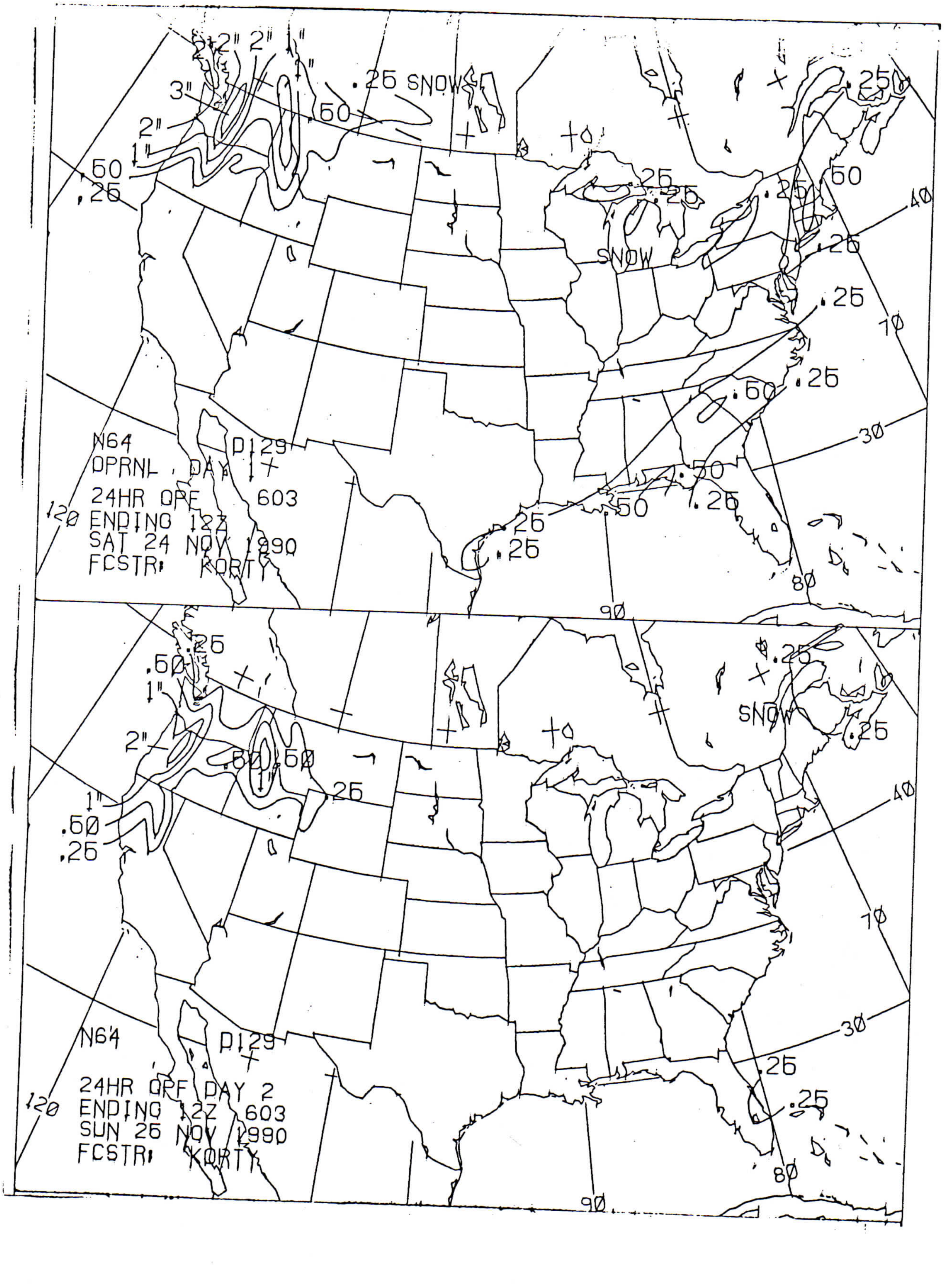

N64
OPRNL DAY 1
D129
24HR QPF 603
ENDING 12Z
SAT 24 NOV 1990
FCSTR: KORTY
SNOW
SNOW
N64
D129
24HR QPF DAY 2
ENDING 12Z 603
SUN 25 NOV 1990
FCSTR: KORTY
SNOW
120
90
80
70
40
30

FIGURE 16

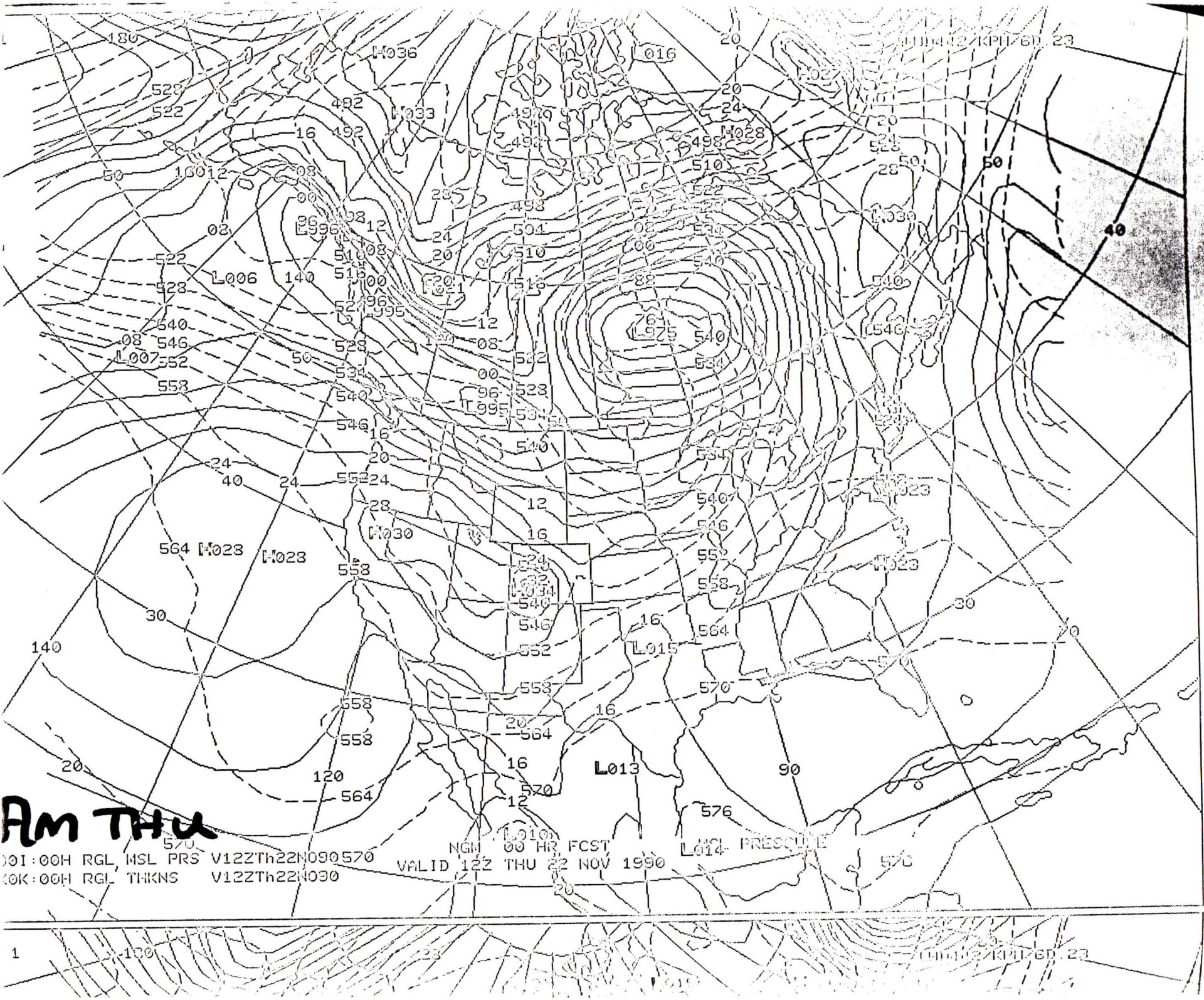

Am THU
NGM 00 HR FCST
VALID 12Z THU 22 NOV 1990
MSL PRESSURE
001:00H RGL MSL PRS V12ZTh22N090
K0K:00H RGL THKNS V12ZTh22N090

FIGURE 17

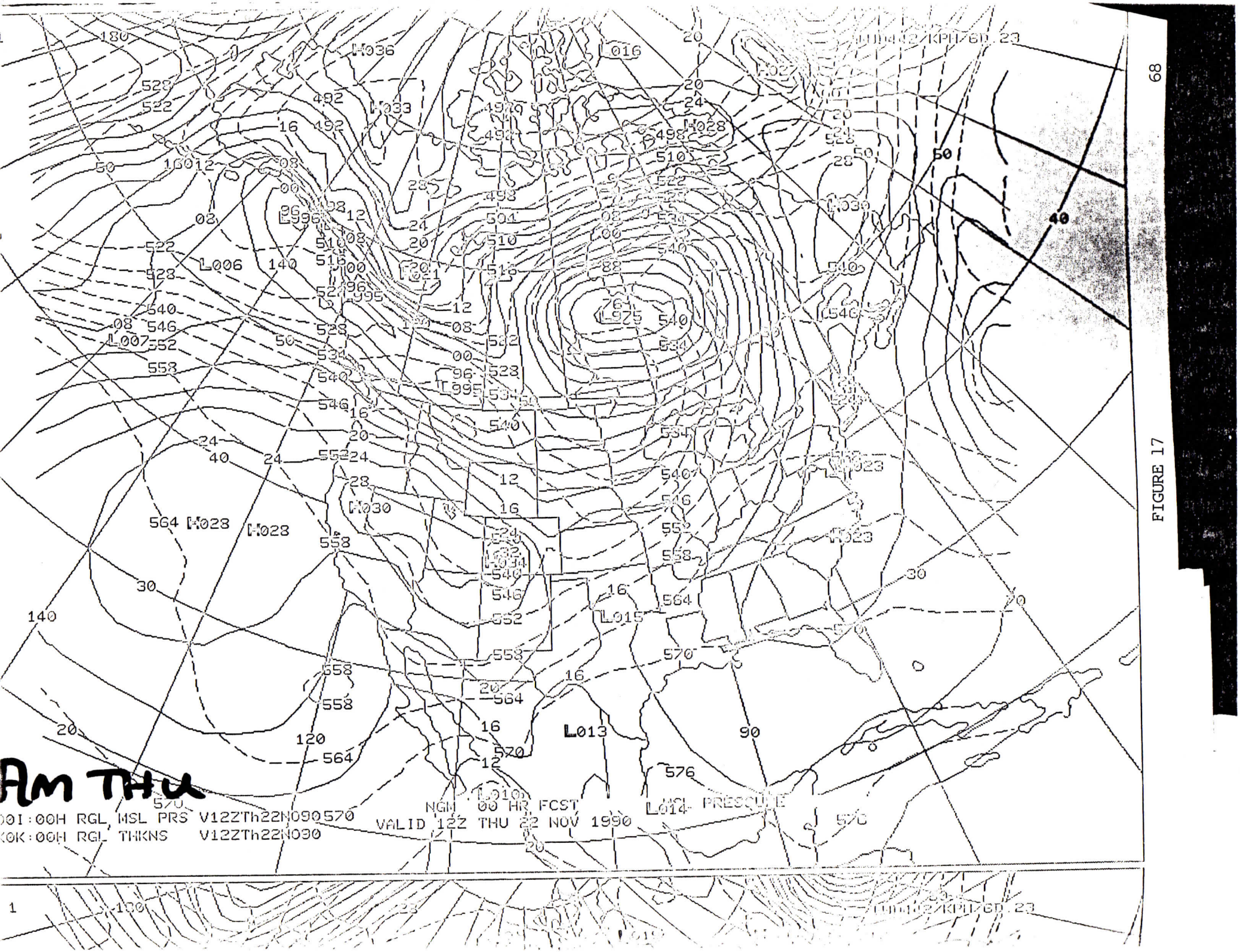

Am THU
NGM 00 HR FCST
VALID 12Z THU 22 NOV 1990
MSL PRESSURE
001:00H RGL MSL PRS V12ZTh22N090
K0K:00H RGL THKNS V12ZTh22N090

FIGURE 17

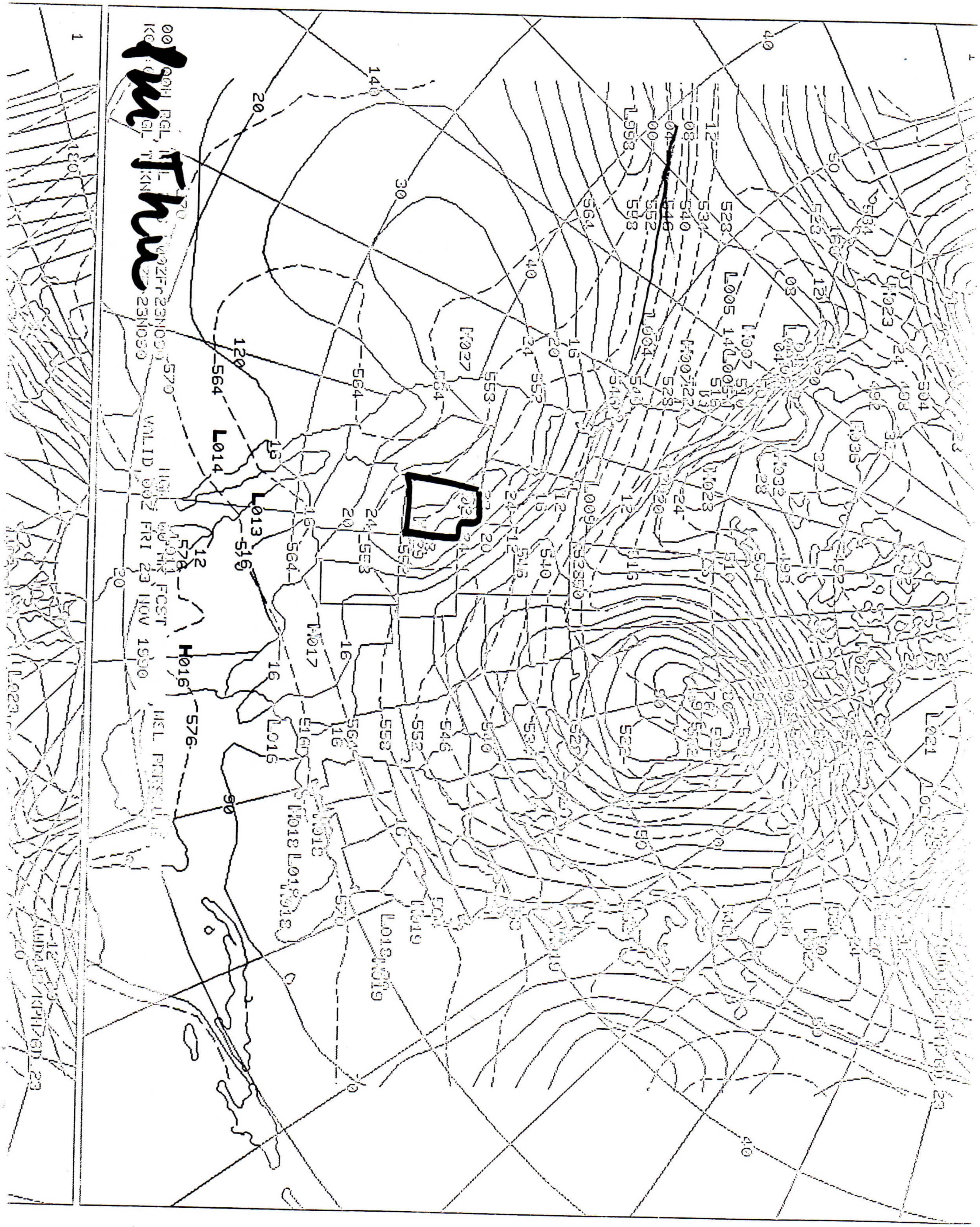


FIGURE 18

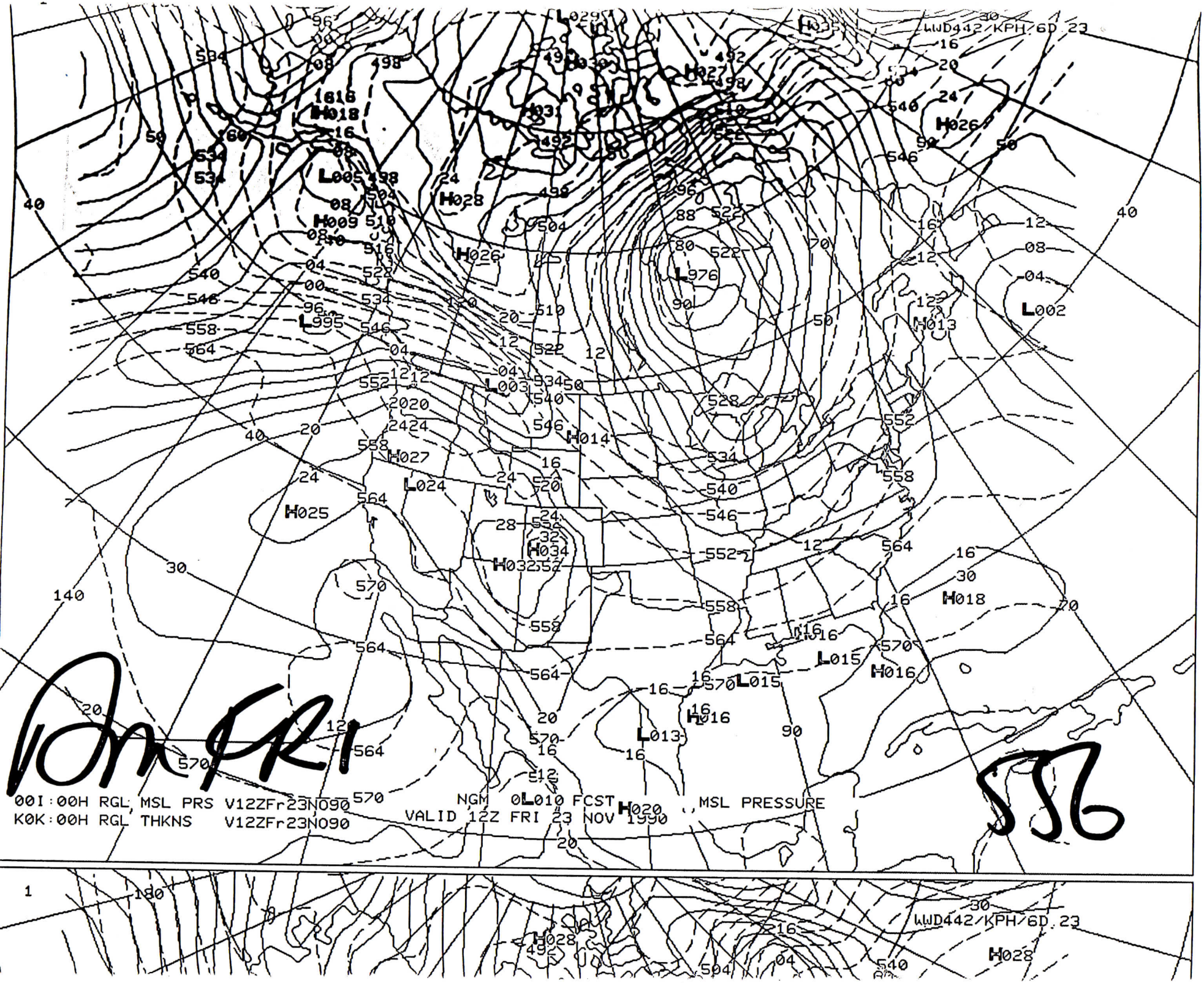

00I:00H RGL MSL PRS V12ZFr23NO90
K0K:00H RGL THKNS V12ZFr23NO90
NGM 0L010 FCST VALID 12Z FRI 23 NOV 1990
MSL PRESSURE
WWD442/KPH/6D.23
FRI
556

FIGURE 19

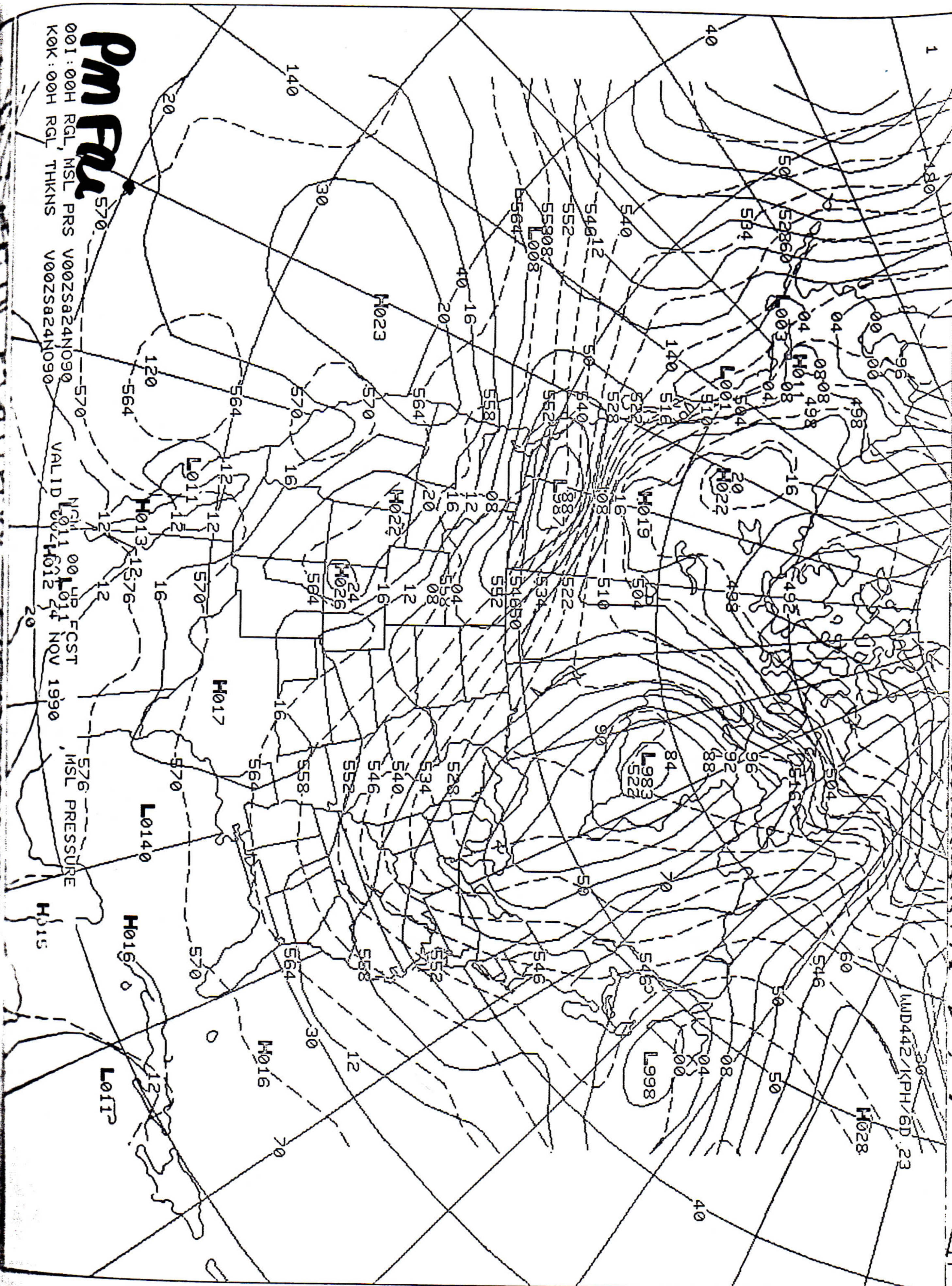

Pm Fcst
00I:00H RGL, MSL PRS V00ZSa24N090
K0K:00H RGL THKNS V00ZSa24N090
NGM 00 UP FCST
VALID 00Z 24 NOV 1990
, MSL PRESSURE
WWD442/KPH/6D 23

FIGURE 20

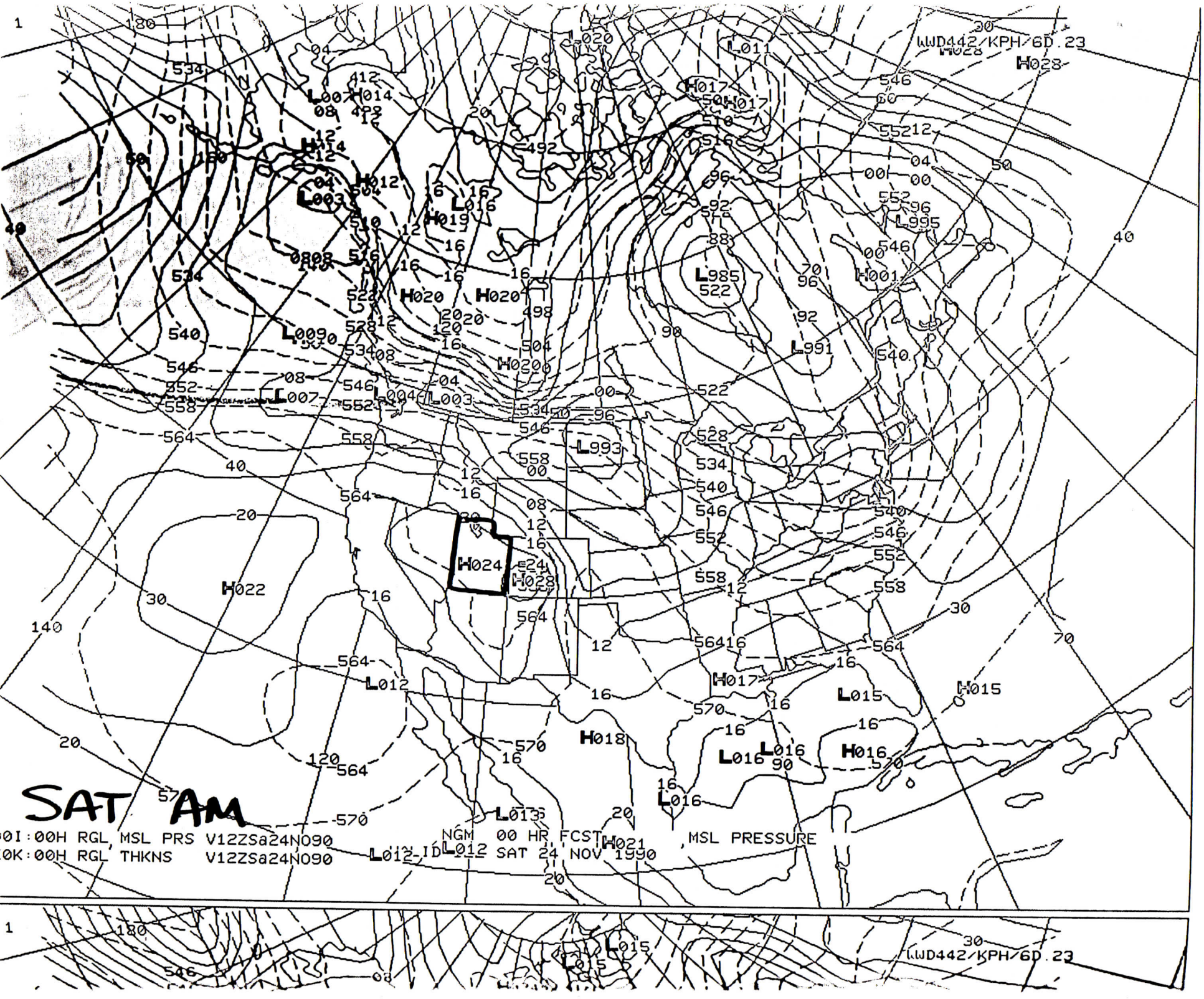

SAT AM
NGM 00 HR FCST MSL PRESSURE
L012 SAT 24 NOV 1990
WWD442/KPH/6D.23

FIGURE 21

FIGURE 22

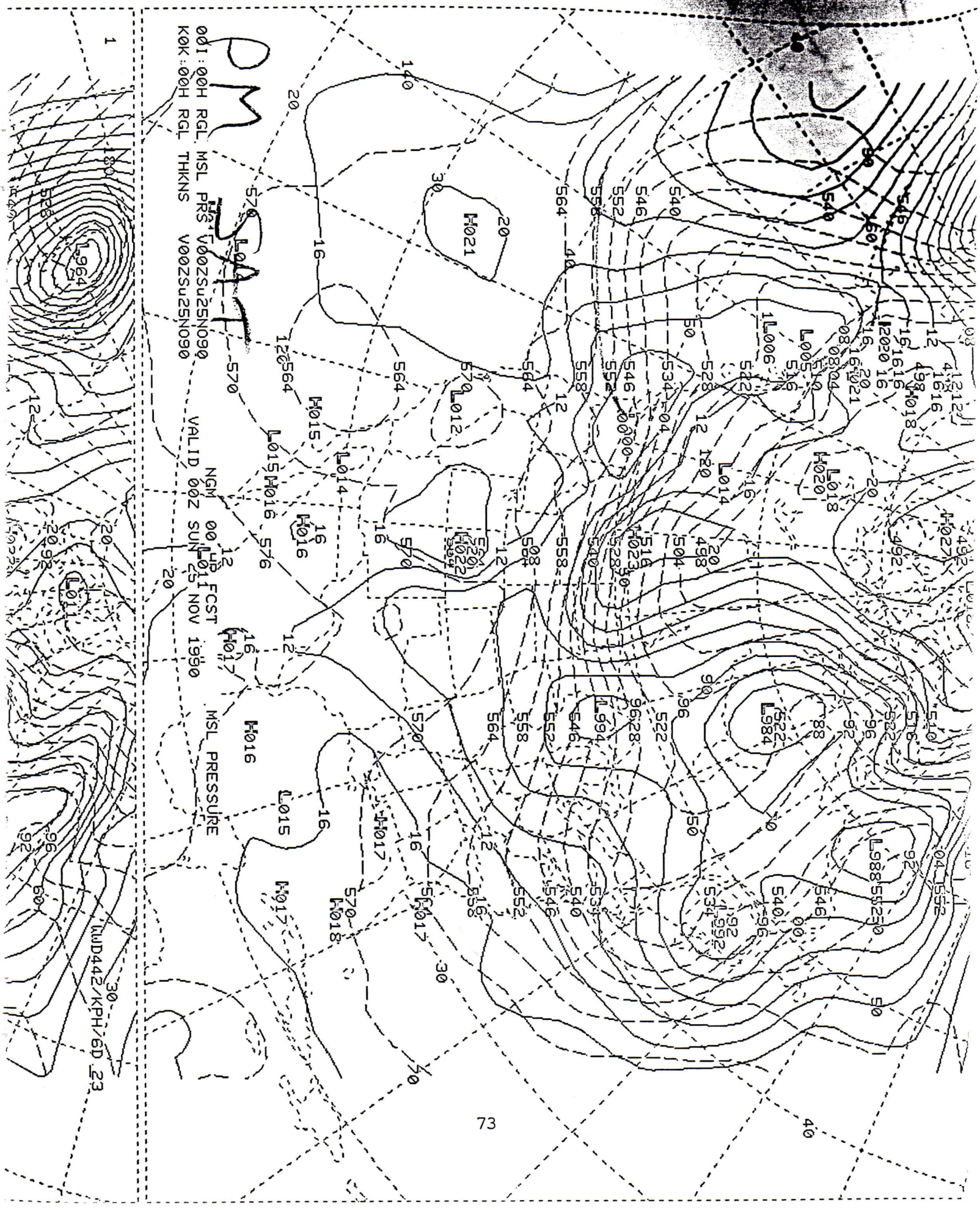
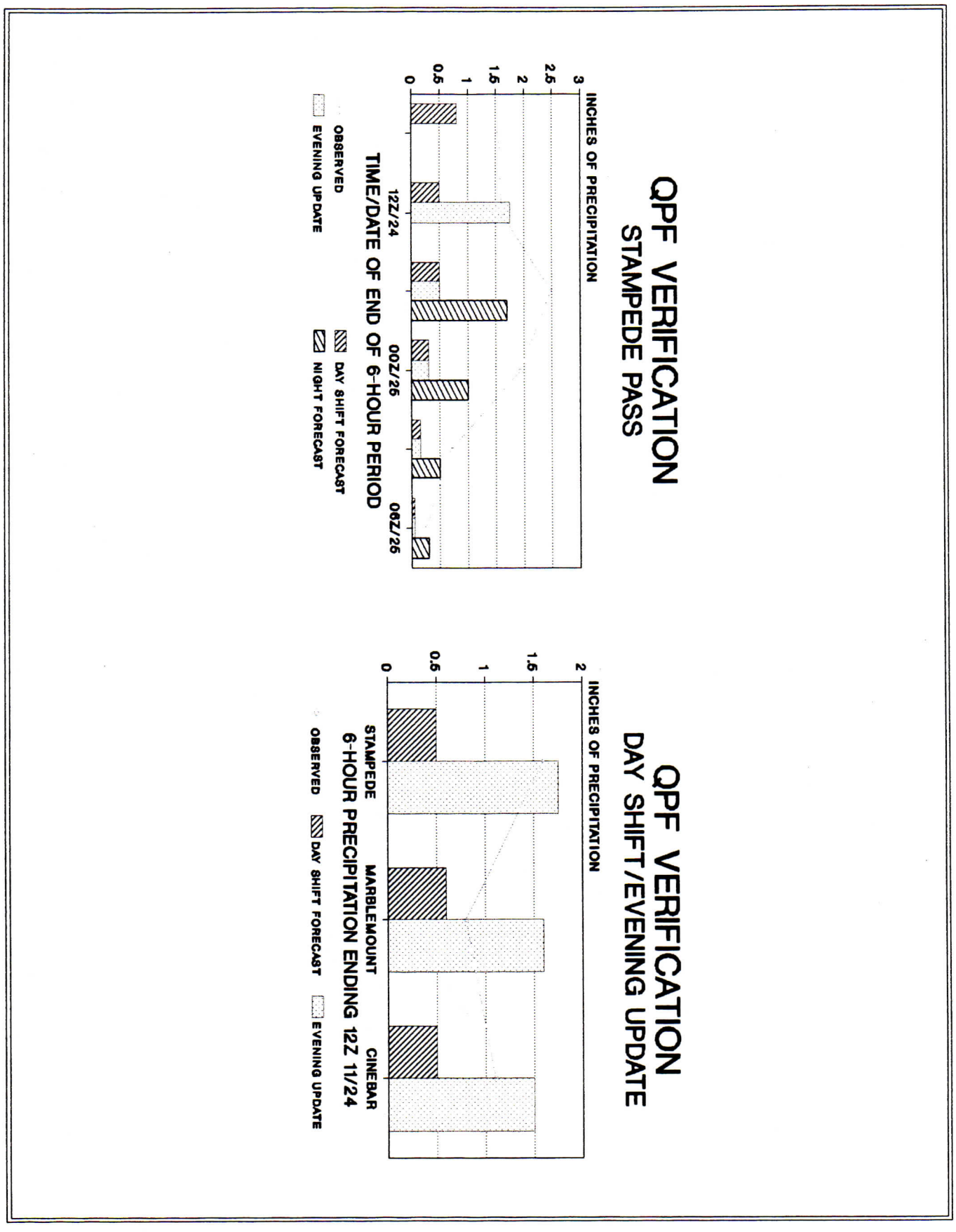

00I:00H RGL MSL PRS V00ZSu25N090
K0K:00H RGL THKNS V00ZSu25N090
VALID 00Z SUN 25 NOV 1990
NGM 00 HR FCST
MSL PRESSURE
TWD442/KPH/6D 23

FIGURE 23


QPF VERIFICATION
STAMPEDE PASS
INCHES OF PRECIPITATION
3
2.5
2
1.5
1
0.5
0
12Z/24
00Z/25
06Z/25
TIME/DATE OF END OF 6-HOUR PERIOD
OBSERVED
DAY SHIFT FORECAST
EVENING UPDATE
NIGHT FORECAST
QPF VERIFICATION
DAY SHIFT/EVENING UPDATE
INCHES OF PRECIPITATION
2
1.5
1
0.5
0
STAMPEDE
MARBLEMOUNT
CINEBAR
6-HOUR PRECIPITATION ENDING 12Z 11/24
OBSERVED
DAY SHIFT FORECAST
EVENING UPDATE

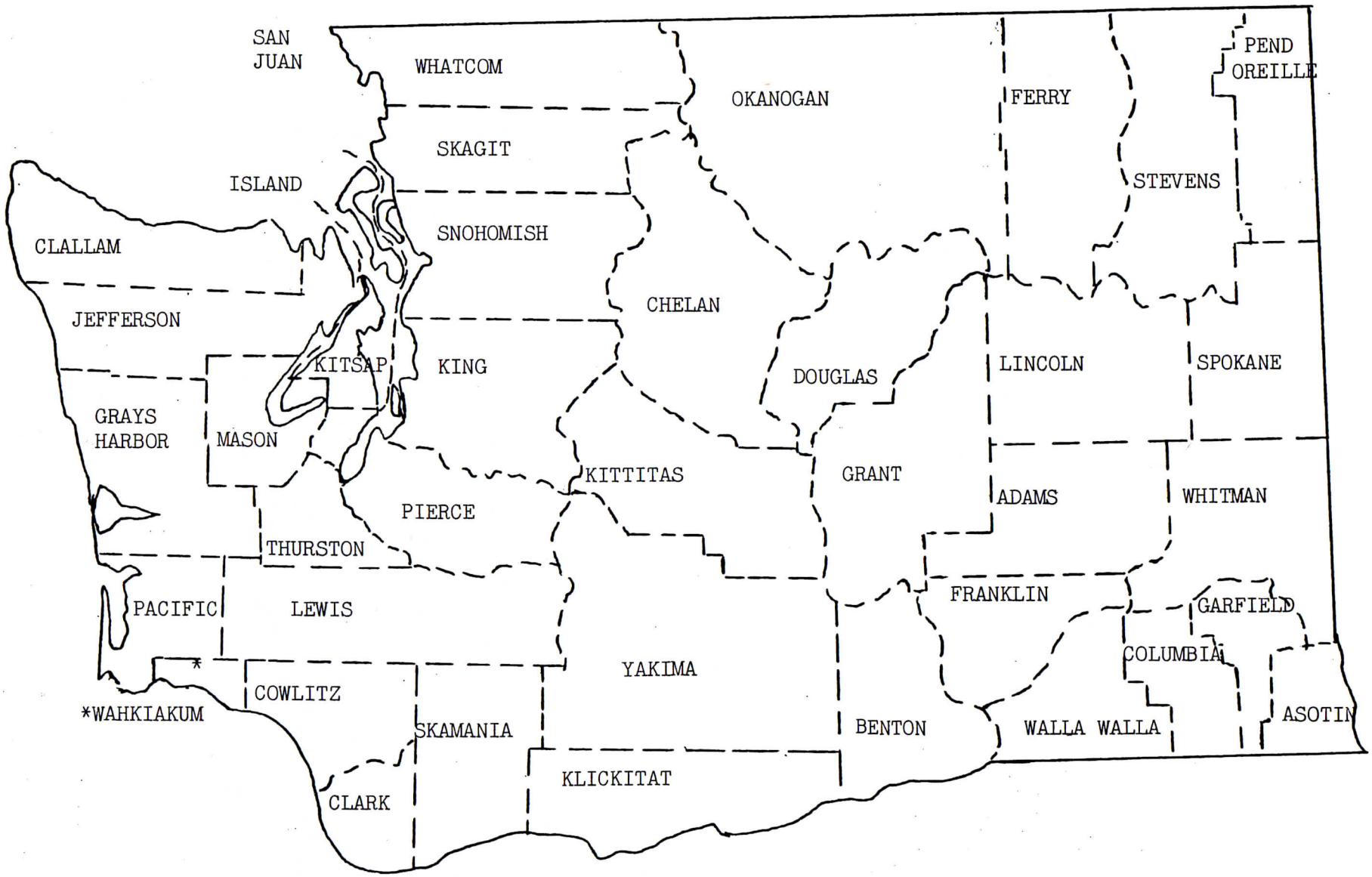
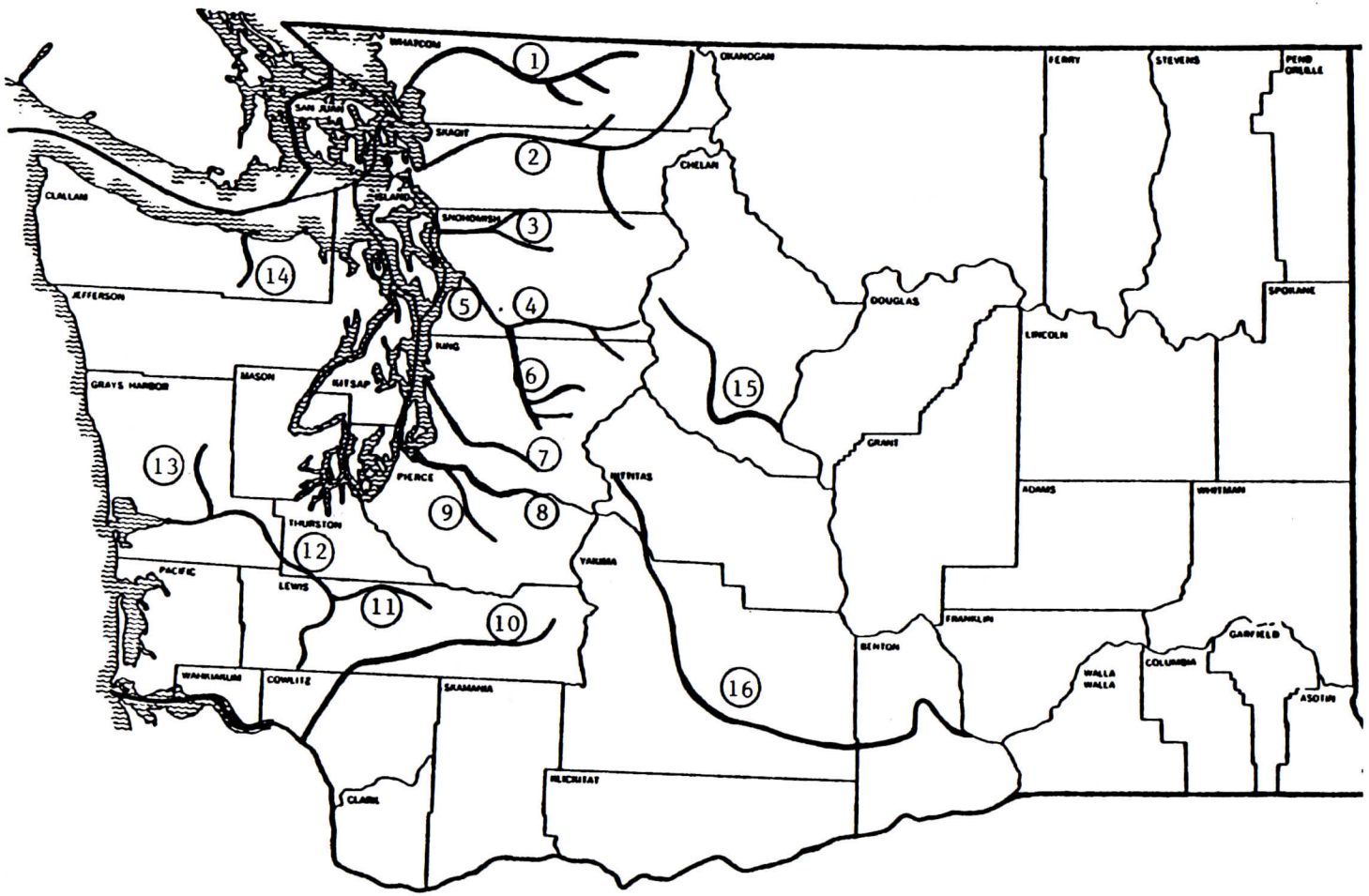

SAN
JUAN
WHATCOM
OKANOGAN
FERRY
PEND
OREILLE
SKAGIT
ISLAND
STEVENS
SNOHOMISH
CLALLAM
CHELAN
JEFFERSON
KITSAP
KING
DOUGLAS
LINCOLN
SPOKANE
GRAYS
HARBOR
MASON
KITTITAS
GRANT
ADAMS
WHITMAN
PIERCE
THURSTON
FRANKLIN
GARFIELD
PACIFIC
LEWIS
COLUMBIA
YAKIMA
*WAHKIAKUM
COWLITZ
SKAMANIA
BENTON
WALLA WALLA
ASOTIN
KLICKITAT
CLARK

FIGURE 24

WASHINGTON



1. Nooksack R.
2. Skagit R.
3. Stillaguamish R.
4. Skykomish R.
5. Snohomish R.
6. Snoqualmie R.
7. Cedar R.
8. White R.
9. Puyallup R.
10. Cowlitz R.
11. Skookumchuck R.
12. Chehalis R.
13. Satsop R.
14. Elwha R.
15. Wenatchee R.
16. Yakima R.

NATIONAL WEATHER SERVICE
Western Region

Scale of Miles
0 10 20 30 40 50

N

FIGURE 25