Office of Environmental Management – Grand Junction

MOAB UTAH UMTRA

UMTRA Project

Revised Remedial Action Plan and Site Design for Stabilization of Moab Title I Uranium Mill Tailings at the Crescent Junction, Utah, Disposal Site

Attachment 1: Disposal Cell Design Specs

June 2007

U.S. Department of Energy

Office of Environmental Management

Work Performed Under DOE Contract No. DE–AC01–02GJ79491
for the U.S. Department of Energy Office of Environmental Management.
Approved for public release; distribution is unlimited.

Remedial Action Plan and Site Design for Stabilization of Moab Title I Uranium Mill Tailings at the Crescent Junction, Utah , Disposal Site

Attachment 1: Disposal Cell Design Specifications

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U.S. Department of Energy—Grand Junction, Colorado

Calculation Cover Sheet

Calc. No.: MOA-02-08-2006-5-19-01 **Discipline:** Engineering Design **No. of Sheets:** 6
Doc No.: X0173800

Location: Attachment 1, Appendix A

Project: Moab UMTRA Project

Site: Crescent Junction Disposal Site

Feature: Freeze/Thaw Layer Design

Sources of Data:

Climate Data:

Western Regional Climate Center
Desert Research Institute
University of Nevada, Reno, Nevada
Climate Data from Thompson, Utah
National Climate Data Center COOP Station # 428705
Latitude: 38°58'
Longitude: 109°43'
Elevation: 5150' AMS

Soil Data:

Drilling at Crescent Junction: Field Test Documentation

"Geotechnical Properties of Native Materials" calculation set, RAP Attachment 5, Appendix E.

Sources of Formulae and References:

See "Sources of Formulae and References" on page 3.

Preliminary Calc. ☐ **Final Calc.** ☒ **Supersedes Calc. No.** MOA-02-05-2006-5-19-00

Author:	Roslyn Stz	6/6/07	**Checked by:**	[illegible]	5/30/07
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Approved by:	John E Elmer	5/31/07		[illegible]	5/31/07
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				[illegible]	May 31, 07
				Name	Date
			REVIEWED:	Frank B. Gerow	5-30-07
				Name	Date

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Problem Statement:

An important design parameter for the final cover of the Moab uranium mill tailings repository is the maximum depth to which frost can be expected to penetrate into the cover. When surficial soils freeze, the coupled processes of freeze-induced expansion and desiccation result in reduced soil density and the development of cracks and fissures in the cover soils. These occurrences lead to increases in hydraulic conductivity and gas permeability, which manifest as detrimental increases in the infiltration of meteoric water into the cover, and also to increased flux of soil gases (e.g. radon) from the cover. As it is a design imperative to reduce both the water infiltration into and the radon flux out of the repository, the upper surface of the radon barrier must be situated sufficiently below the effective ground surface that it is protected from seasonal freeze/thaw effects. The objective of this calculation set is to identify the design maximum frost penetration (design frost depth) at the repository site assuming a recurrence interval of 200 years for design of the freeze/thaw protective layer.

Method of Solution:

- Obtain climate data for the site.
- Obtain material properties for the in-situ borrow materials from the "Geotechnical Properties of Native Materials" calculation set (Attachment 5, Vol. I, Appendix E) for the Crescent Junction Site.
- Use the method described in Smith and Rager (2002) to predict the maximum depth of frost penetration for the Crescent Junction Disposal Site.

Assumptions:

- No climate data is available for the Crescent Junction Disposal Site. Climate data from Thompson Springs, Utah, was available for 36 of 61 years from 1933 to 1994. Thompson Springs is located approximately 5 miles due east of the proposed disposal cell site. The elevation at the weather station (5,150 feet [ft]) is approximately 112 ft higher than the estimated highest top-of-cover elevation (5,038 ft) at the Crescent Junction Site. It is assumed that the climate at the Crescent Junction Disposal Site is the same as that of nearby Thompson Springs, Utah.
- Literature sources are reliable and representative sources of the physical phenomena.
- Regardless of the final cover configuration selected, the loosely compacted cover materials will act as either the protective layer over a typical compacted soil radon barrier or as the upper zone of a monolithic cover. The effects of rock mulch or other surface treatment were conservatively neglected. Frost penetration decreases with both increasing soil bulk density and increasing water content, due to the insulating effect of ice that forms as water freezes. Although the loosely placed cover materials will initially have higher bulk density and water content than the in-situ borrow materials, the cover soil density and moisture conditions will eventually return to their in-situ state due to prolonged exposure to freezing and thawing cycles. Consequently, soil conditions for the frost prediction model were assumed to approximate those of the in-situ borrow soils, as indicated below.

Borrow Material Condition	Dry Density (pcf*)	Water Content (gravimetric) %
Loosely placed cover (85% ASTM D 1557 max dry density @ 2% below optimum water content)	103.5	9.7
Average in-situ conditions	91.3	6.3
Conditions modeled	91.3	6.3

*Pounds per cubic feet

Calculation:

- Step 1. Determine Freeze-Index Parameters
  Climate data consisting of 36 years of maximum and minimum daily air temperatures were used to compute the air-freeze index (degree-days), duration of freeze, and mean annual temperature for each year. Plotted data are included as Appendix A.

- Step 2. Determine Surface Temperature Correction Data

  The daily temperature data used to determine the freeze-index parameters are typically measured 1.5 meters (m) above ground surface. However, measured ground temperatures can be greater than air temperatures due to the effects of snow cover, net solar radiation, thermal conduction from warmer soils below the surface, and convective heat transfer (Smith and Rager 2002). The ratio of the surface-freeze index to the air-freeze index is related through a factor, N. Because of the complexity and uncertainty between the freeze indices, a conservative estimate for N is recommended for practitioners (U.S. Army and U.S. Air Force 1998). The surface correction factor, N, was conservatively assumed to be 1.0 for analysis of the Crescent Junction Disposal Site. In addition, values for N of 0.8 and 0.9 are used as more realistic estimates for depth of frost penetration assuming a vegetative cover and a rock cover, respectively.

- Step 3. Determine Soil Thermal Properties

  Soil thermal properties—thermal conductivity, heat capacity, and latent heat of fusion—are products of empirical relationships between the dry unit weight (pounds per cubic feet [pcf]) and gravimetric moisture content (%). These relationships are reproduced in Aitken and Berg (1968) originally published by Aldrich and Paynter (1953) and Kersten (1949).

- Step 4. Determine Annual Frost Depths

  Annual frost depths were determined for each of the subject years using the Modified Berggren Formula (MBF) as discussed in Smith and Rager (2002). The MBF was converted to PC software by the U. S. Army Corps of Engineers in 1997. Computer output for each year analyzed are presented as Appendix B, including design air freezing index, design surface freezing index, mean annual temperature, length of freezing season, and total frost penetration.

- Step 5. Determine Extreme Frost Depth

  Extreme-value frost depths for the 200-year recurrence interval are determined by extrapolating beyond the record of observed data using the cumulative probability distribution of the Gumbel function (Smith and Rager 2002). Frost depths are plotted in relation to the standard variate and recurrence interval, and linear regression is used to extrapolate and interpolate freezing depths. Graphical results of the extreme-frost-depth analysis are included in Appendix C, and indicate a maximum frost penetration of 44 inches (104 centimeters [cm]) for a recurrence interval of 200 years with a surface factor of 1.0. Frost-depth predictions are also made with surface factors of 0.9, predicted depth of 41.5 inches; and with a surface factor of 0.8, a frost-penetration depth of 38.5 inches is determined.

Discussion:

Placing a 44-inch-thick frost-protection layer over the radon barrier layer is the maximum thickness of soil required to prevent freeze-thaw degradation of the barrier layer (N=1.0). Less thicknesses of 41.5 inches (N=0.9), down to 38.5 inches (N=0.8) are also predicted dependent on the ratio between the air temperature and surface temperature. Verification of the 41.5-inch predicted frost depth at proposed Crescent Junction Disposal Site compares well to other uranium mill tailings disposal cells in the general region as shown in the table below.

Site	Design Dry Density (pcf)	Design Water Content (%)	Predicted Frost Depth (inches)
Monticello, UT	90	17	45
Cheney (Grand Junction, CO)[1]	104	12	38
Estes Gulch (Rifle, CO)[1]	106	9	69
Green River, UT	No frost protection layer included in the design		

[1]Three layers in protective cover: 12-inch coarse material (rock riprap), 6-inch coarse material (sand bedding), and fine material with these properties reported.

Green River, Utah, is the closest constructed disposal cell to the proposed Crescent Junction Site. No information was found to document that a frost-penetration analysis had been performed here. The cover at the Green River Site consists of a 12-inch-thick riprap layer underlain by a 6-inch-thick sand drainage layer. Discussions with designers of the disposal cell reveal that an analysis was performed and without a protective layer, the depth of frost penetration does extend into the radon barrier, but not completely through the layer. No performance data was discovered.

Given similar density and moisture conditions, the depth of frost penetration into coarse-grained soils, such as a sand layer, is slightly greater than for a fine-grained soil layer. Thus, inclusion of a sand drainage layer below a protective layer of soil would slightly increase the magnitude of frost penetration, if the sand were used to replace the fine-grained soil. However, the magnitude of the difference in thicknesses is not expected to be significant.

Conclusions and Recommendations:

- Based on results of the freeze/thaw analysis, a maximum frost penetration of 41.5 inches (1.05 m) should be assumed for design of the Moab uranium tailings cover at the Crescent Junction Disposal Site, using a rock cover, and 38.5 inches (0.98 m) if a vegetated cover is used.
- The design depth of frost protections depends on the type of cover chosen in the final design.

Computer Source:

MBF (Modified Berggren Formula). Coded for personal computer use by U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory in 1997.

Sources of Formulae and References:

Aitken, G.W., and R. L. Berg, 1968. *Digital Solution of Modified Berggren Equation to Calculate Depths of Freeze and Thaw in multilayered Systems*, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, Special Report 122.

Aldrich, H.P., and H.M. Paynter, 1953. *Analytical Studies of Freezing and Thawing of Soils, First Interim Report*, U.S. Army Corps of Engineers, New England Division, Arctic Construction and Frost Effects Laboratory Technical Report 42.

Kersten, M.S., 1949. *Laboratory Research for the Determination of the Thermal Properties of Soils, Final Report,* U.S. Army Corps of Engineers, New England Division, Arctic Construction and Frost Effects Laboratory Technical Report 23.

NAVFAC (Naval Facilities Engineering Command), 1986. *Soil Mechanics Design Manual 7.01,* Alexandria, Virginia, pp. 7.1–42.

Smith, G.E. and R.E. Rager, 2002. "Protective Layer Design in Landfill Covers Based on Frost Penetration," American Society of Civil Engineers, *Journal of Geotechnical/Geoenvironmental Engineering,* 128(9), pp. 794–799.

U.S. Army and U.S. Air Force, 1988. *Arctic and Subarctic Construction Calculation Methods for Determination of Depths of Freeze and Thaw in Soils, First Intern Report,* Army Technical Manual 5-852-6, Air Force Regulation 88-19, Vol. 6.

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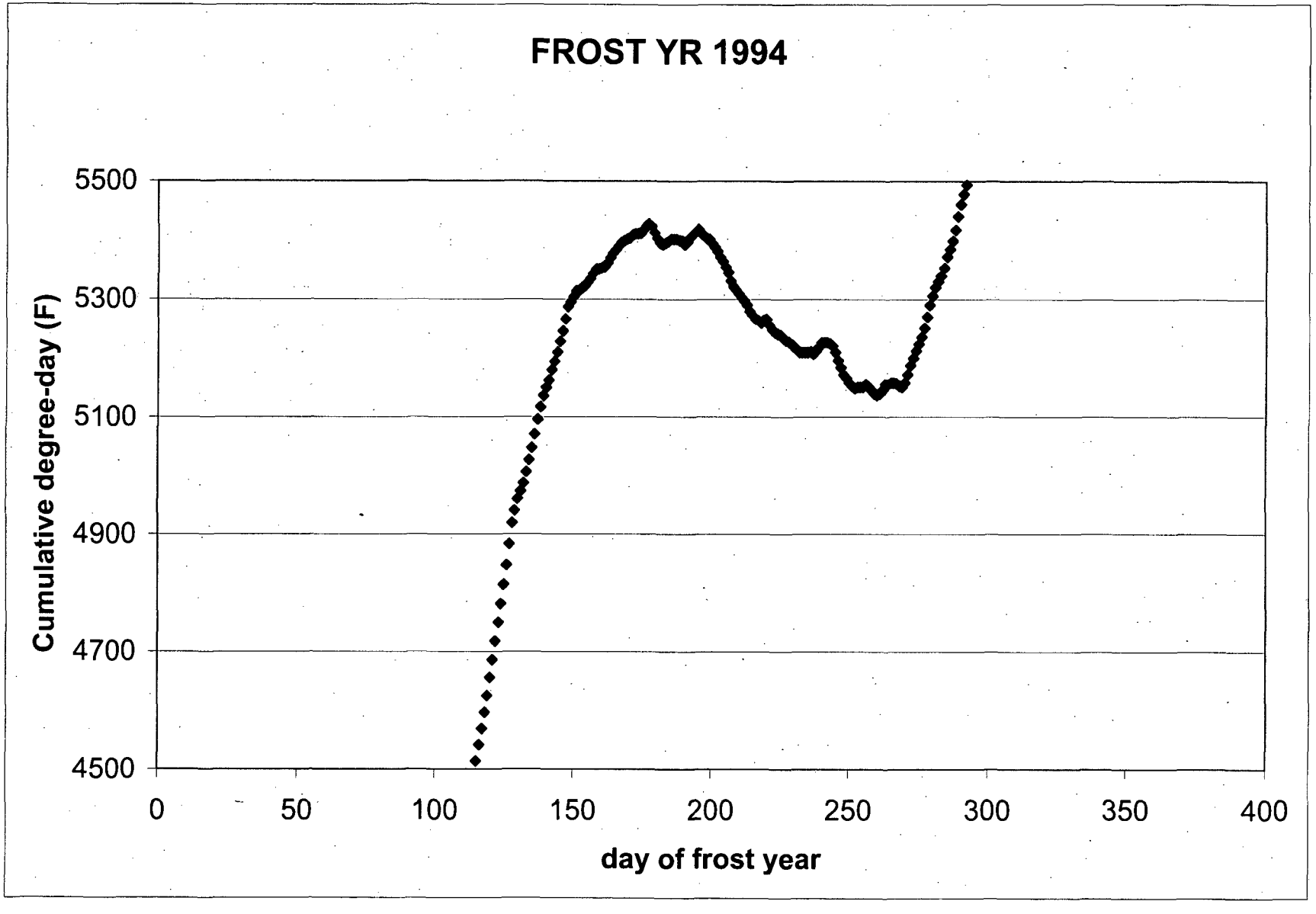
APPENDIX A

PLOTTED FREEZE-INDEX DATA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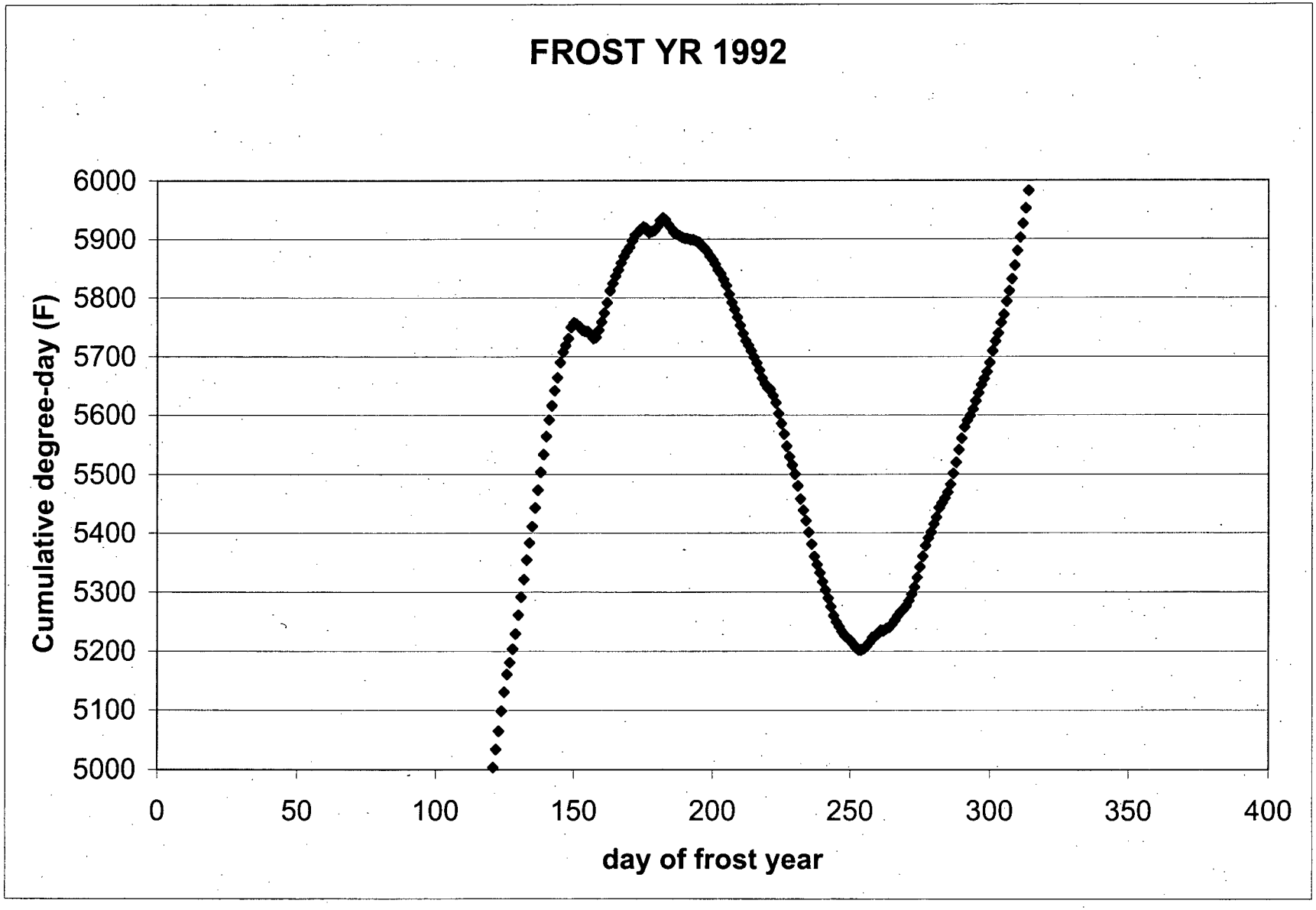
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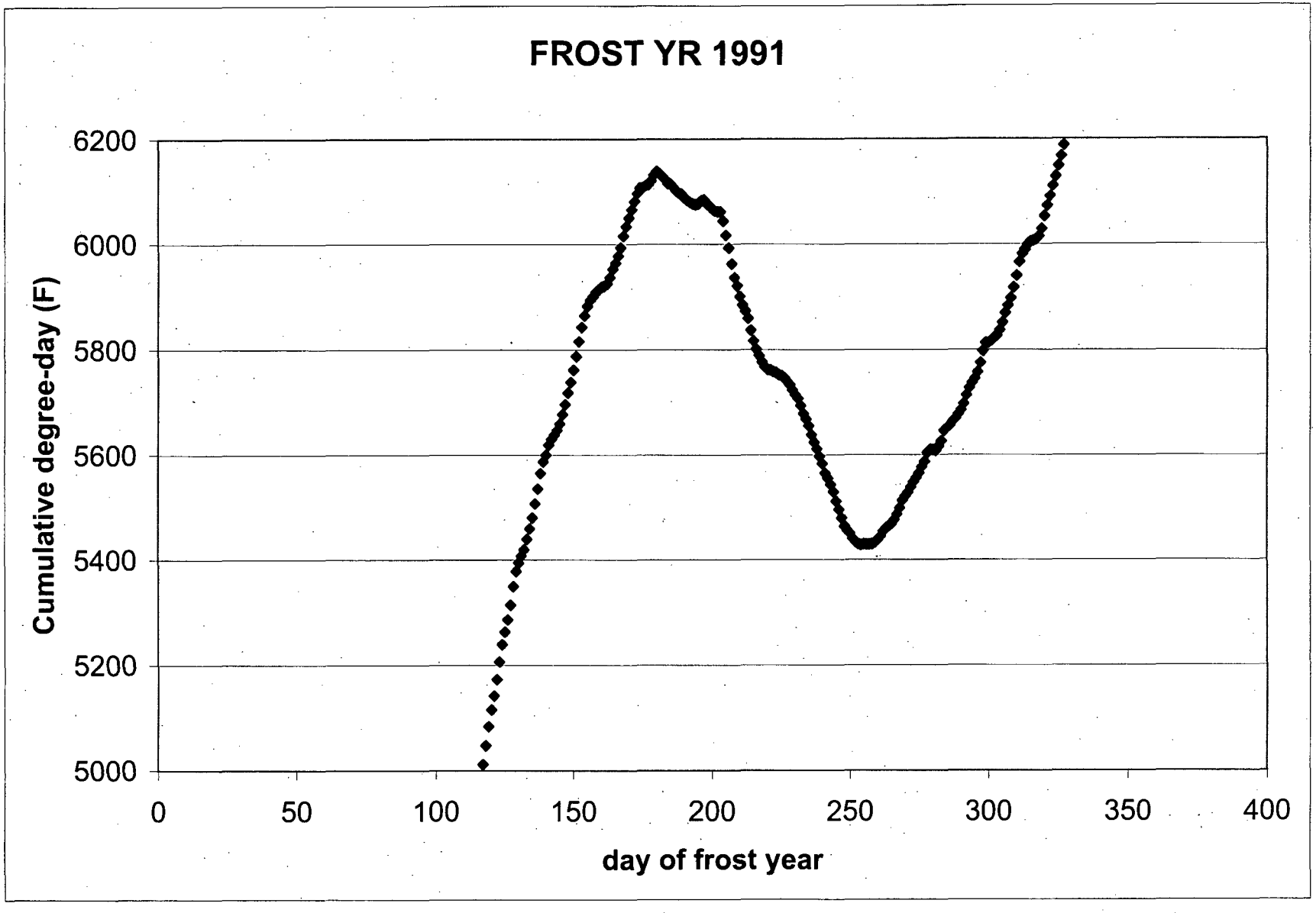
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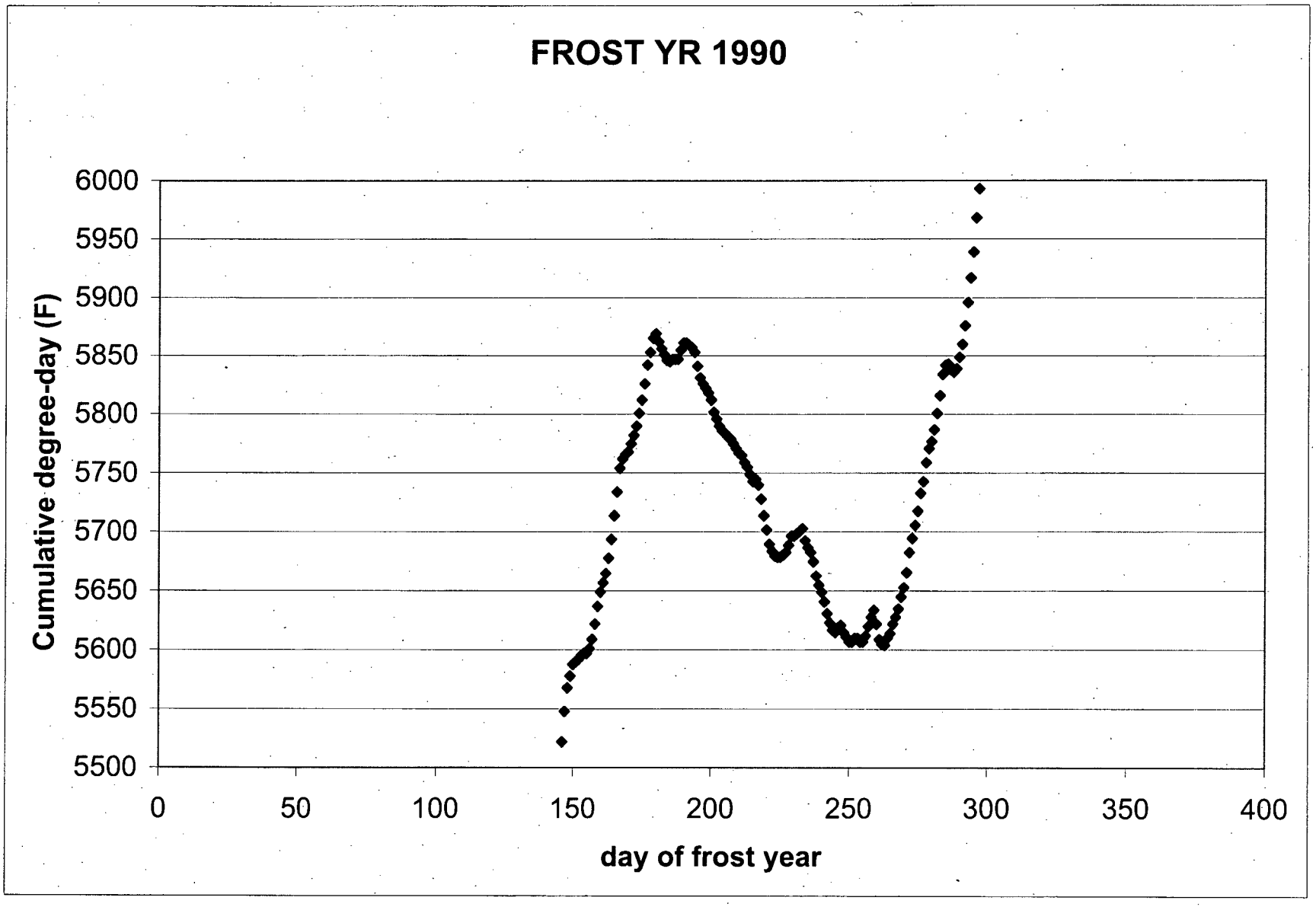
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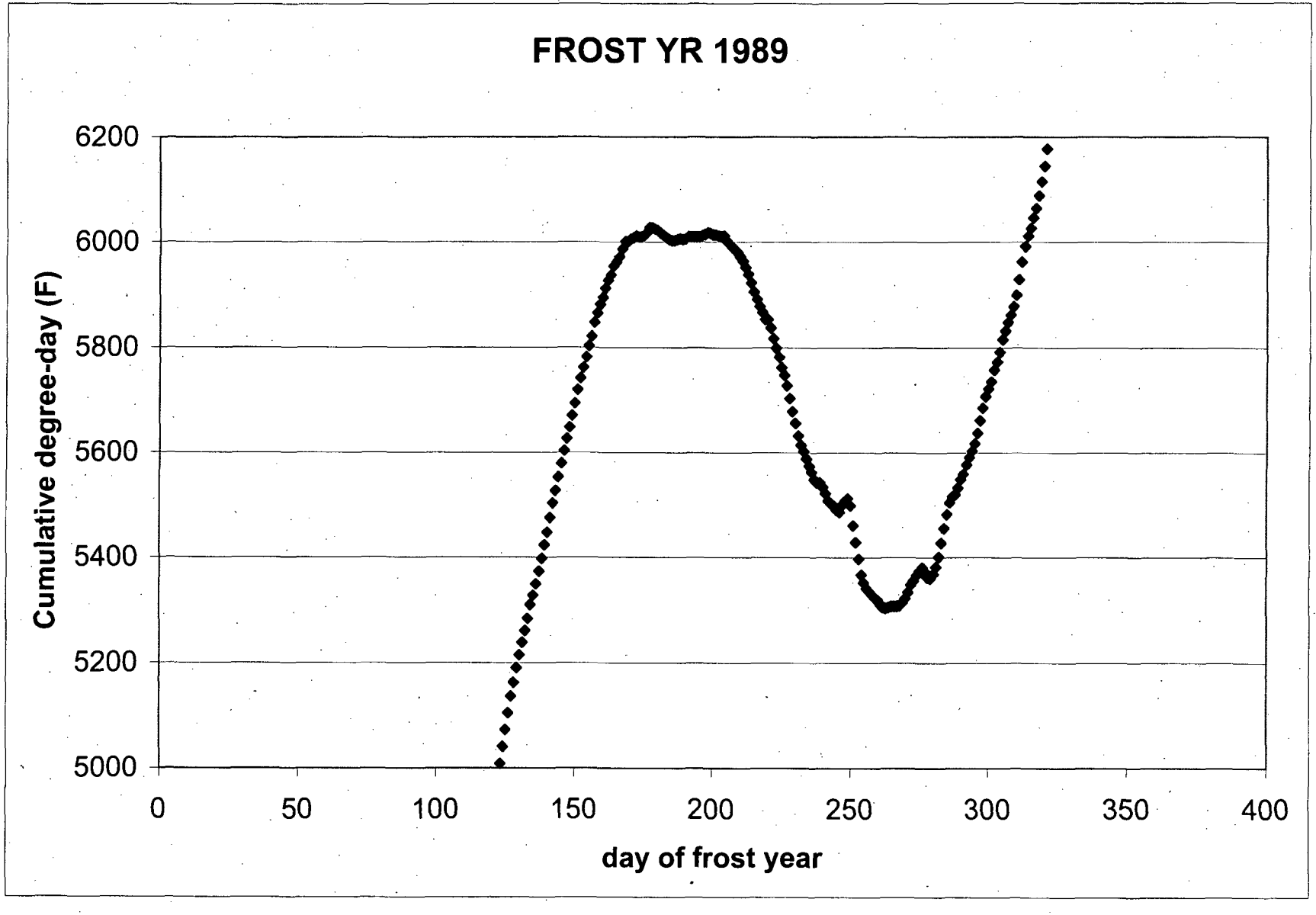
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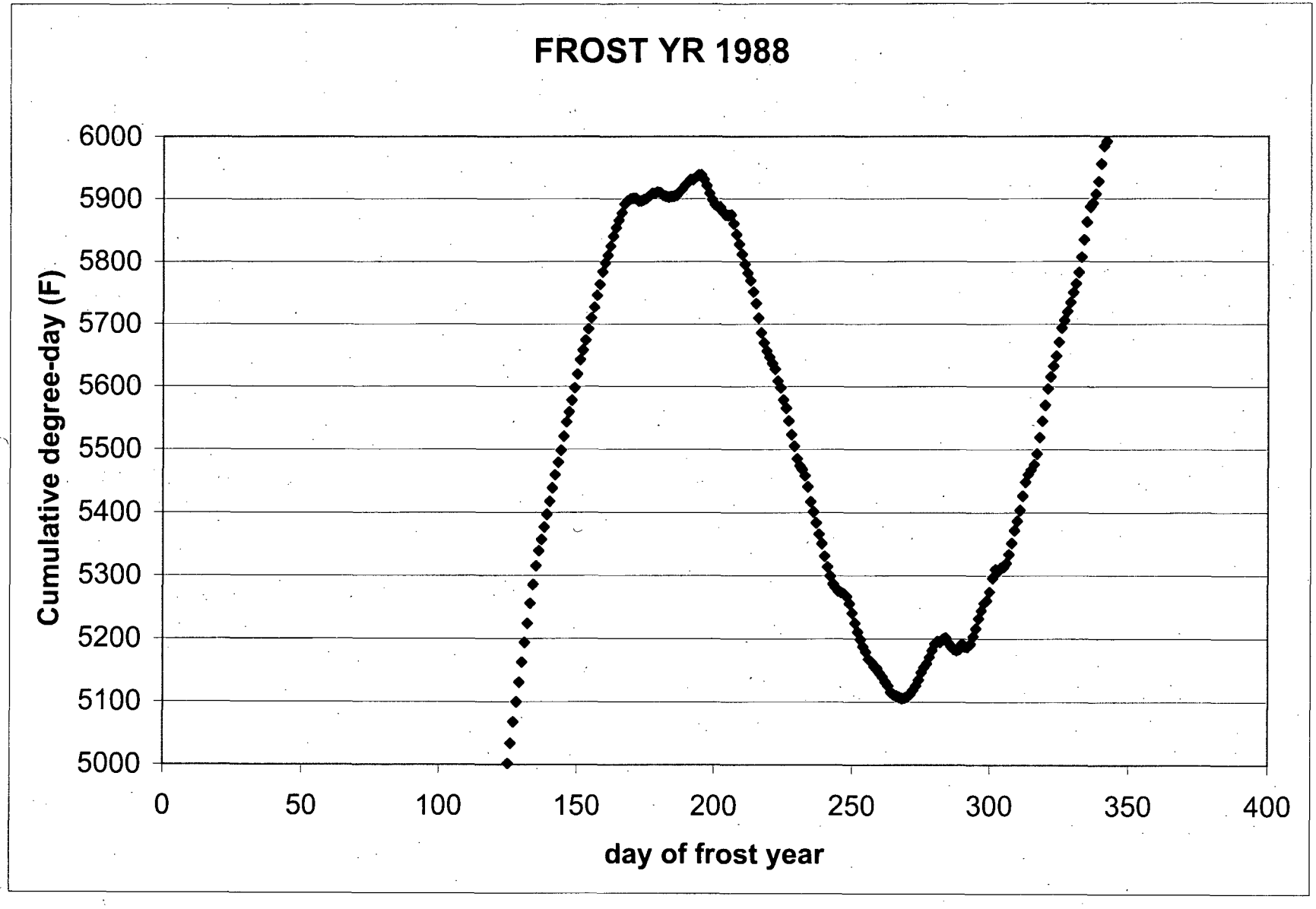
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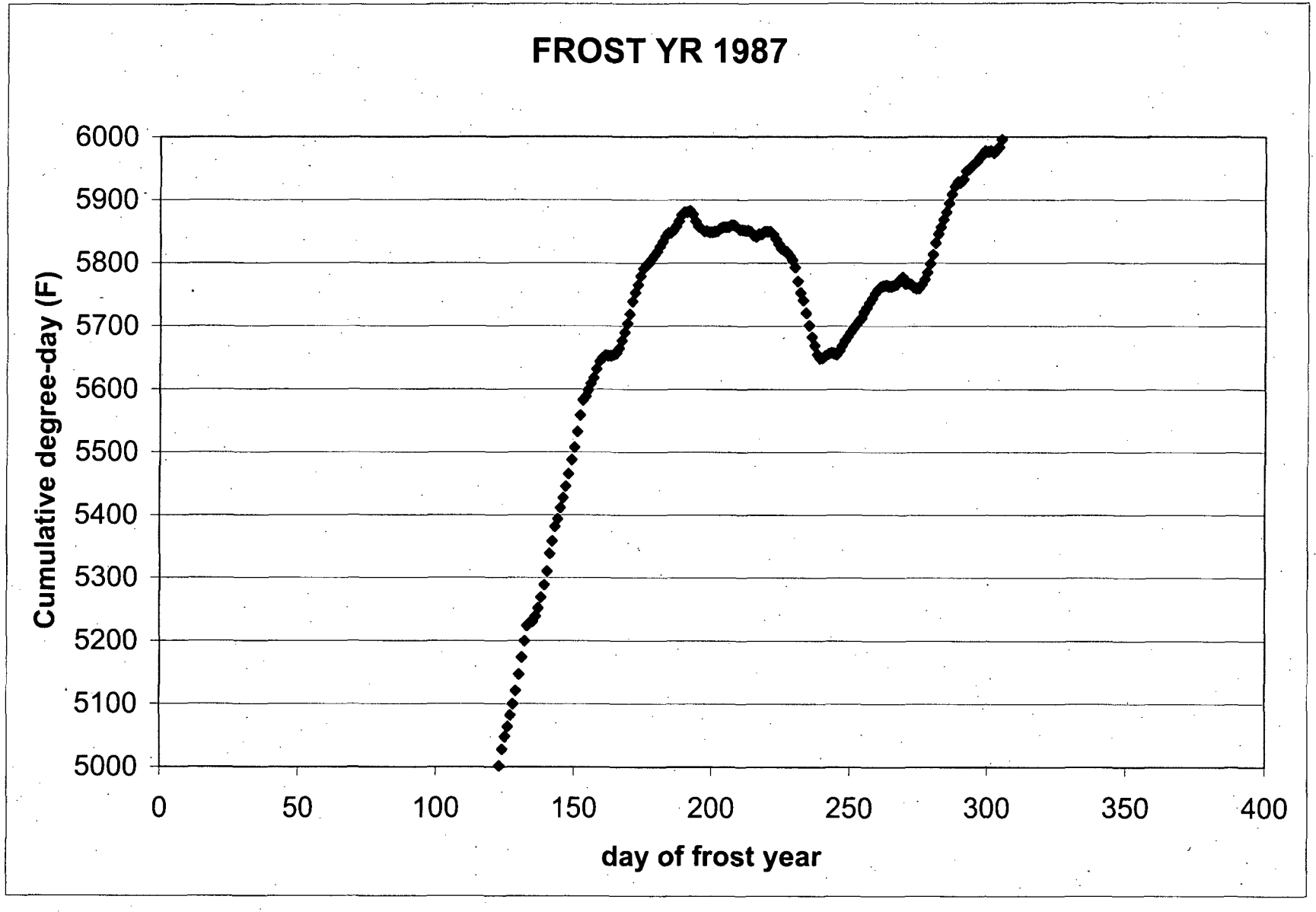
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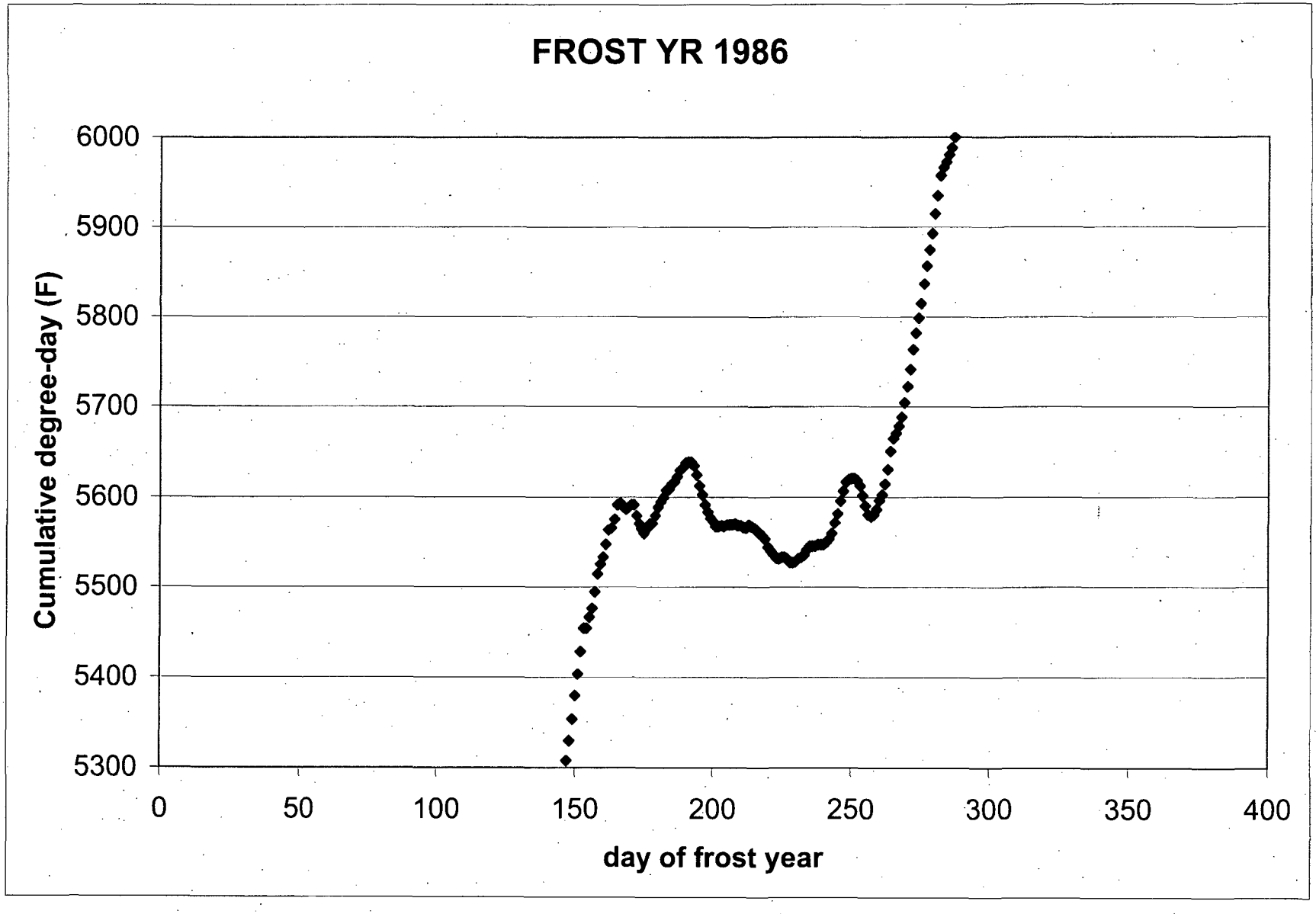
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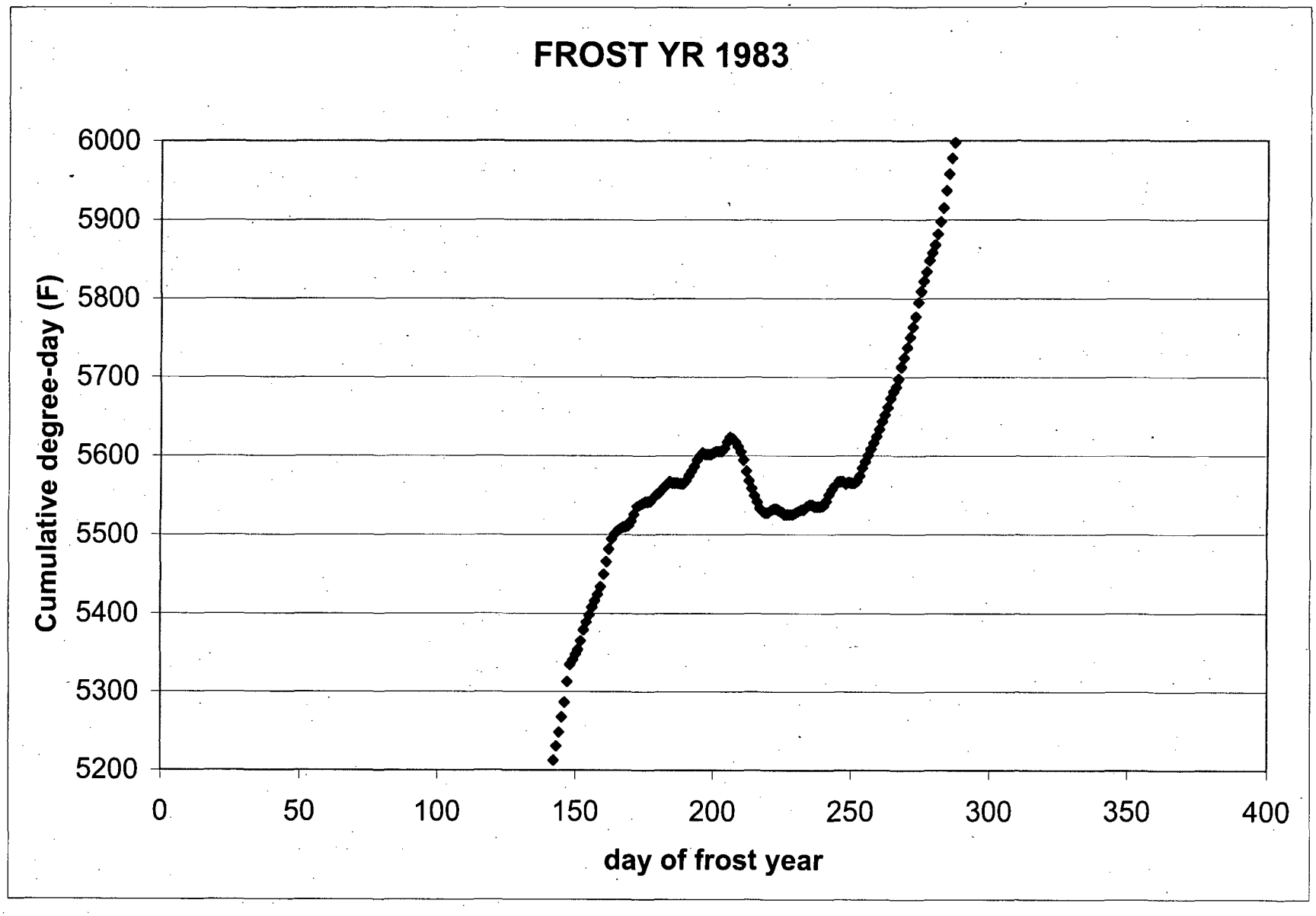
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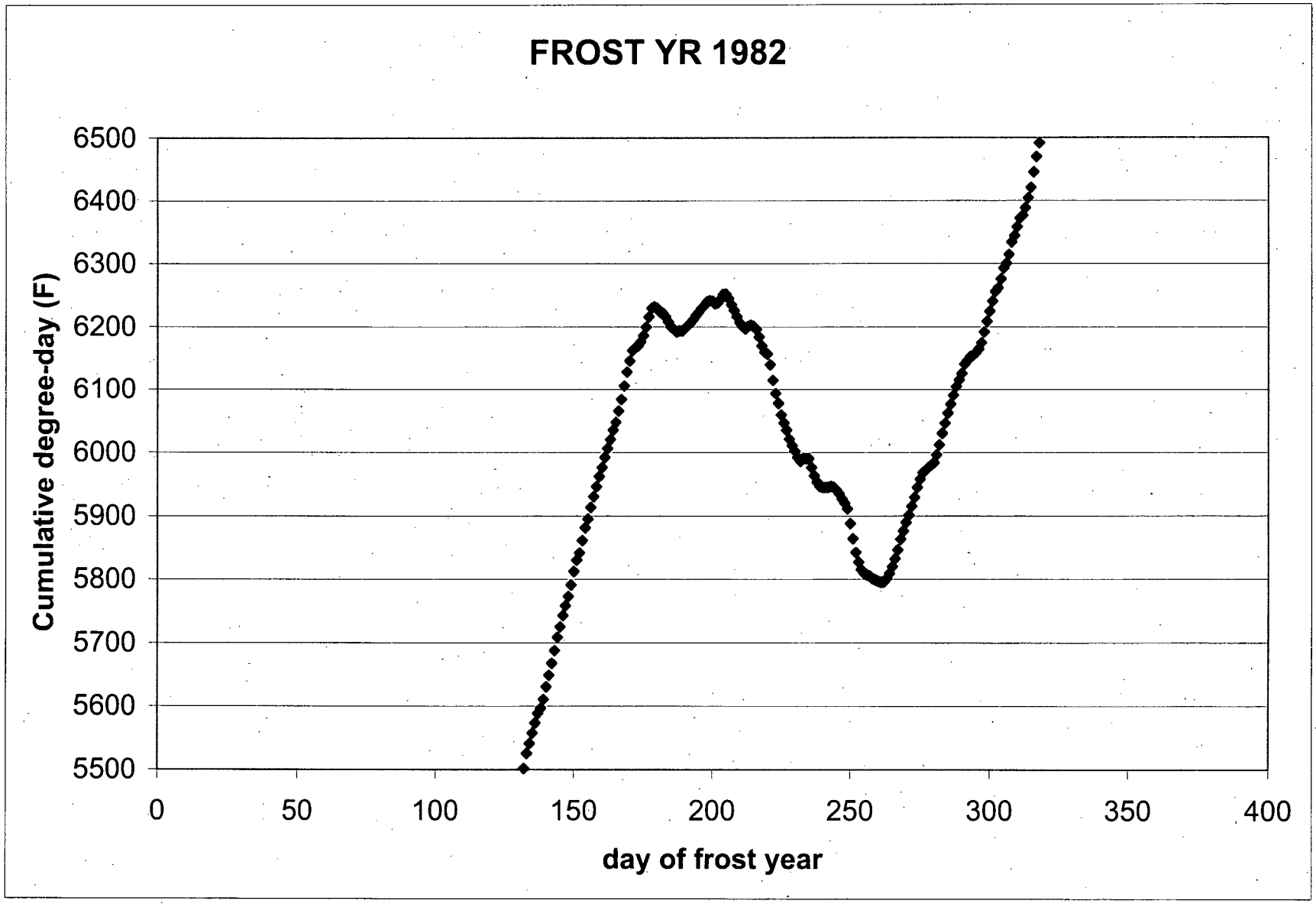
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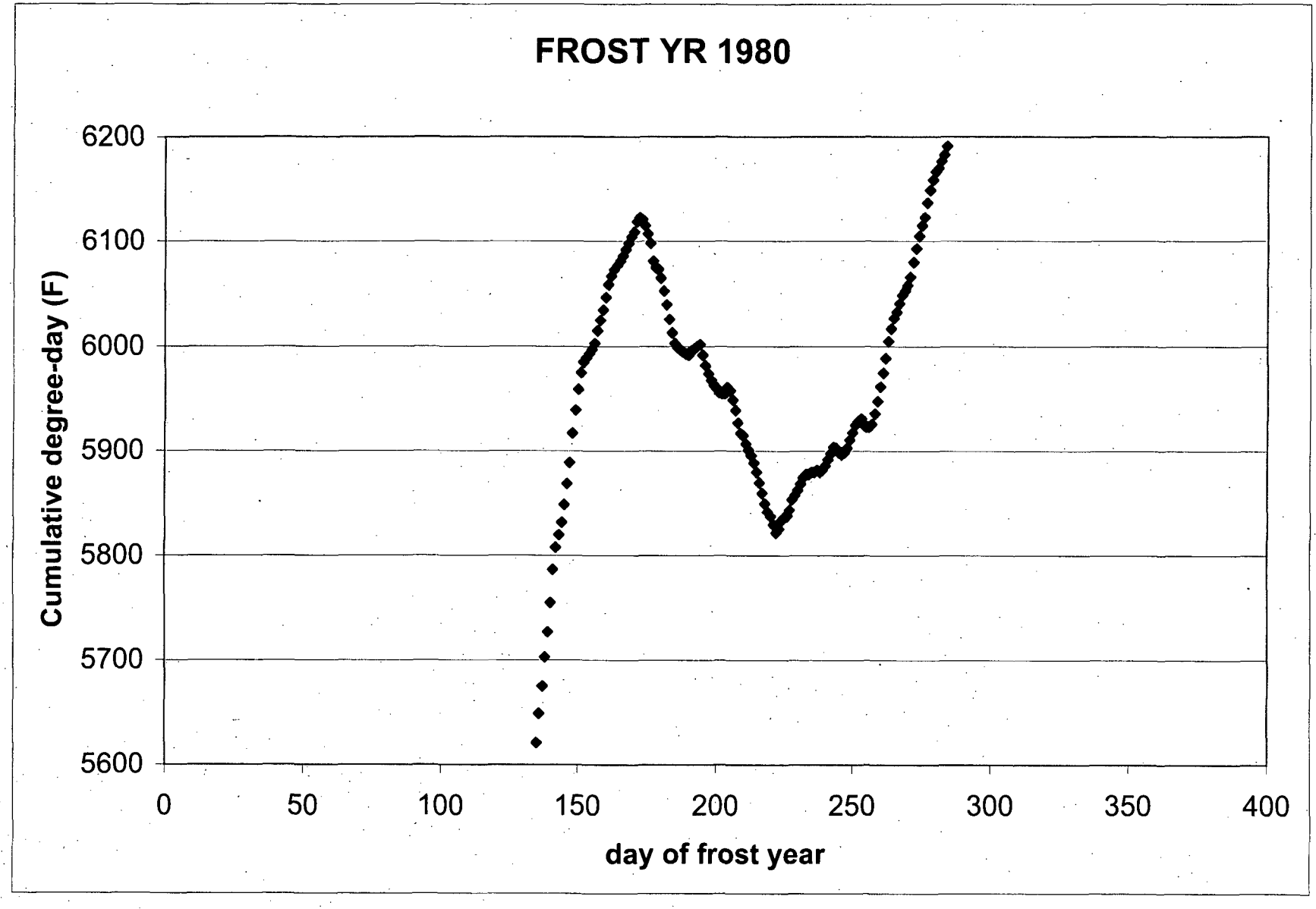
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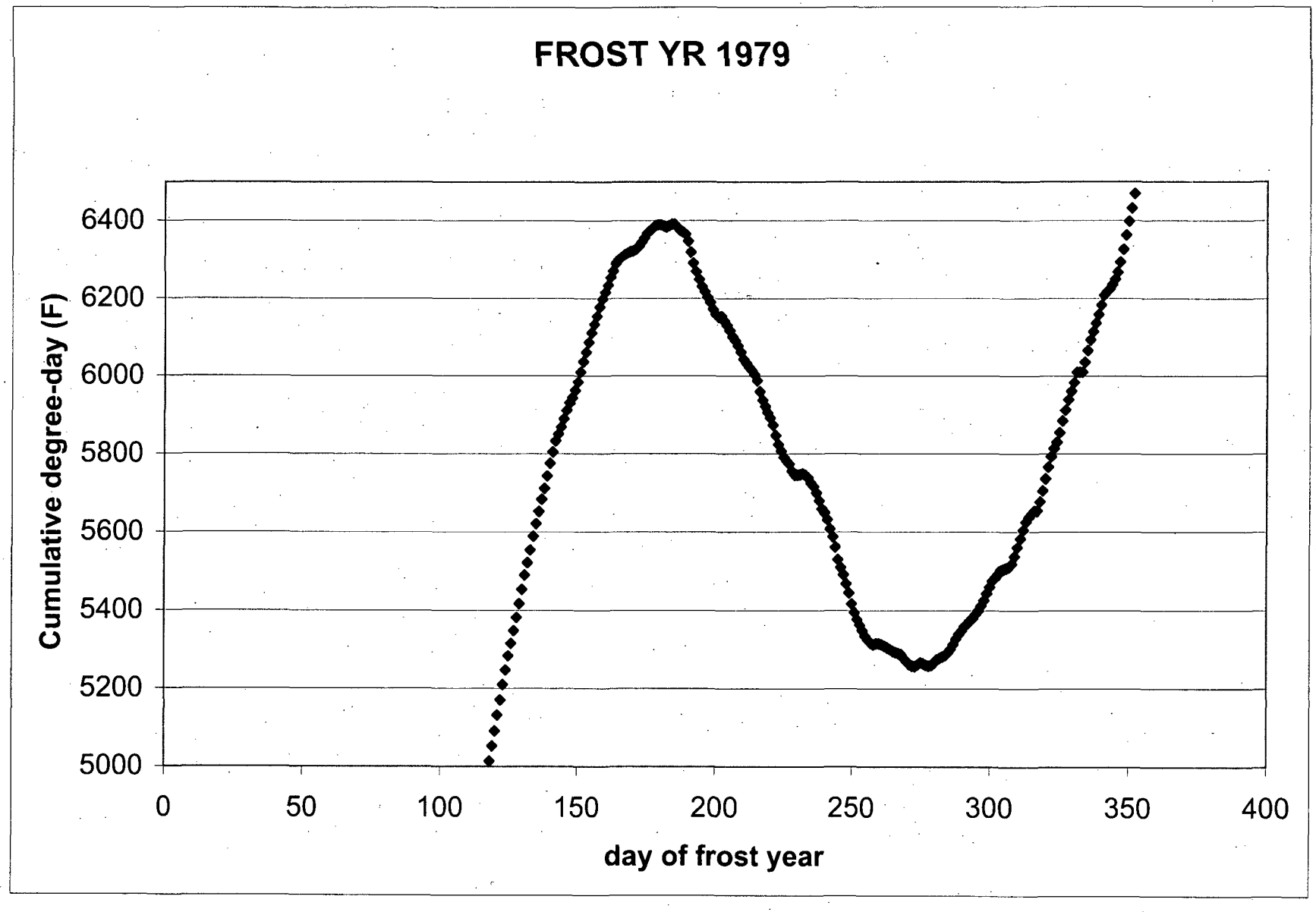
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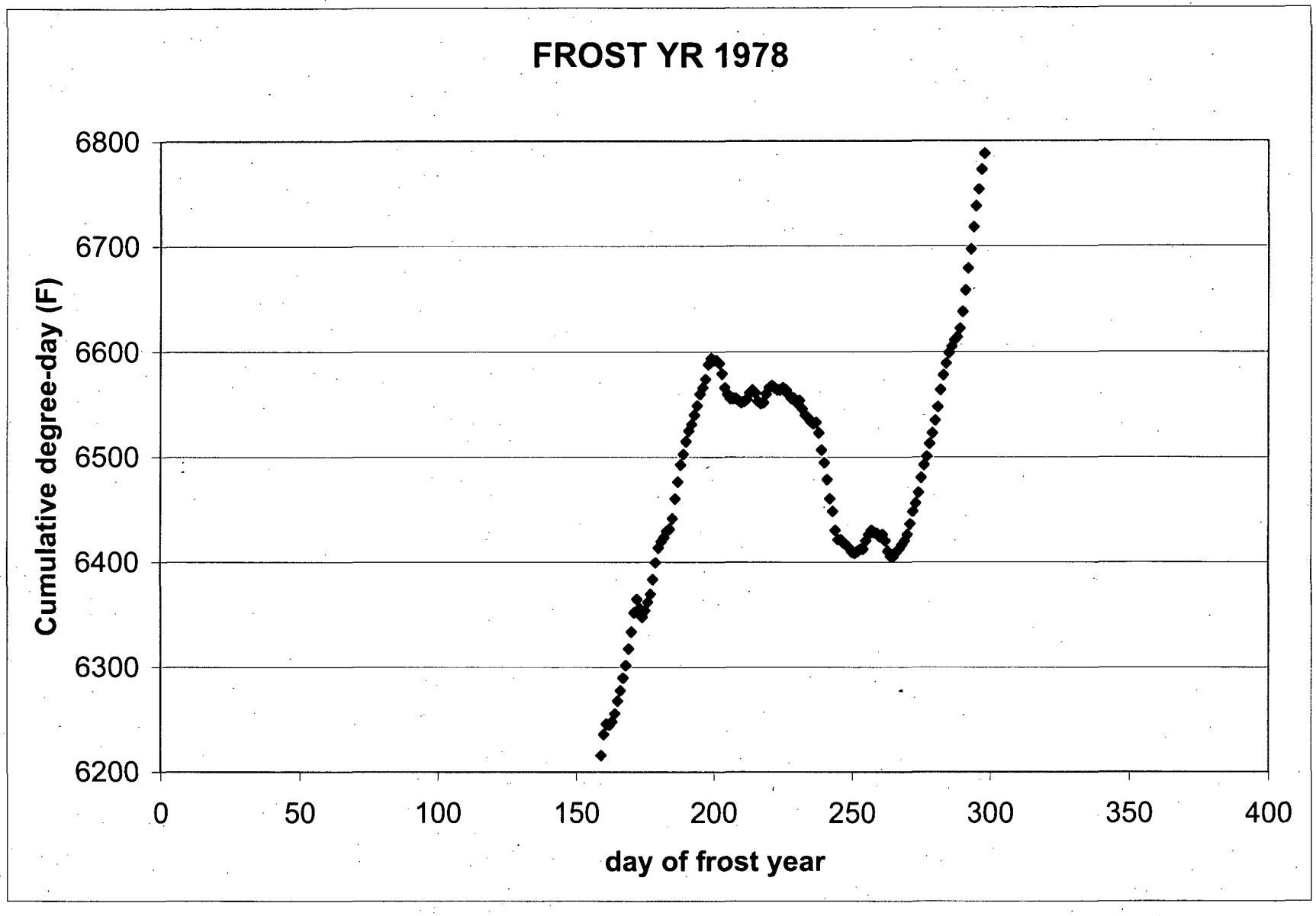
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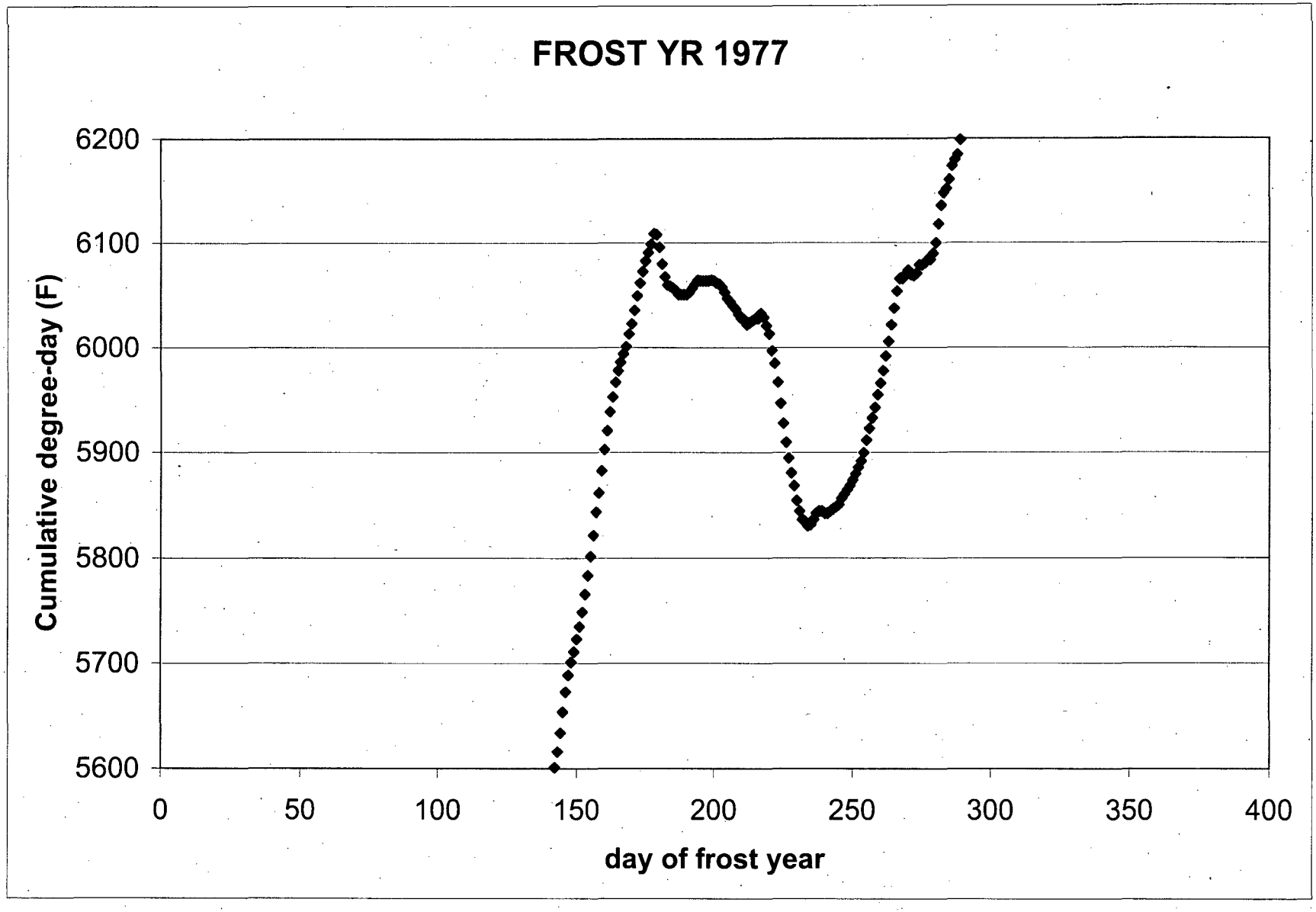
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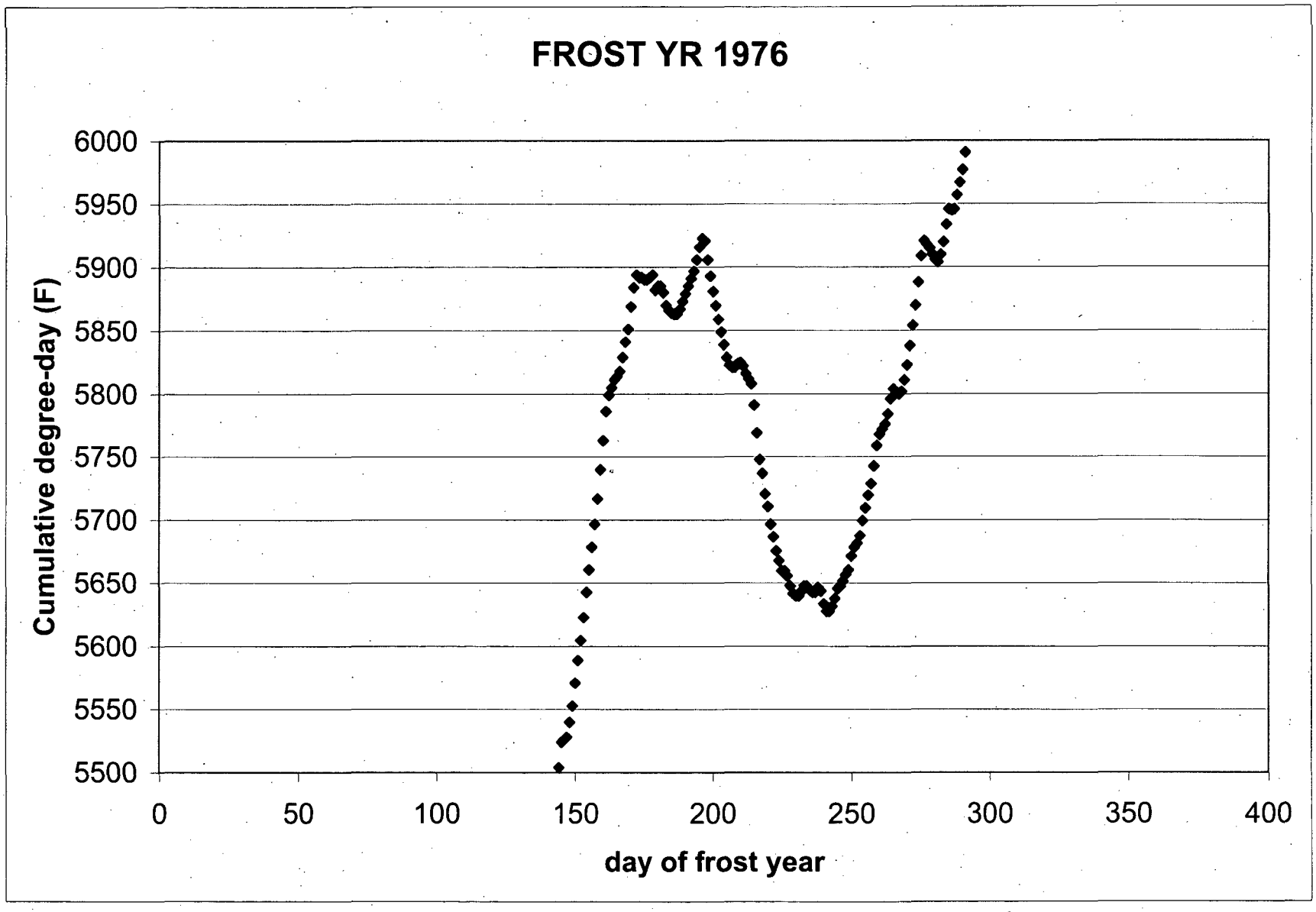
day of frost year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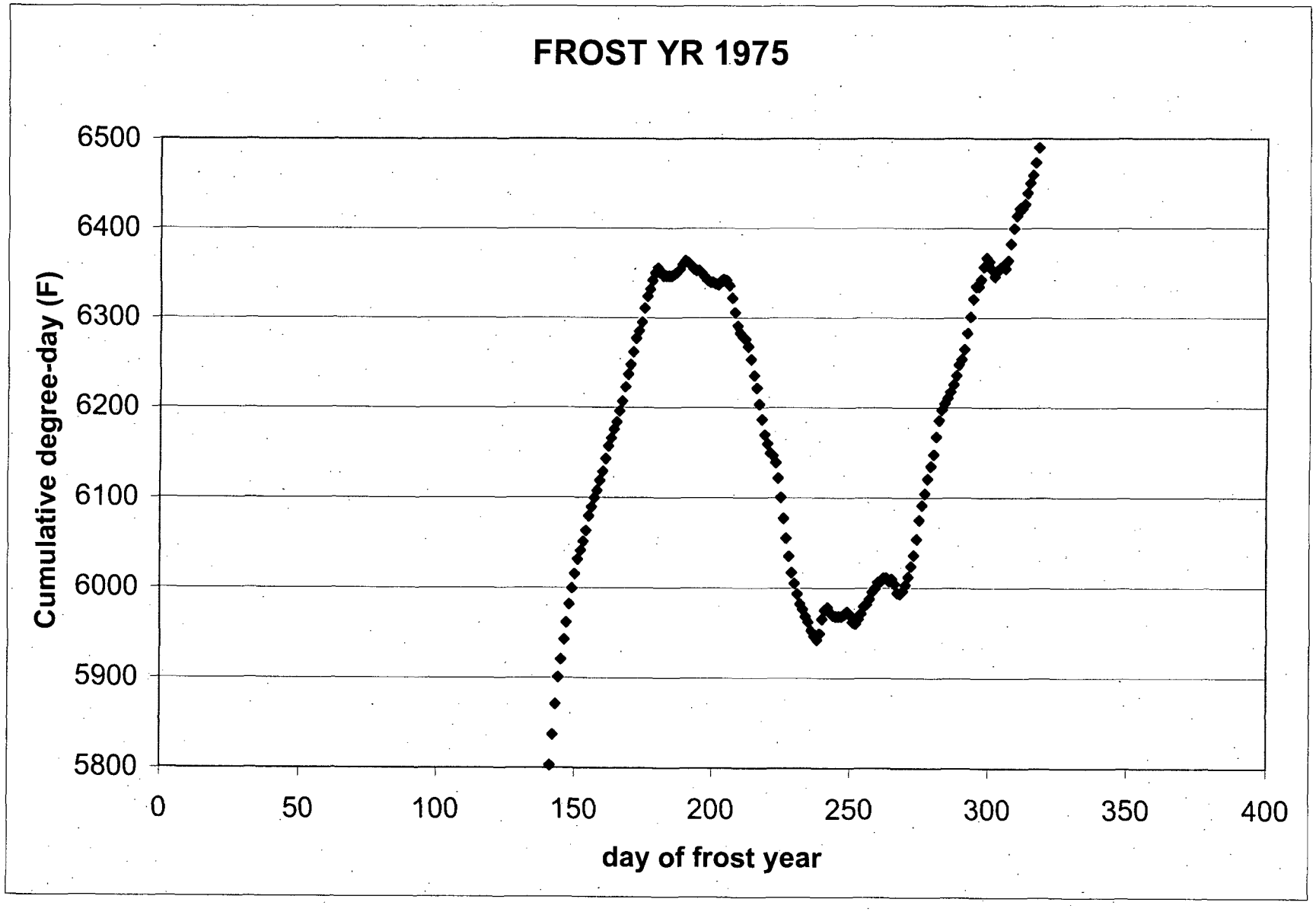
day of frost year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250
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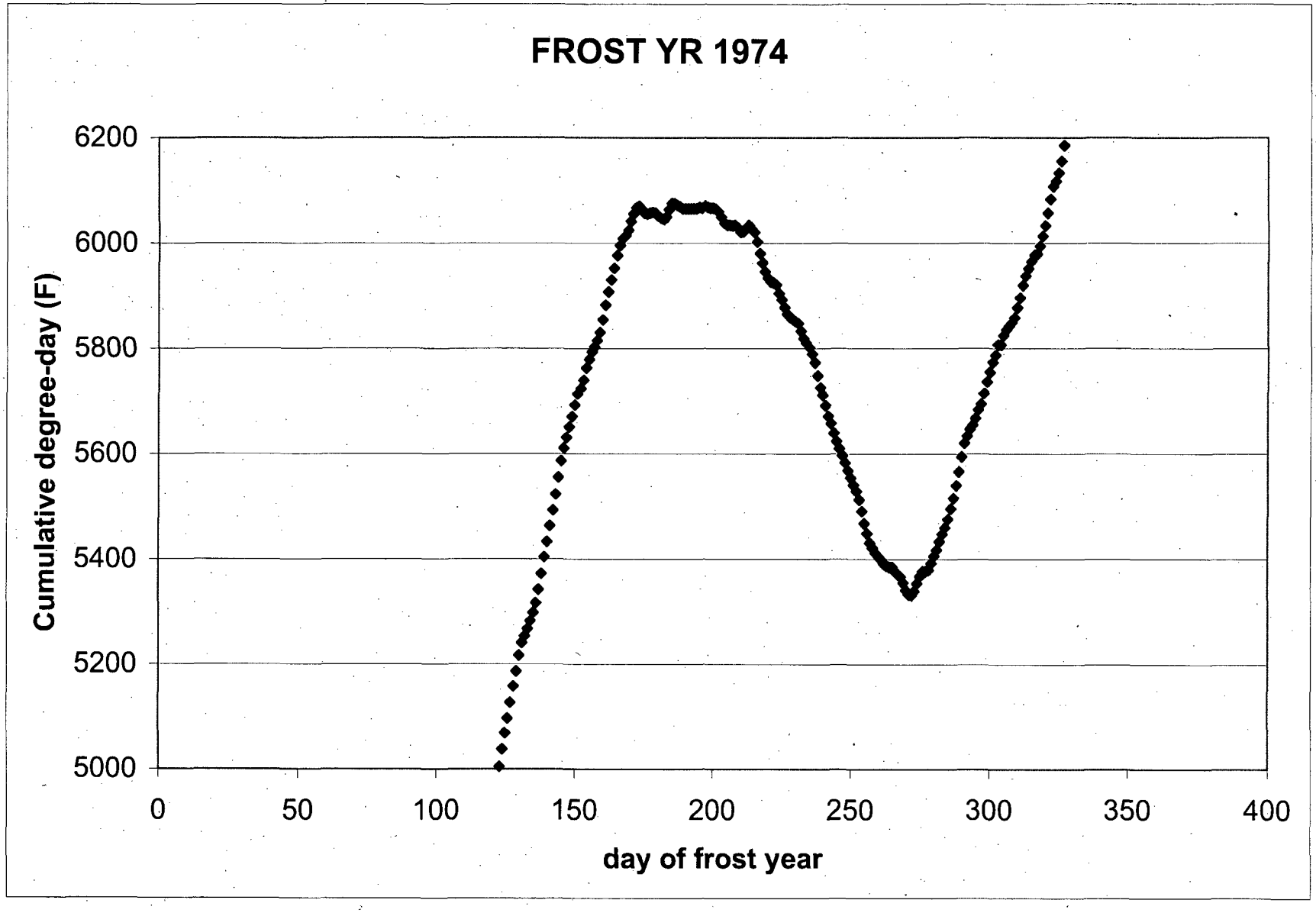
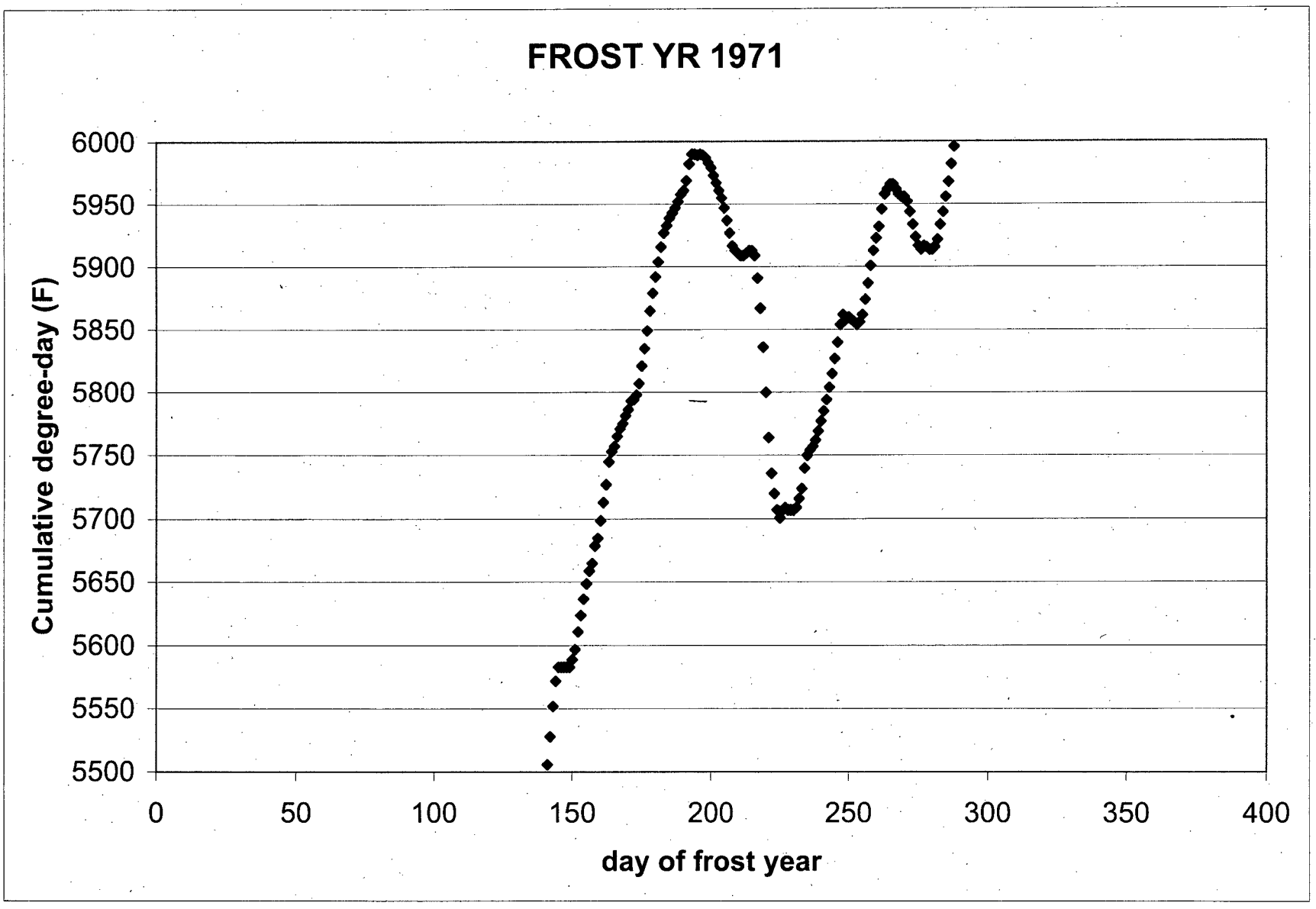
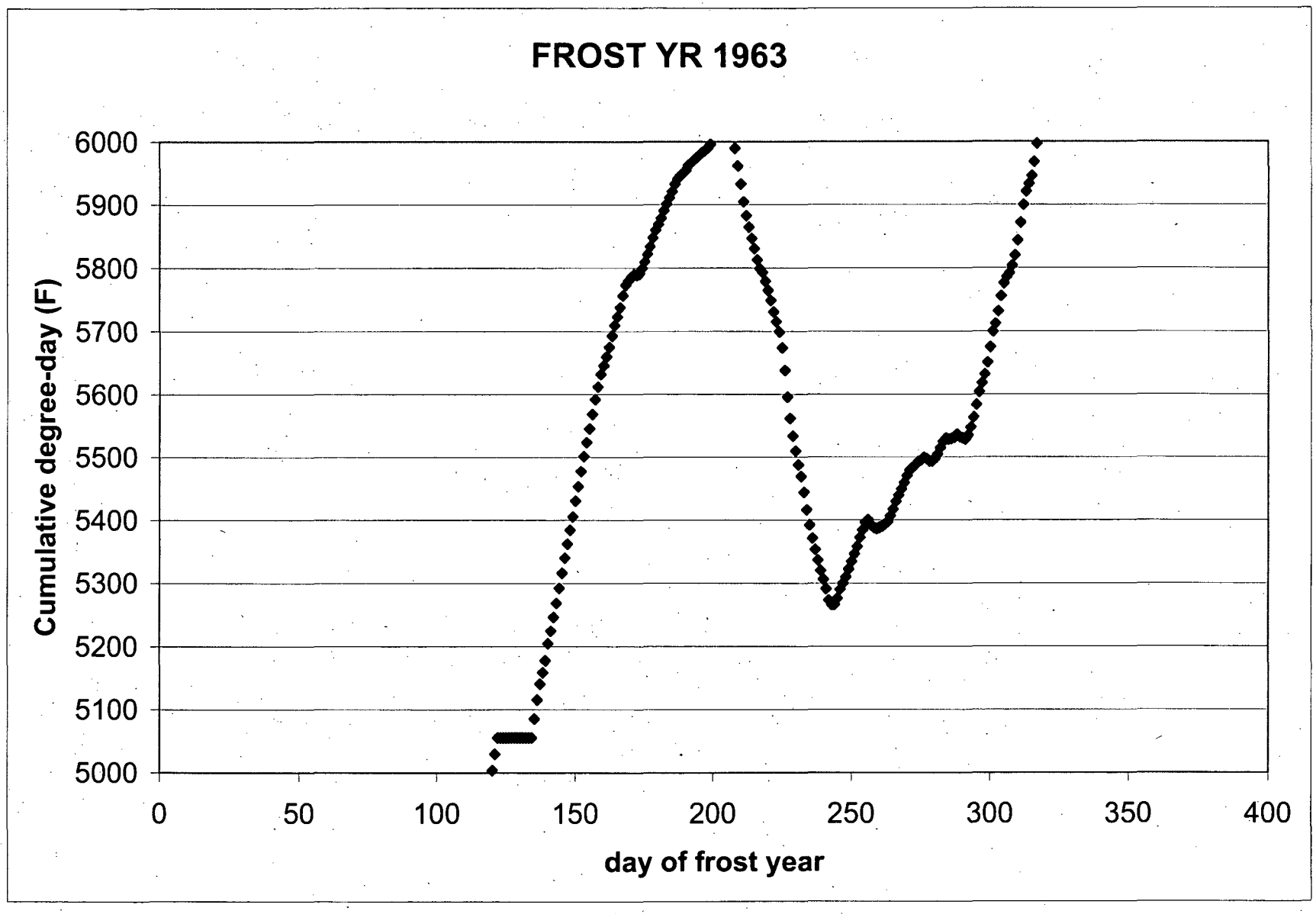
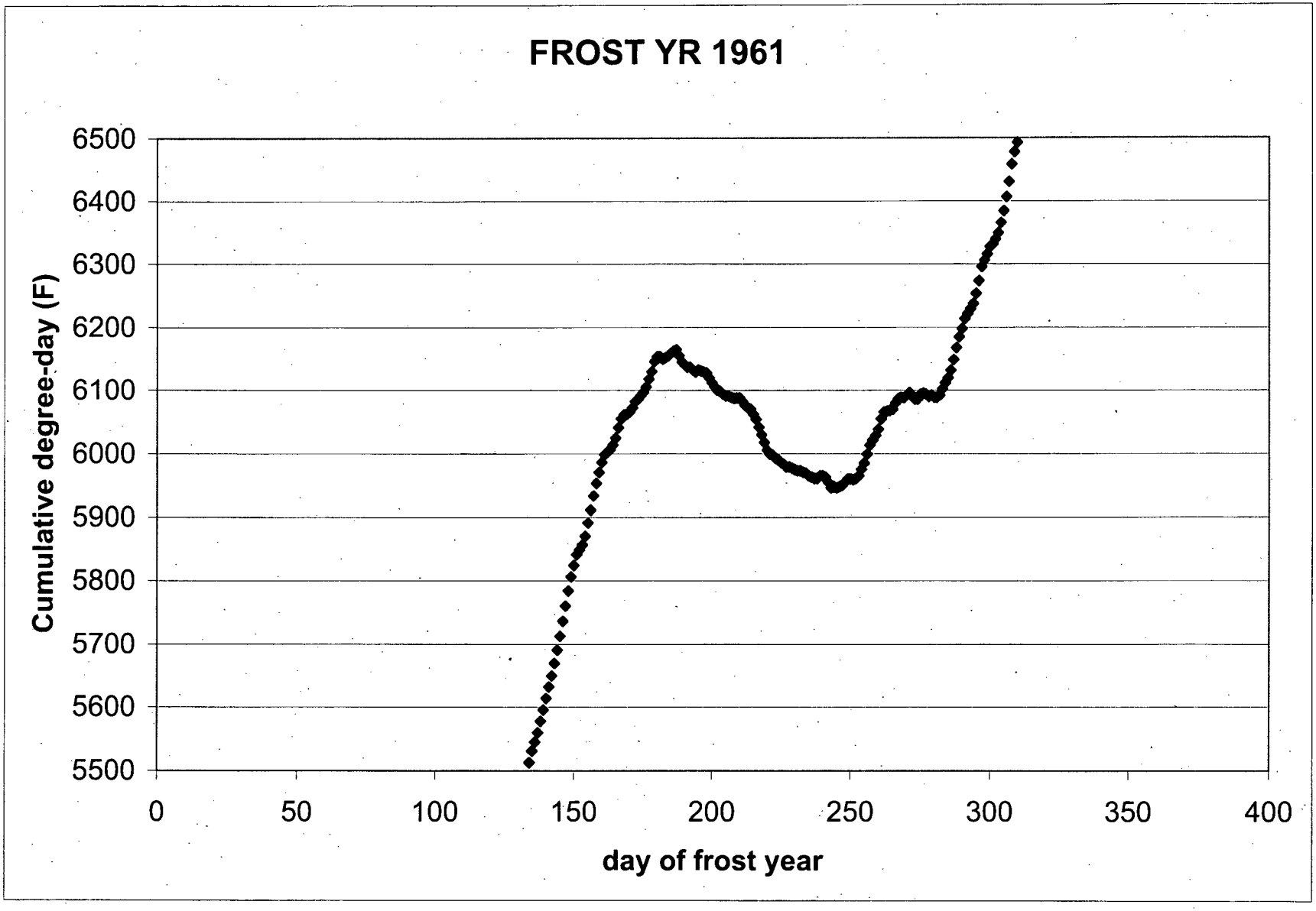
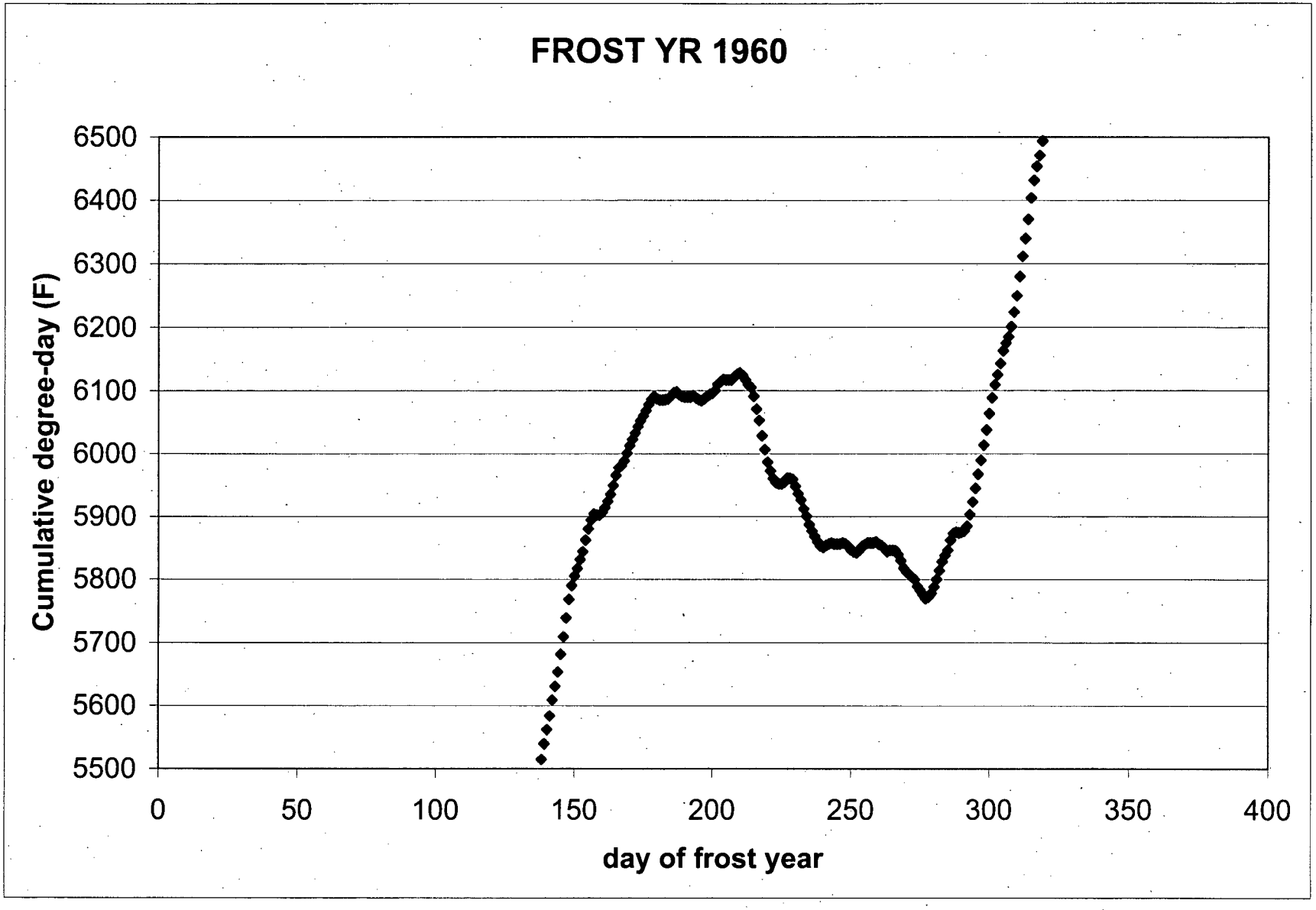
350
400
day of frost year

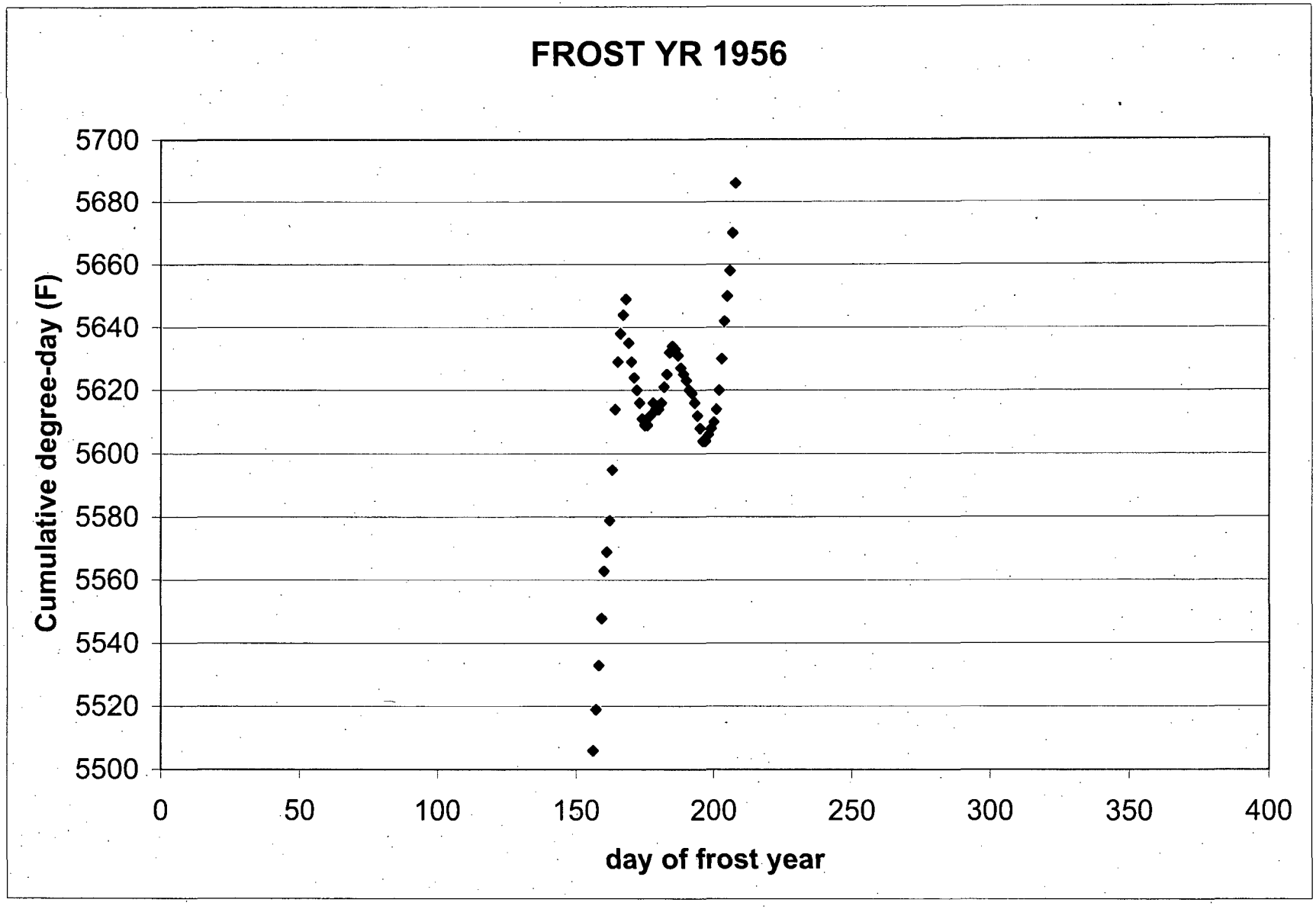

FROST YR 1974
Cumulative degree-day (F)
6200
6000
5800
5600
5400
5200
5000
0
50
100
150
200
250
300
350
400
day of frost year

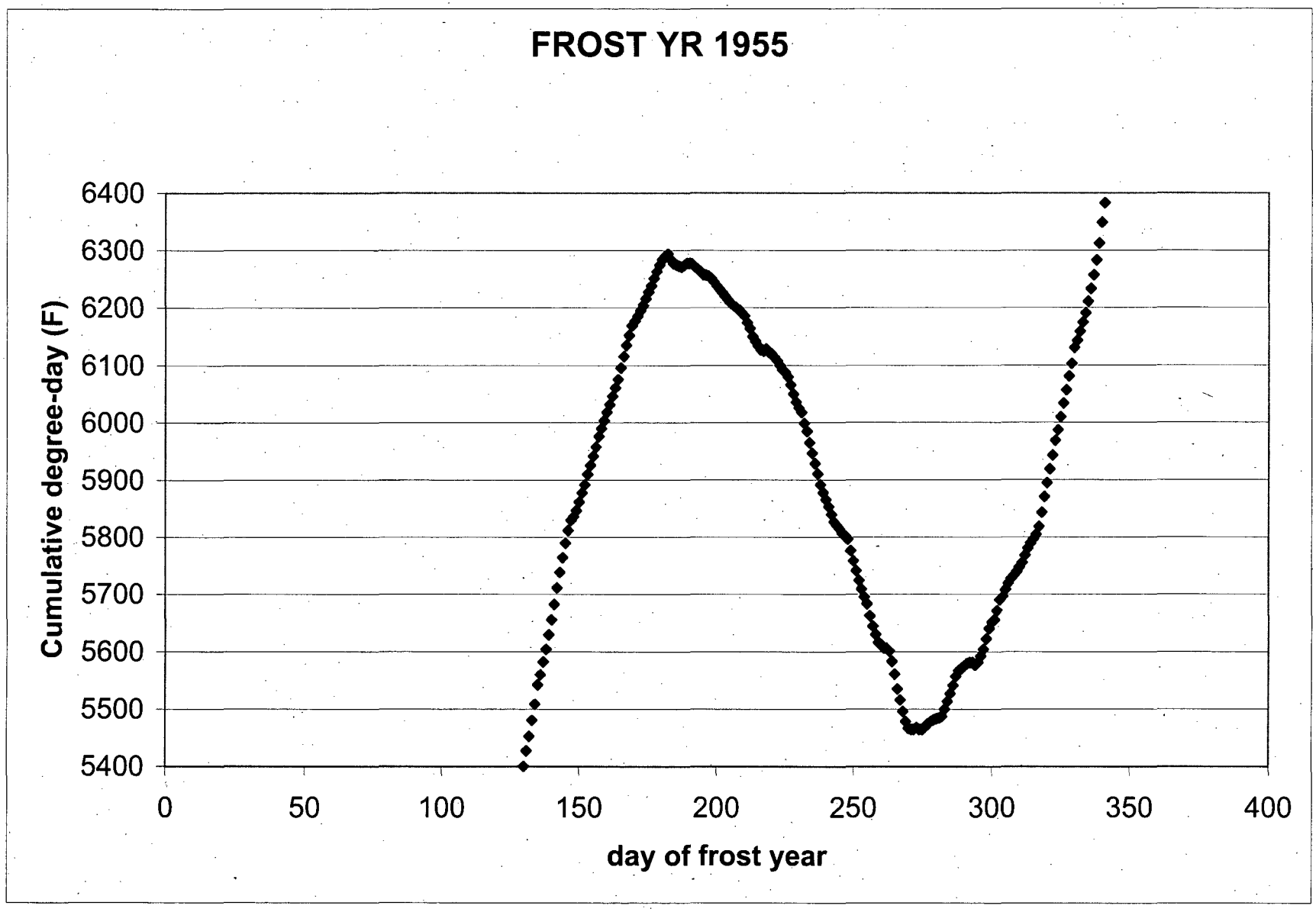

FROST YR 1971
Cumulative degree-day (F)
6000
5950
5900
5850
5800
5750
5700
5650
5600
5550
5500
0
50
100
150
200
250
300
350
400
day of frost year

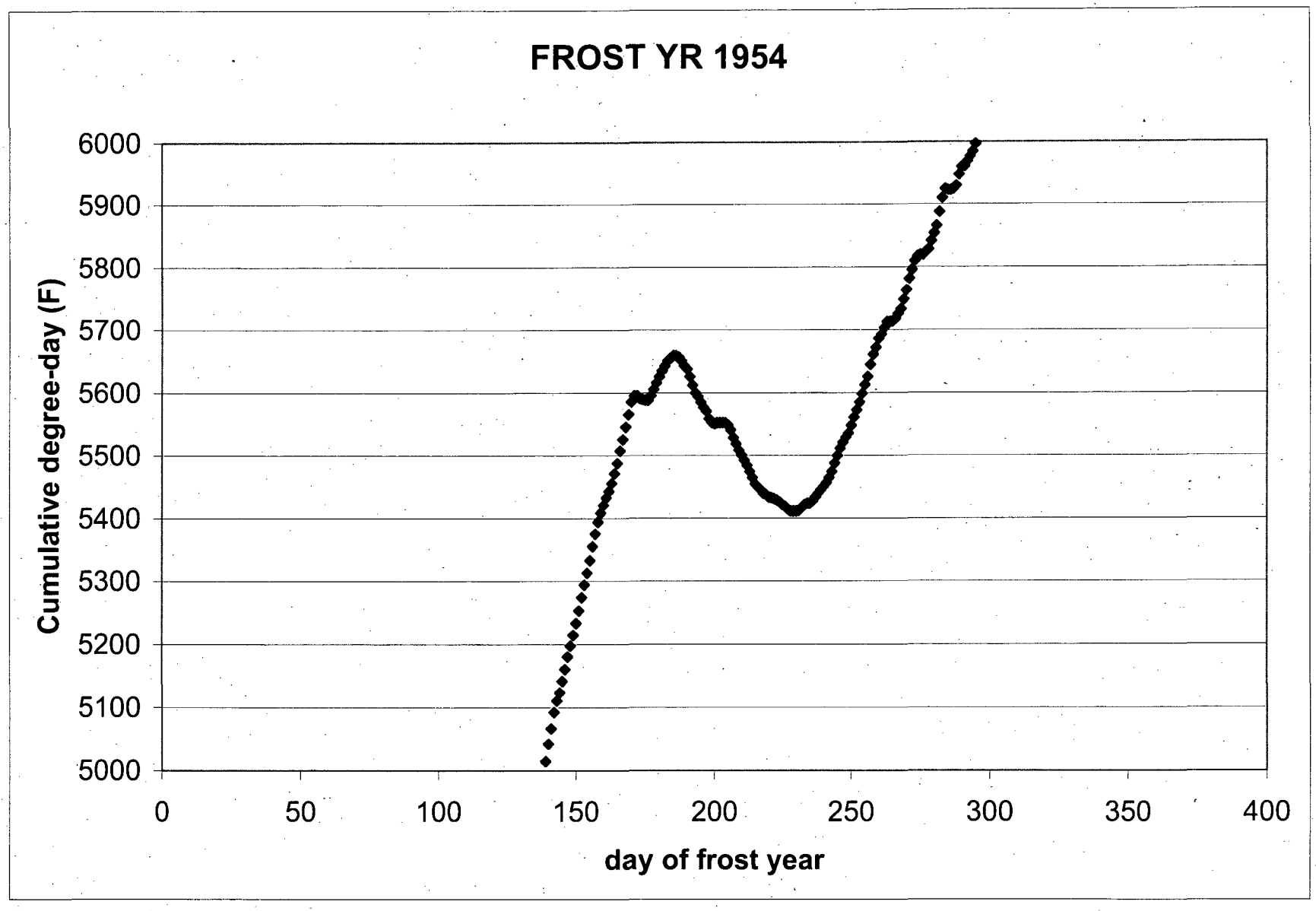

FROST YR 1963
Cumulative degree-day (F)
6000
5900
5800
5700
5600
5500
5400
5300
5200
5100
5000
0
50
100
150
200
250
300
350
400
day of frost year

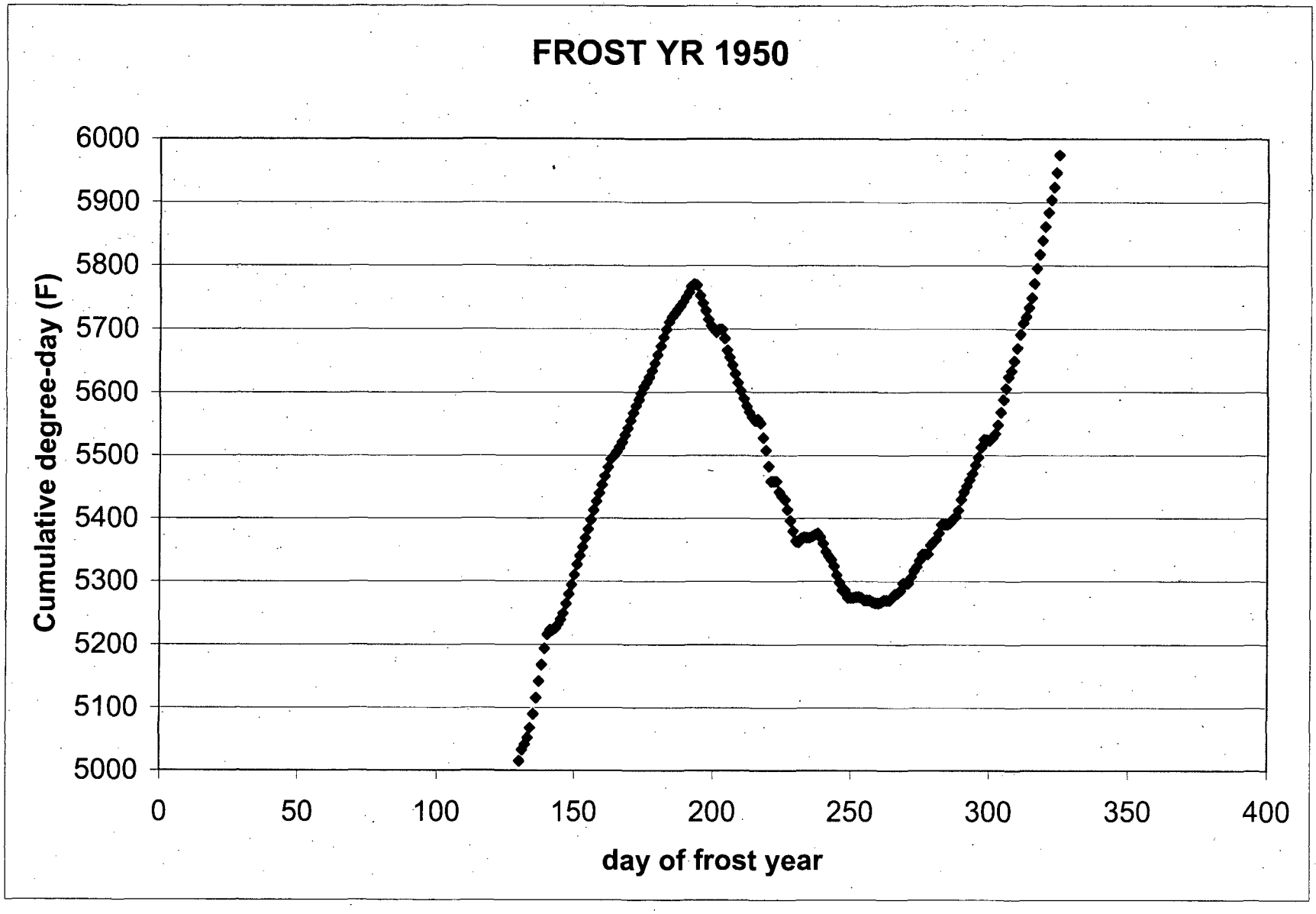

FROST YR 1961
Cumulative degree-day (F)
6500
6400
6300
6200
6100
6000
5900
5800
5700
5600
5500
0
50
100
150
200
250
300
350
400
day of frost year

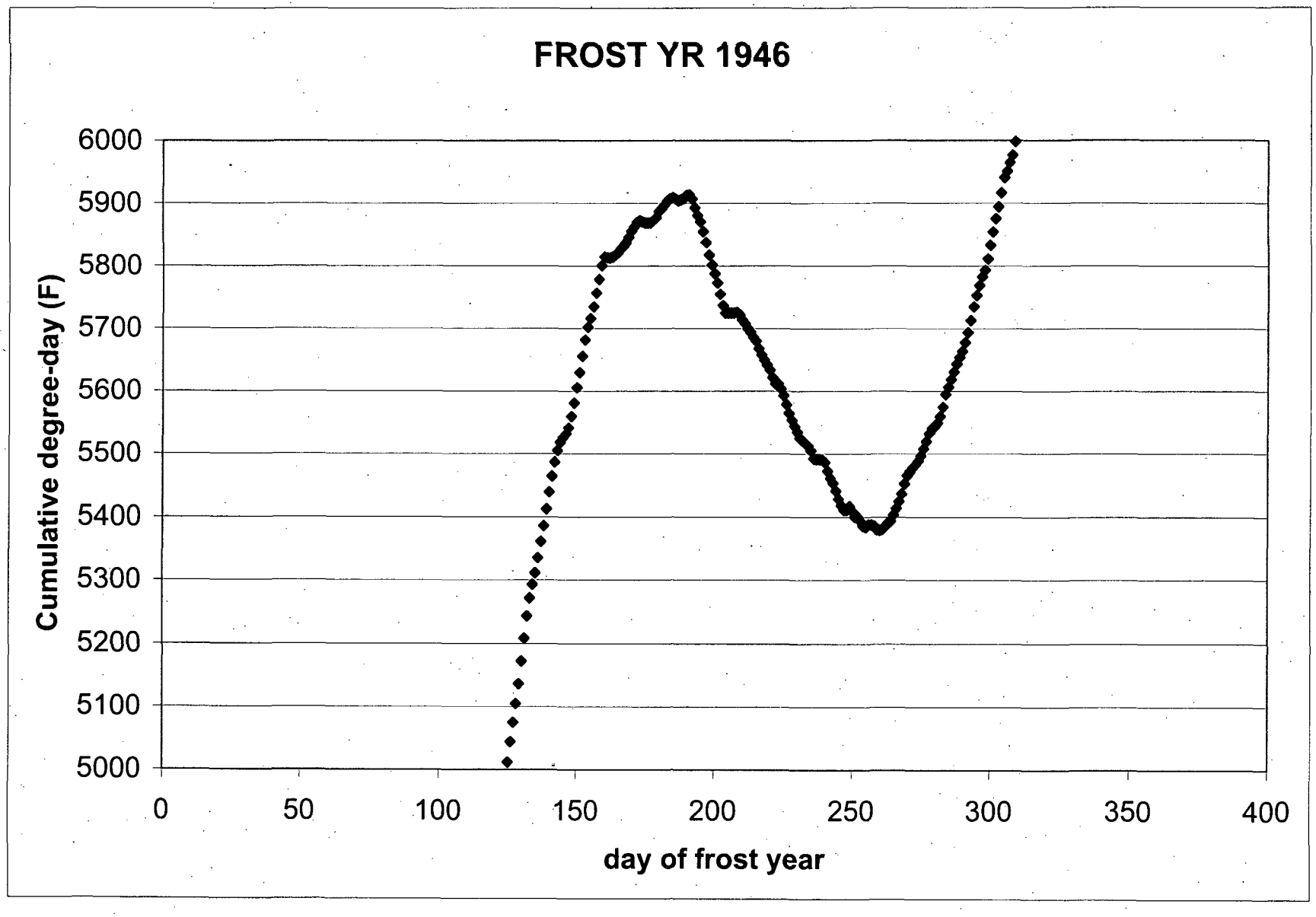

FROST YR 1960
Cumulative degree-day (F)
6500
6400
6300
6200
6100
6000
5900
5800
5700
5600
5500
0
50
100
150
200
250
300
350
400
day of frost year

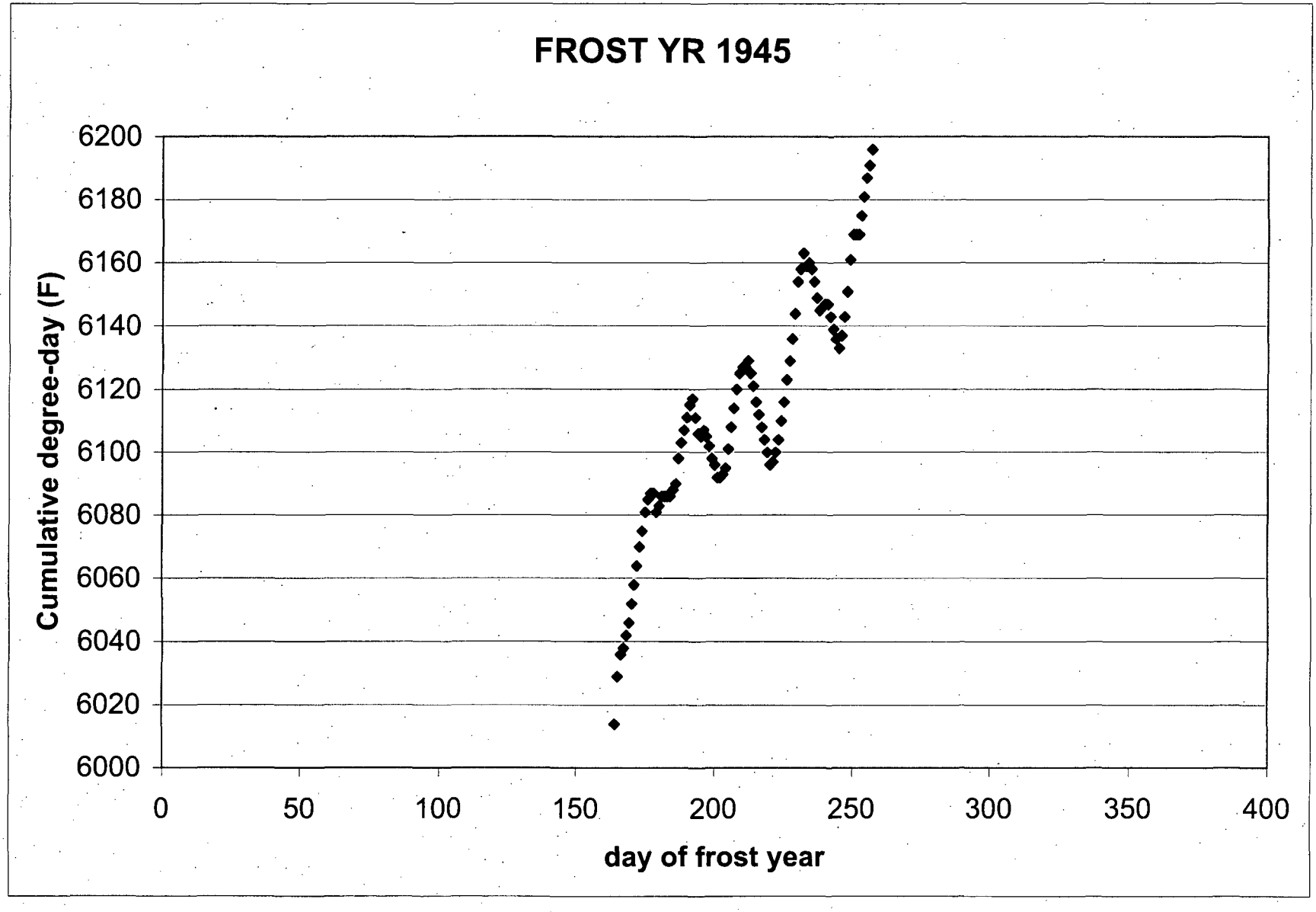

FROST YR 1956
Cumulative degree-day (F)
5700
5680
5660
5640
5620
5600
5580
5560
5540
5520
5500
0
50
100
150
200
250
300
350
400
day of frost year

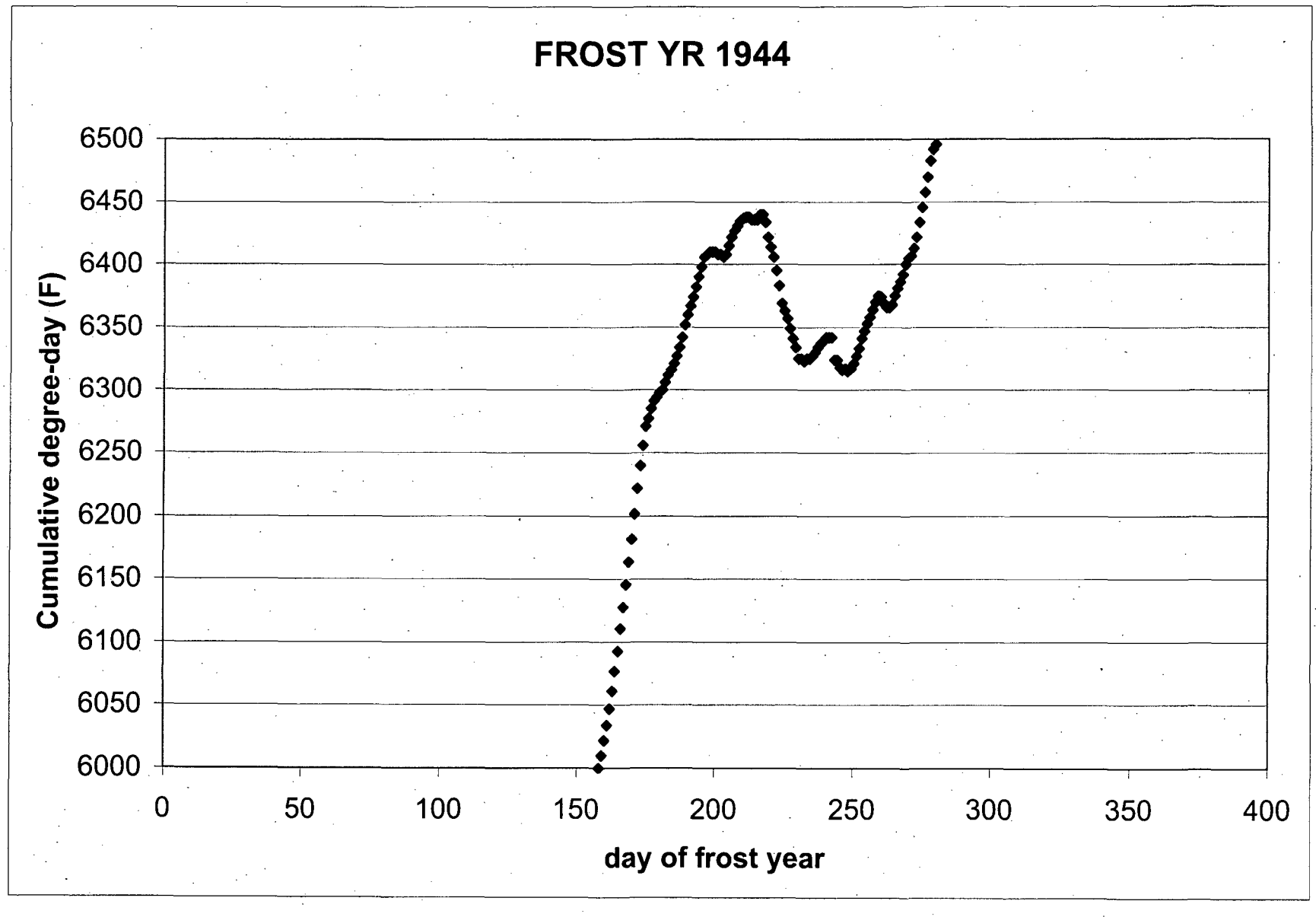

FROST YR 1955
Cumulative degree-day (F)
6400
6300
6200
6100
6000
5900
5800
5700
5600
5500
5400
0
50
100
150
200
250
300
350
400
day of frost year

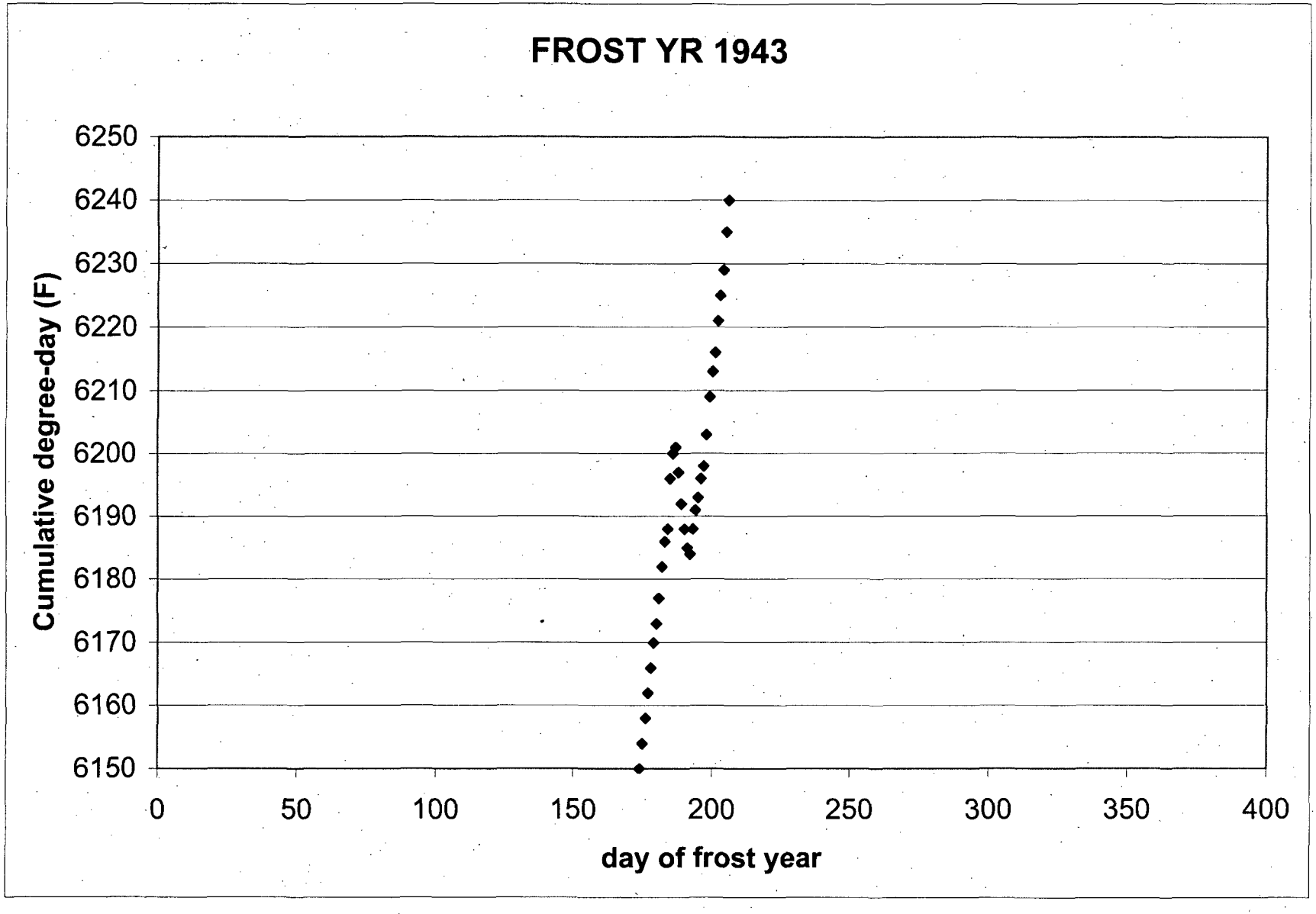

FROST YR 1954
Cumulative degree-day (F)
6000
5900
5800
5700
5600
5500
5400
5300
5200
5100
5000
0
50
100
150
200
250
300
350
400
day of frost year

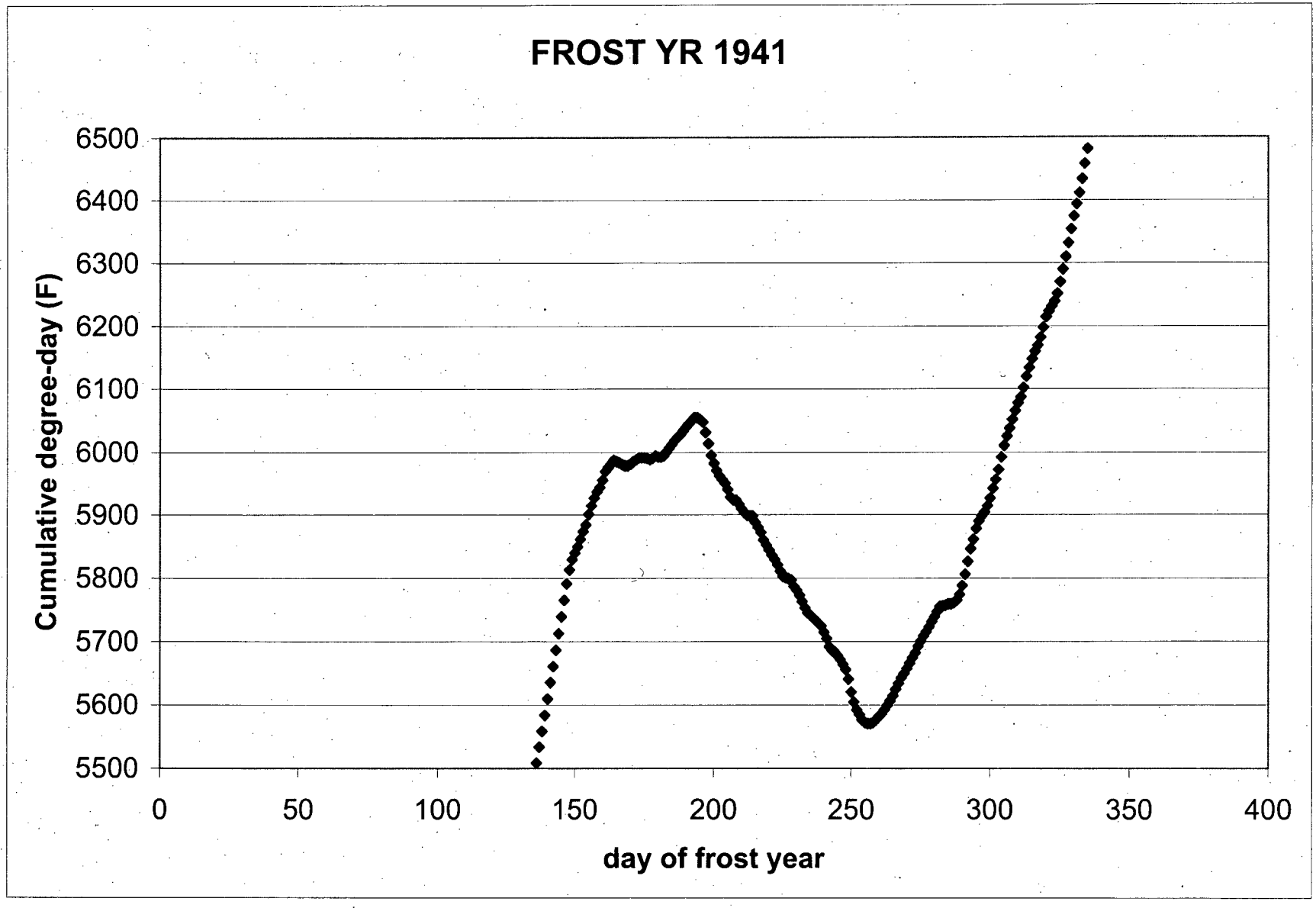

FROST YR 1950
Cumulative degree-day (F)
6000
5900
5800
5700
5600
5500
5400
5300
5200
5100
5000
0
50
100
150
200
250
300
350
400
day of frost year

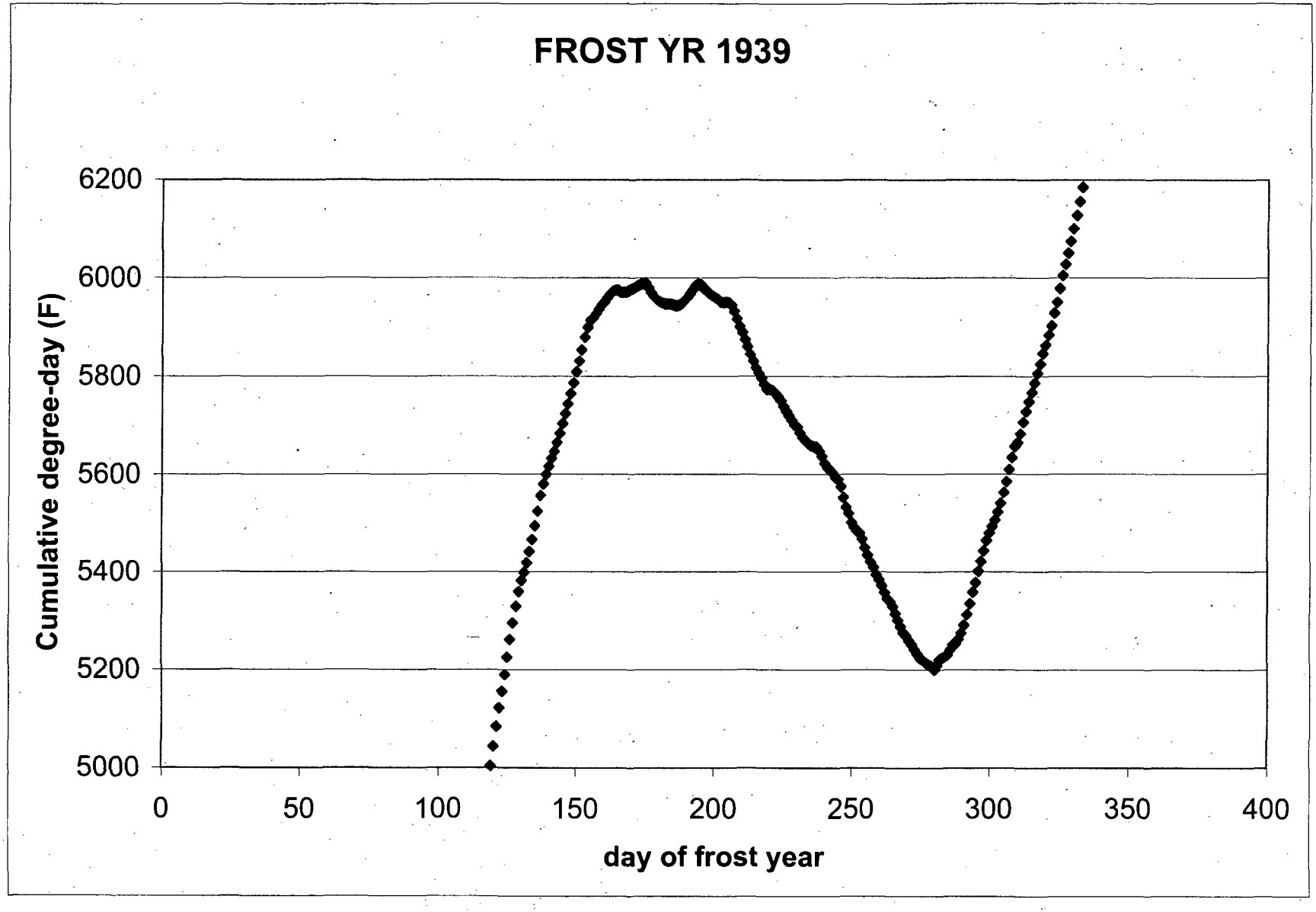

FROST YR 1946
Cumulative degree-day (F)
6000
5900
5800
5700
5600
5500
5400
5300
5200
5100
5000
0
50
100
150
200
250
300
350
400
day of frost year

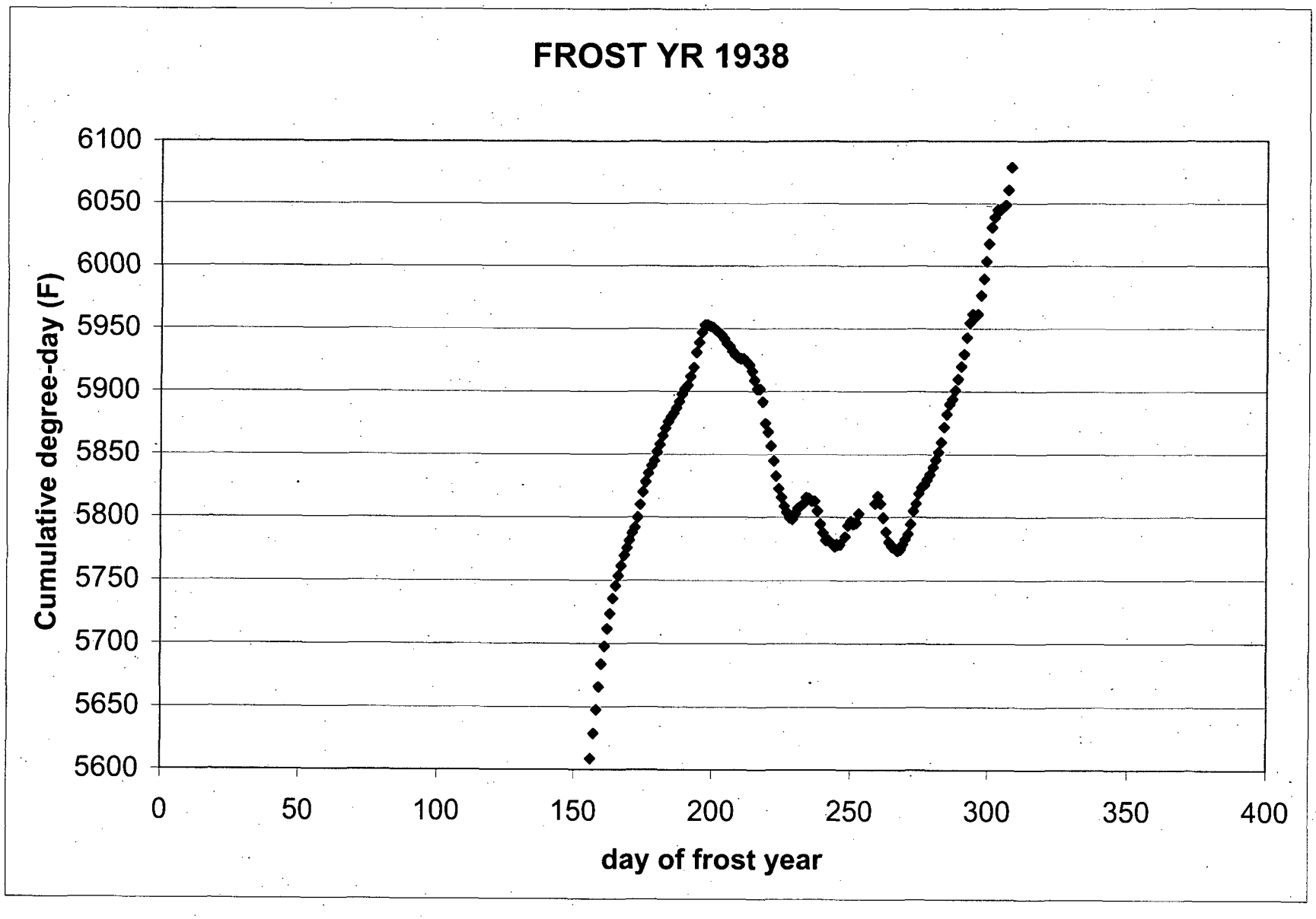

FROST YR 1945
Cumulative degree-day (F)
6200
6180
6160
6140
6120
6100
6080
6060
6040
6020
6000
0
50
100
150
200
250
300
350
400
day of frost year

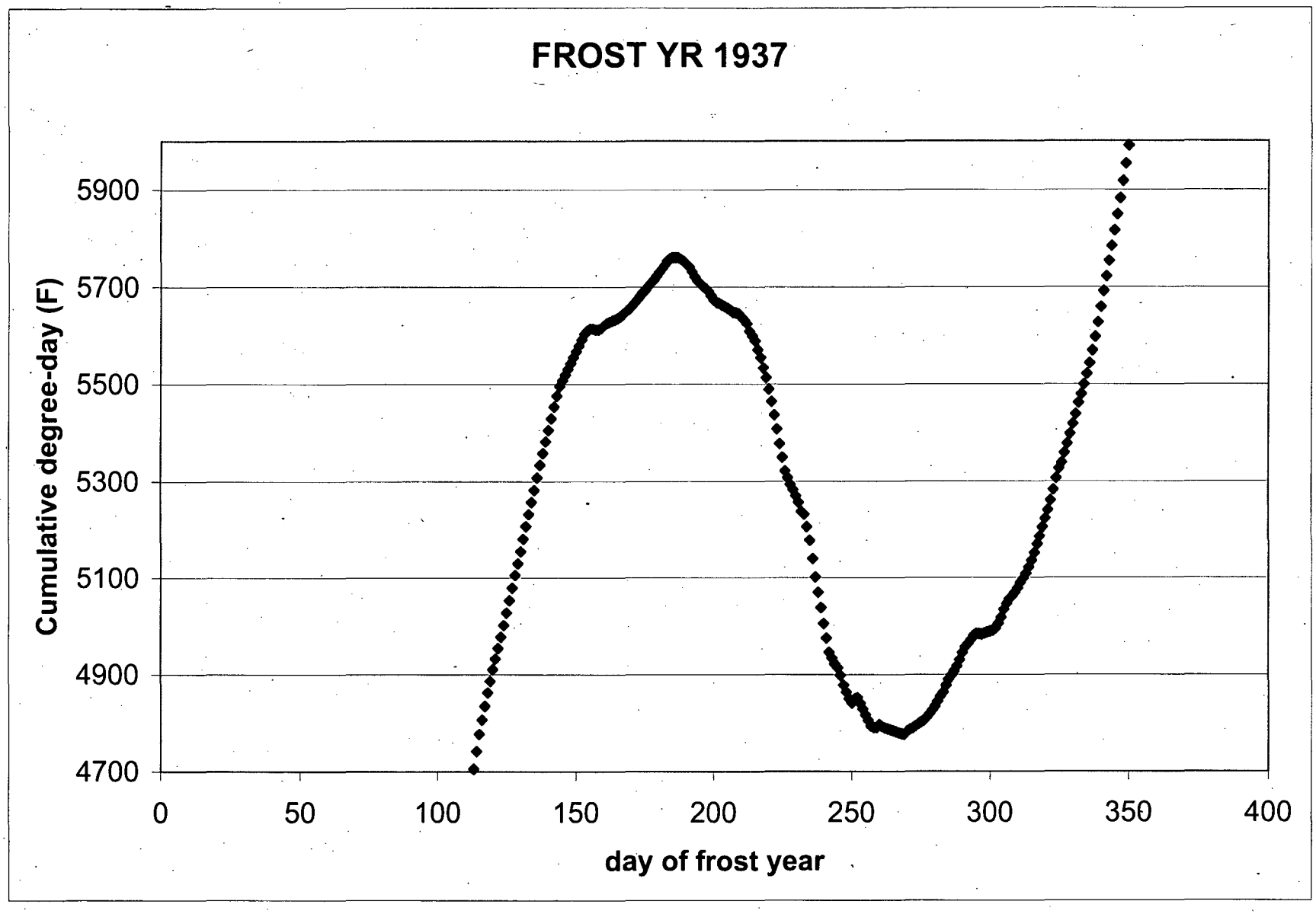

FROST YR 1944
Cumulative degree-day (F)
6500
6450
6400
6350
6300
6250
6200
6150
6100
6050
6000
0
50
100
150
200
250
300
350
400
day of frost year

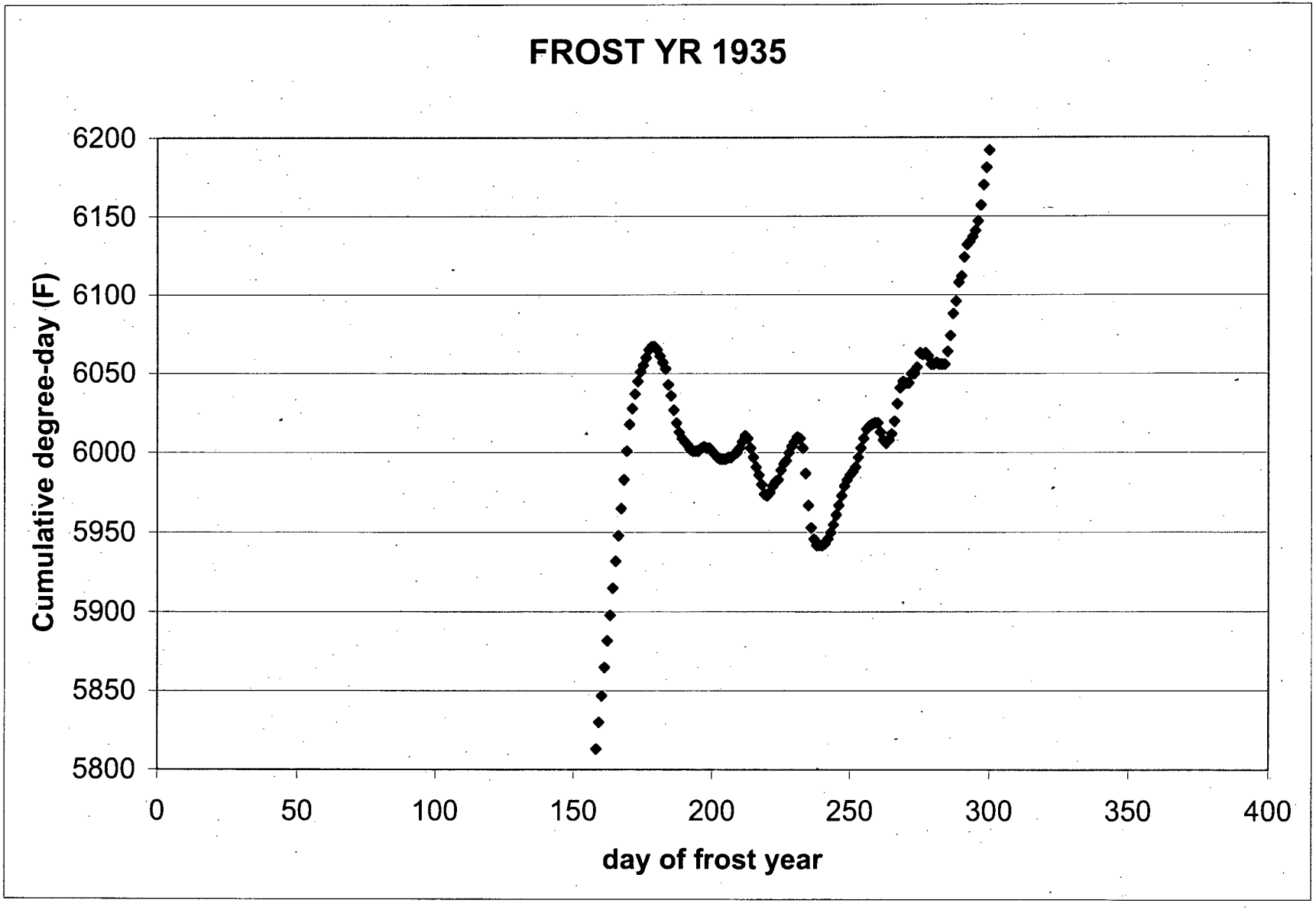

FROST YR 1943
Cumulative degree-day (F)
6250
6240
6230
6220
6210
6200
6190
6180
6170
6160
6150
0
50
100
150
200
250
300
350
400
day of frost year

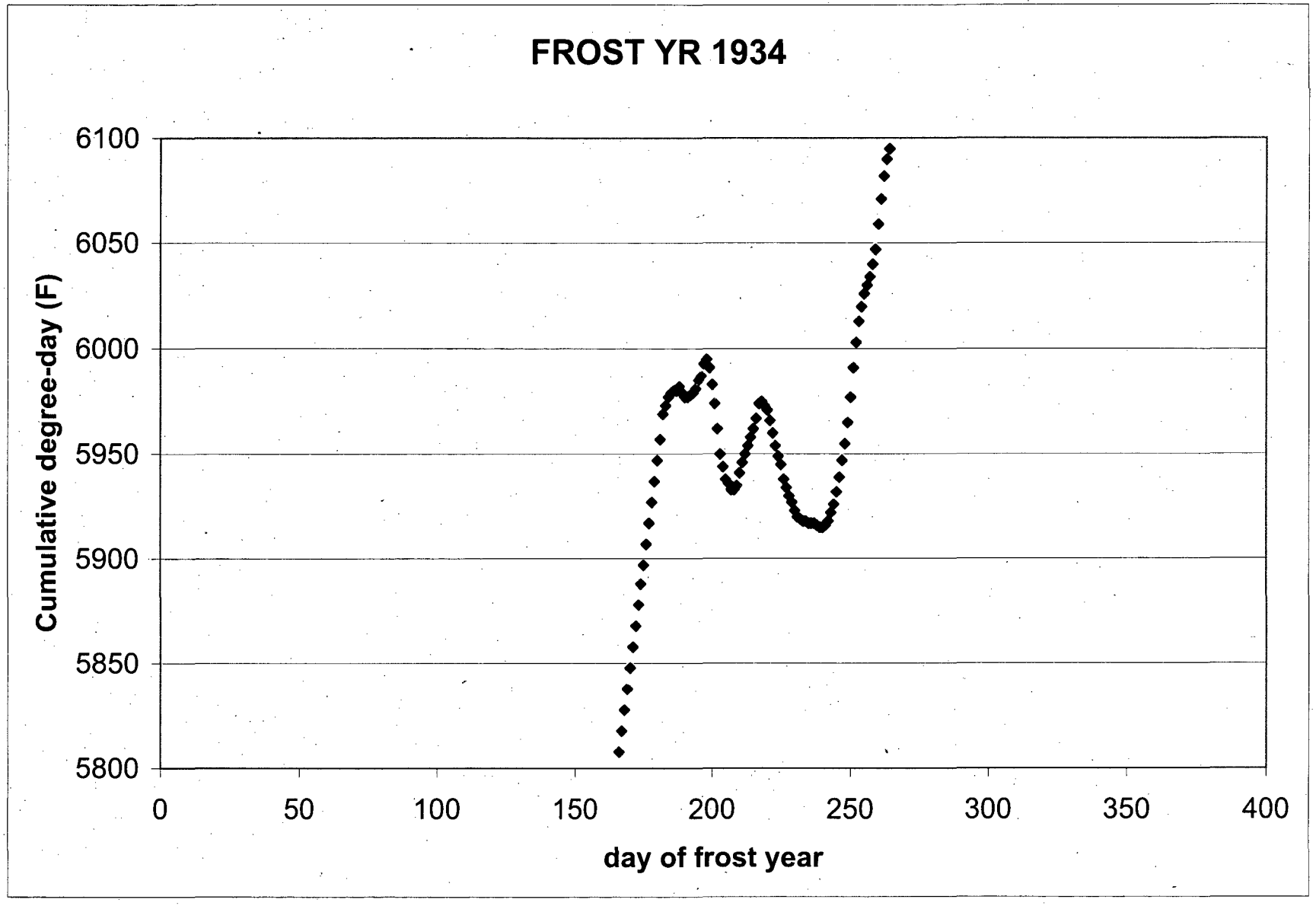

FROST YR 1941
Cumulative degree-day (F)
6500
6400
6300
6200
6100
6000
5900
5800
5700
5600
5500
0
50
100
150
200
250
300
350
400
day of frost year

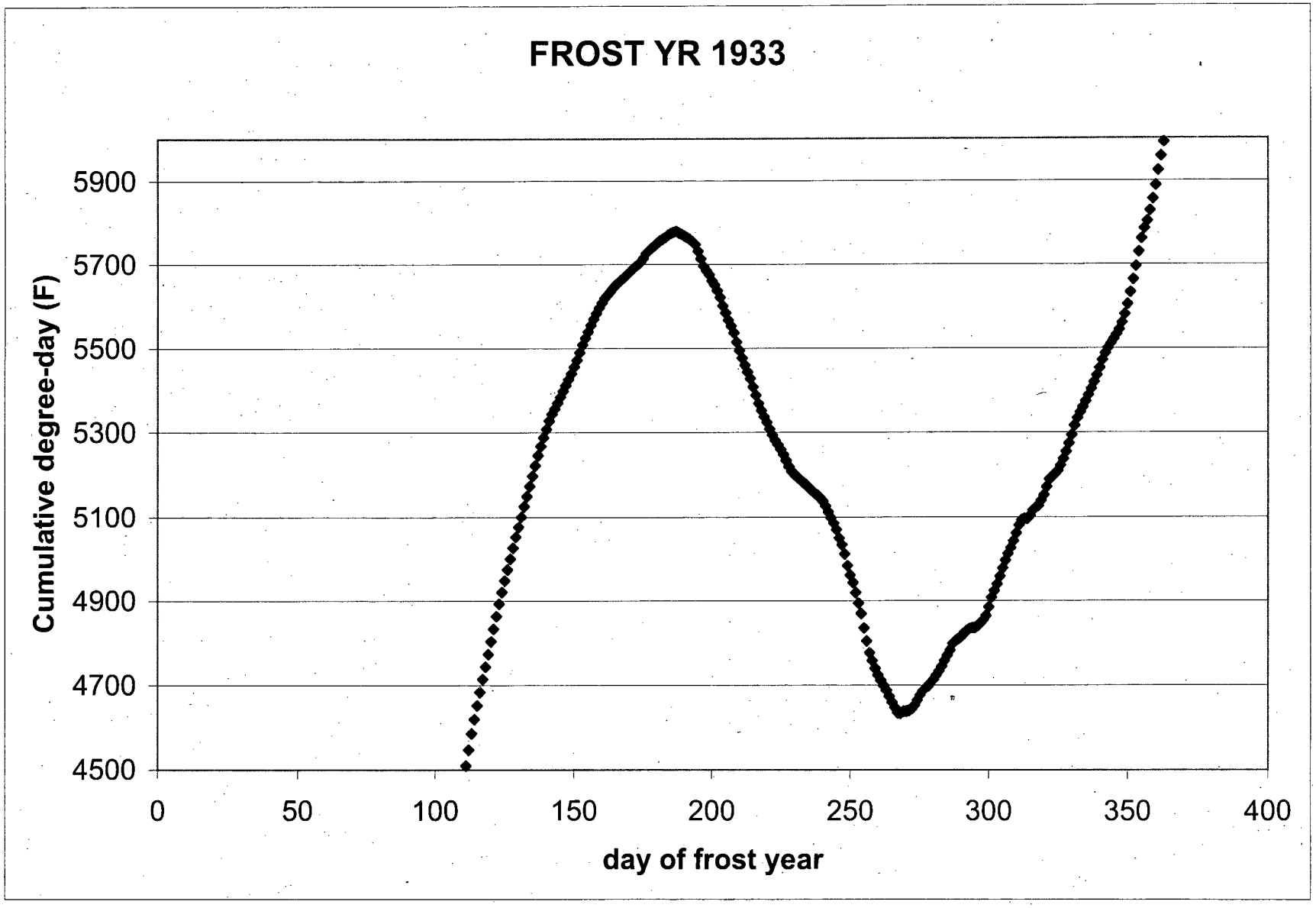

FROST YR 1939
Cumulative degree-day (F)
6200
6000
5800
5600
5400
5200
5000
0
50
100
150
200
250
300
350
400
day of frost year


FROST YR 1938
Cumulative degree-day (F)
6100
6050
6000
5950
5900
5850
5800
5750
5700
5650
5600
0
50
100
150
200
250
300
350
400
day of frost year


FROST YR 1937
Cumulative degree-day (F)
5900
5700
5500
5300
5100
4900
4700
0
50
100
150
200
250
300
350
400
day of frost year


FROST YR 1935
Cumulative degree-day (F)
6200
6150
6100
6050
6000
5950
5900
5850
5800
0
50
100
150
200
250
300
350
400
day of frost year


FROST YR 1934
Cumulative degree-day (F)
6100
6050
6000
5950
5900
5850
5800
0
50
100
150
200
250
300
350
400
day of frost year


FROST YR 1933
Cumulative degree-day (F)
5900
5700
5500
5300
5100
4900
4700
4500
0
50
100
150
200
250
300
350
400
day of frost year

APPENDIX B

MBF COMPUTER OUTPUT

1933

```
C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

                Summary: MODIFIED BERGGREN SOLUTION

          Design Freezing Index (AIR)      = 1141 F-days
          Design Freezing Index (SURFACE)  = 1141 F-days
          Mean Annual Temperature          = 48.8 °F
          Length of Freezing Season        =   93 Days

 ------------------------------------------------------------------
                              LAYER      FREEZING INDEX DISTRIBUTION
      LAYER                THICKNESS
     #: Type               (inches)     Each Layer     Accumulated
 -------------------      ---------    ------------   -------------
 1: Fine-grained            12.0           112            112
 2: Fine-grained            12.0           336            448
 3: Fine-grained            12.0           560           1008
 4: Fine-grained             2.3           134           1142
 ----------------- End of Frost Penetration ------------------

 TOTAL FROST PENETRATION =  38.3 inches


 Do you want a hard copy of this data (Y or default: N)?
```

1934

```
C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

                Summary: MODIFIED BERGGREN SOLUTION

          Design Freezing Index (AIR)      =   [illegible] F-days
          Design Freezing Index (SURFACE)  =   [illegible] F-days
          Mean Annual Temperature          =   [illegible] °F
          Length of Freezing Season        =   [illegible] Days

 ------------------------------------------------------------------
                              LAYER      FREEZING INDEX DISTRIBUTION
      LAYER                THICKNESS
     #: Type               (inches)     Each Layer     Accumulated
 -------------------      ---------    ------------   -------------
 [illegible]                [illegible]    [illegible]    [illegible]
 [illegible]                [illegible]    [illegible]    [illegible]
 [illegible]                [illegible]    [illegible]    [illegible]
 [illegible]                [illegible]    [illegible]    [illegible]
 ----------------- End of Frost Penetration ------------------

 TOTAL FROST PENETRATION =  [illegible] inches

 Do you want a hard copy of this data (Y or [illegible])?
```

1935

```
C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

            Summary: MODIFIED BERGGREN SOLUTION

        Design Freezing Index (AIR)      =  124 F-days
        Design Freezing Index (SURFACE)  =  124 F-days
        Mean Annual Temperature          = 53.3 °F
        Length of Freezing Season        =   62 Days

-------------------------------------------------------------
                          LAYER     FREEZING INDEX DISTRIBUTION
      LAYER             THICKNESS
     #: Type             (inches)    Each Layer    Accumulated
-----------------       ---------   ------------  ------------
1: Fine-grained           6.0           71            71
2: Fine grained           2.0           54           125
---------------- End of Frost Penetration -----------------

TOTAL FROST PENETRATION -   8.0 inches



Do you want a hard copy of this data (Y or [illegible] N)?
```

1937

```
C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

            Summary: MODIFIED BERGGREN SOLUTION

        Design Freezing Index (AIR)      =  970 F-days
        Design Freezing Index (SURFACE)  =  970 F-days
        Mean Annual Temperature          = 53.1 °F
        Length of Freezing Season        =   83 Days

-------------------------------------------------------------
                          LAYER     FREEZING INDEX DISTRIBUTION
      LAYER             THICKNESS
     #: Type             (inches)    Each Layer    Accumulated
-----------------       ---------   ------------  ------------
1: Fine grained           12.0          [illegible]   [illegible]
2: Fine-grained           2.0           [illegible]   [illegible]
3: Fine grained           9.9           [illegible]   [illegible]
---------------- End of Frost Penetration -----------------

TOTAL FROST PENETRATION -  [illegible] inches



Do you want a hard copy of this data (Y or        N)?
```

C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

Summary: MODIFIED BERGGREN SOLUTION

Design Freezing Index (AIR) = 177 F-days
Design Freezing Index (SURFACE) = 177 F-days
Mean Annual Temperature = 53.[illegible] °F
Length of Freezing Season = [illegible] Days

LAYER #: Type	LAYER THICKNESS (inches)	FREEZING INDEX DISTRIBUTION Each Layer	Accumulated
1. Fine grained	5.8	62	62
2. Fine grained	4.2	115	187

End of Frost Penetration

TOTAL FROST PENETRATION = [illegible] inches

Do you want a hard copy of this data (Y or [illegible] N)?

1939

```
C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

                Summary: MODIFIED BERGGREN SOLUTION

          Design Freezing Index (AIR)      =  765 F-days
          Design Freezing Index (SURFACE)  =  765 F-days
          Mean Annual Temperature          = 52.1 °F
          Length of Freezing Season        =   87 Days

 ------------------------------------------------------------------
                          LAYER     FREEZING INDEX DISTRIBUTION
      LAYER             THICKNESS
     #: Type            (inches)    Each Layer     Accumulated
 -------------------    ---------   ------------   -------------
 1: Fine-grained         12.0          142            142
 2: Fine-grained         12.0          425            567
 3: Fine-grained          3.7          189            756
 ---------------- End of Frost Penetration ------------------

 TOTAL FROST PENETRATION =  27.7 inches


 Do you want a hard copy of this data (Y or default N)?
```

1941

```
C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

                Summary: MODIFIED BERGGREN SOLUTION

          Design Freezing Index (AIR)      =  765 F-days
          Design Freezing Index (SURFACE)  =  765 F-days
          Mean Annual Temperature          = 52.1 °F
          Length of Freezing Season        =   87 Days

 ------------------------------------------------------------------
                          LAYER     FREEZING INDEX DISTRIBUTION
      LAYER             THICKNESS
     #: Type            (inches)    Each Layer     Accumulated
 -------------------    ---------   ------------   -------------
 1: Fine-grained         12.2          142            142
 2: Fine-grained         12.2          425            567
 3: Fine-grained          3.7          189            756
 ---------------- End of Frost Penetration ------------------

 TOTAL FROST PENETRATION =  27.7 inches


 Do you want a hard copy of this data (Y or          N)?
```

1943

```
C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

                Summary: MODIFIED BERGGREN SOLUTION

          Design Freezing Index (AIR)      =   17 F-days
          Design Freezing Index (SURFACE)  =   17 F-days
          Mean Annual Temperature          = 65.8 °F
          Length of Freezing Season        =    5 Days

                                  LAYER      FREEZING INDEX DISTRIBUTION
      LAYER                     THICKNESS
     #: Type                     (inches)    Each Layer     Accumulated
1. Fine grained                    2.0            7
---------------- End of Frost Penetration ----------

TOTAL FROST PENETRATION -   2.0 inches



Do you want a hard copy of this data (Y or [illegible] N)?
```

1944

```
C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

                [illegible]

          Design Freezing Index (AIR)      =   [illegible] F-days
          Design Freezing Index (SURFACE)  [illegible] F-days
          Mean Annual Temperature          [illegible] °F
          Length of Freezing Season        =   [illegible] Days

                                  LAYER      FREEZING INDEX DISTRIBUTION
      LAYER                     THICKNESS
     #: Type                     (inches)    Each Layer     Accumulated
[illegible]
[illegible] End of Frost Penetration [illegible]

TOTAL FROST PENETRATION [illegible] inches



Do you want a hard copy of this data ([illegible] or [illegible])?
```

1945

C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

```
                Summary: MODIFIED BERGGREN SOLUTION

          Design Freezing Index (AIR)      =   32 F-days
          Design Freezing Index (SURFACE)  =   32 F-days
          Mean Annual Temperature          = 54.7 °F
          Length of Freezing Season        =    9 Days

-------------------------------------------------------------
                          LAYER     FREEZING INDEX DISTRIBUTION
      LAYER             THICKNESS
     #: Type             (inches)    Each Layer    Accumulated
-------------------     ---------    -----------   -----------
1: Fine-grained           2.0            6              6
2: Fine-grained           1.0            8             14
3: Fine-grained           1.0           11             25
----------------- End of Frost Penetration -----------------

TOTAL FROST PENETRATION =   4.0 inches



Do you want a hard copy of this data (Y or [illegible] N)?
```

1946

C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

```
                Summary: MODIFIED BERGGREN SOLUTION

          Design Freezing Index (AIR)      =  520 F-days
          Design Freezing Index (SURFACE)  =  520 F-days
          Mean Annual Temperature          = 53.2 °F
          Length of Freezing Season        =   73 Days

-------------------------------------------------------------
                          LAYER     FREEZING INDEX DISTRIBUTION
      LAYER             THICKNESS
     #: Type             (inches)    Each Layer    Accumulated
-------------------     ---------    -----------   -----------
1: Fine-grained          12.0          [illegible]     [illegible]
2: Fine-grained          12.0          [illegible]     [illegible]
----------------- End of Frost Penetration -----------------

TOTAL FROST PENETRATION =  [illegible] inches



Do you want a hard copy of this data (Y or [illegible] N)?
```

1950

C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

Summary: MODIFIED BERGGREN SOLUTION

Design Freezing Index (AIR) = 501 F-days
Design Freezing Index (SURFACE) = 501 F-days
Mean Annual Temperature = 52.5 °F
Length of Freezing Season = 67 Days

LAYER #: Type	LAYER THICKNESS (inches)	FREEZING INDEX DISTRIBUTION Each Layer	Accumulated
1: Fine grained	6.0	38	38
2: Fine grained	6.0	114	152
3: Fine grained	6.0	189	341
4: Fine grained	3.6	151	492

---------- End of Frost Penetration ----------

TOTAL FROST PENETRATION = 21.6 inches

Do you want a hard copy of this data (Y or [illegible] N)?

1954

C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

Summary: MODIFIED BERGGREN SOLUTION

Design Freezing Index (AIR) = 240 F-days
Design Freezing Index (SURFACE) = 240 F-days
Mean Annual Temperature = 55.3 °F
Length of Freezing Season = 45 Days

LAYER #: Type	LAYER THICKNESS (inches)	FREEZING INDEX DISTRIBUTION Each Layer	Accumulated
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

---------- End of Frost Penetration ----------

TOTAL FROST PENETRATION = [illegible] inches

Do you want a hard copy of this data (Y or [illegible] N)?

1955

C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

```
Summary: MODIFIED BERGGREN SOLUTION

Design Freezing Index (AIR)      =  829 F-days
Design Freezing Index (SURFACE)  =  829 F-days
Mean Annual Temperature          = 51.4 °F
Length of Freezing Season        =   93 Days

------------------------------------------------------------
                          LAYER     FREEZING INDEX DISTRIBUTION
     LAYER              THICKNESS
     #: Type             (inches)    Each Layer    Accumulated
-------------------     ---------   ------------  -------------
1: Fine grained           12.0          136           136
2: Fine grained           12.0          408           544
3: Fine grained            5.7          289           833
----------------- End of Frost Penetration -----------------

TOTAL FROST PENETRATION =  29.7 inches



Do you want a hard copy of this data (Y or [illegible] N)?
```

1956

C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

```
Summary: MODIFIED BERGGREN SOLUTION

Design Freezing Index (AIR)      =   45 F-days
Design Freezing Index (SURFACE)  =   45 F-days
Mean Annual Temperature          = 55.3 °F
Length of Freezing Season        =   29 Days

------------------------------------------------------------
                          LAYER     FREEZING INDEX DISTRIBUTION
     LAYER              THICKNESS
     #: Type             (inches)    Each Layer    Accumulated
-------------------     ---------   ------------  -------------
1: Fine grained           12.0           [illegible]      [illegible]
2: Fine grained            6.0           [illegible]      [illegible]
3: Fine grained            6.0           24            54
----------------- End of Frost Penetration -----------------

TOTAL FROST PENETRATION =  24.0 inches



Do you want a hard copy of this data (Y or         N)?
```

1960

```
C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

                Summary: MODIFIED BERGGREN SOLUTION

          Design Freezing Index (AIR)      =  338 F-days
          Design Freezing Index (SURFACE)  =  338 F-days
          Mean Annual Temperature          = 53.8 °F
          Length of Freezing Season        =   67 Days

 ------------------------------------------------------------------
                          LAYER     FREEZING INDEX DISTRIBUTION
      LAYER             THICKNESS
     #: Type            (inches)    Each Layer     Accumulated
 ------------------     ---------   ------------   ------------
 1: Fine grained          6.0           46             46
 2: Fine grained          6.0          138            184
 3: Fine grained          4.0          144            328
 ---------------- End of Frost Penetration -----------------

 TOTAL FROST PENETRATION =  16.0 inches



 Do you want a hard copy of this data (Y or [illegible] N)?
```

1961

```
C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

                Summary: MODIFIED BERGGREN SOLUTION

          Design Freezing Index (AIR)      =  [illegible] F-days
          Design Freezing Index (SURFACE)  =  [illegible] F-days
          Mean Annual Temperature          [illegible] °F
          Length of Freezing Season        =  [illegible] Days

 ------------------------------------------------------------------
                          LAYER     FREEZING INDEX DISTRIBUTION
      LAYER             THICKNESS
     #: Type            (inches)    Each Layer     Accumulated
 ------------------     ---------   ------------   ------------
 [illegible]
 [illegible]
 ---------------- End of Frost Penetration [illegible]

 TOTAL FROST PENETRATION =        inches



 Do you want a hard copy of this data ([illegible] or [illegible])?
```

1963

```
C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

              Summary: MODIFIED BERGGREN SOLUTION

        Design Freezing Index (AIR)      =  735 F-days
        Design Freezing Index (SURFACE)  =  735 F-days
        Mean Annual Temperature          = 52.9 °F
        Length of Freezing Season        =   44 Days

-------------------------------------------------------------------
                          LAYER     FREEZING INDEX DISTRIBUTION
     LAYER              THICKNESS
     #: Type             (inches)    Each Layer     Accumulated
-------------------    ---------    ------------   -------------
1: Fine-grained          12.0          126            126
2: Fine grained          12.0          379            505
3: Fine grained           4.9          225            730
----------------- End of Frost Penetration ------------------

TOTAL FROST PENETRATION =  28.9 inches



Do you want a hard copy of this data (Y or [illegible] N)?
```

1971

```
C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

              Summary: MODIFIED BERGGREN SOLUTION

        Design Freezing Index (AIR)      =  269 F-days
        Design Freezing Index (SURFACE)  =  269 F-days
        Mean Annual Temperature          = 54.0 °F
        Length of Freezing Season        =   29 Days

-------------------------------------------------------------------
                          LAYER     FREEZING INDEX DISTRIBUTION
     LAYER              THICKNESS
     #: Type             (inches)    Each Layer     Accumulated
-------------------    ---------    ------------   -------------
1: Fine grained          6.0           [illegible]    [illegible]
2: Fine grained          6.0           [illegible]    [illegible]
3: Fine grained          4.0           [illegible]    [illegible]
----------------- End of Frost Penetration ------------------

TOTAL FROST PENETRATION =  [illegible] inches



Do you want a hard copy of this data (Y or        N)?
```

1974

```
C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

                Summary: MODIFIED BERGGREN SOLUTION

          Design Freezing Index (AIR)      =  734 F-days
          Design Freezing Index (SURFACE)  =  734 F-days
          Mean Annual Temperature          = 53.0 °F
          Length of Freezing Season        =   82 Days

-------------------------------------------------------------
                          LAYER     FREEZING INDEX DISTRIBUTION
      LAYER             THICKNESS
     #: Type            (inches)    Each Layer    Accumulated
-----------------      ---------   ------------  -------------
1: Fine-grained          12.0          146           146
2: Fine-grained          12.0          437           583
3: Fine-grained           3.0          153           736
---------------- End of Frost Penetration -----------------

TOTAL FROST PENETRATION =  27.0 inches



Do you want a hard copy of this data (Y or [illegible] N)?
```

1975

```
C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

                Summary: MODIFIED BERGGREN SOLUTION

          Design Freezing Index (AIR)      =  [illegible] F-days
          Design Freezing Index (SURFACE)  =  [illegible] F-days
          Mean Annual Temperature          = [illegible] °F
          Length of Freezing Season        =  [illegible] Days

-------------------------------------------------------------
                          LAYER     FREEZING INDEX DISTRIBUTION
      LAYER             THICKNESS
     #: Type            (inches)    Each Layer    Accumulated
-----------------      ---------   ------------  -------------
[illegible]
---------------- End of Frost Penetration -----------------

TOTAL FROST PENETRATION [illegible] inches



Do you want a hard copy of this data ([illegible] or [illegible])?
```

1976

```
C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

            Summary: MODIFIED BERGGREN SOLUTION

        Design Freezing Index (AIR)      =  293 F-days
        Design Freezing Index (SURFACE)  =  293 F-days
        Mean Annual Temperature          = 53.7 °F
        Length of Freezing Season        =   45 Days

------------------------------------------------------------
                          LAYER     FREEZING INDEX DISTRIBUTION
     LAYER              THICKNESS
     #: Type             (inches)    Each Layer     Accumulated
-------------------     ---------    ----------     -----------
1: Fine grained           12.0          164            164
2: Fine grained            3.8          119            283
---------------- End of Frost Penetration ------------------

TOTAL FROST PENETRATION =  15.8 inches



Do you want a hard copy of this data (Y or [illegible] N)?
```

1977

```
C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

            Summary: MODIFIED BERGGREN SOLUTION

        Design Freezing Index (AIR)      =  264 F-days
        Design Freezing Index (SURFACE)  =  264 F-days
        Mean Annual Temperature          = 54.8 °F
        Length of Freezing Season        =   55 Days

------------------------------------------------------------
                          LAYER     FREEZING INDEX DISTRIBUTION
     LAYER              THICKNESS
     #: Type             (inches)    Each Layer     Accumulated
-------------------     ---------    ----------     -----------
1: Fine grained           12.0          [illegible]    [illegible]
2: Fine grained           [illegible]   [illegible]    [illegible]
---------------- End of Frost Penetration ------------------

TOTAL FROST PENETRATION =  [illegible] inches



Do you want a hard copy of this data (Y or [illegible] N)?
```

1978

```
C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

                Summary: MODIFIED BERGGREN SOLUTION

          Design Freezing Index (AIR)      =  179 F-days
          Design Freezing Index (SURFACE)  =  179 F-days
          Mean Annual Temperature          = 55.0 °F
          Length of Freezing Season        =    5 Days

-------------------------------------------------------------
                          LAYER     FREEZING INDEX DISTRIBUTION
      LAYER             THICKNESS
     #: Type            (inches)    Each Layer    Accumulated
-------------------    ---------   ------------   ------------
1: Fine grained          6.0          30
2: Fine grained          6.0          90
3: Fine grained        < 2.4          52

----------------- End of Frost Penetration ------------------

TOTAL FROST PENETRATION =  14.4 inches

Do you want a hard copy of this data (Y or [illegible] N)?
```

1979

```
C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

                Summary: MODIFIED BERGGREN SOLUTION

          Design Freezing Index (AIR)      = [illegible] F-days
          Design Freezing Index (SURFACE)  = [illegible] F-days
          Mean Annual Temperature          [illegible] °F
          Length of Freezing Season        [illegible] Days

-------------------------------------------------------------
                          LAYER     FREEZING INDEX DISTRIBUTION
      LAYER             THICKNESS
     #: Type            (inches)    Each Layer    Accumulated
-------------------    ---------   ------------   ------------
[illegible]

----------------- End of Frost Penetration ------------------

TOTAL FROST PENETRATION [illegible] inches

Do you want a hard copy of this data (Y or [illegible])?
```

1980

```
C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

            Summary: MODIFIED BERGGREN SOLUTION

        Design Freezing Index (AIR)       =  293 F-days
        Design Freezing Index (SURFACE)   =  293 F-days
        Mean Annual Temperature           = 53.5 °F
        Length of Freezing Season         =   48 Days

-----------------------------------------------------------------
                          LAYER      FREEZING INDEX DISTRIBUTION
     LAYER              THICKNESS
     #: Type             (inches)     Each Layer     Accumulated
-------------------     ---------    ------------   -------------
1: Fine grained           6.0            42             42
2: Fine-grained           6.0           125            167
3: Fine grained           3.6           116            283
----------------- End of Frost Penetration ------------------

TOTAL FROST PENETRATION =  15.6 inches


Do you want a hard copy of this data (Y or default N)?
```

1982

```
C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

            Summary: MODIFIED BERGGREN SOLUTION

        Design Freezing Index (AIR)       =  448 F-days
        Design Freezing Index (SURFACE)   =  448 F-days
        Mean Annual Temperature           = 53.4 °F
        Length of Freezing Season         =   56 Days

-----------------------------------------------------------------
                          LAYER      FREEZING INDEX DISTRIBUTION
     LAYER              THICKNESS
     #: Type             (inches)     Each Layer     Accumulated
-------------------     ---------    ------------   -------------
1: Fine grained           6.0            36             36
2: Fine-grained           6.0           116            152
3: Fine-grained           6.0           191            343
4: Fine grained           2.4            96            439
----------------- End of Frost Penetration ------------------

TOTAL FROST PENETRATION =  20.4 inches


Do you want a hard copy of this data (Y or          N)?
```

1983

```
C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

                Summary: MODIFIED BERGGREN SOLUTION

          Design Freezing Index (AIR)      =   92 F-days
          Design Freezing Index (SURFACE)  =   92 F-days
          Mean Annual Temperature          = 5[illegible].[illegible] °F
          Length of Freezing Season        =   24 Days

 ---------------------------------------------------------------
                          LAYER     FREEZING INDEX DISTRIBUTION
      LAYER             THICKNESS
     #: Type            (inches)    Each Layer    Accumulated
 ------------ -----     ---------   ------------  ------------
 [illegible]             [illegible]   [illegible]   [illegible]
 [illegible]             [illegible]   [illegible]   [illegible]
 -------- -------- End of Frost Penetration -- ----------

 TOTAL FROST PENETRATION =   8.[illegible] inches



 Do you want a hard copy of this data (Y or [illegible] N)?
```

1986

```
C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

                Summary: MODIFIED BERGGREN SOLUTION

          Design Freezing Index (AIR)      =  [illegible] F-days
          Design Freezing Index (SURFACE)  =  [illegible] F-days
          Mean Annual Temperature          =  [illegible] °F
          Length of Freezing Season        =  [illegible] Days

 ---------------------------------------------------------------
                          LAYER     FREEZING INDEX DISTRIBUTION
      LAYER             THICKNESS
     #: Type            (inches)    Each Layer    Accumulated
 ------------ -----     ---------   ------------  ------------
 [illegible]             [illegible]   [illegible]   [illegible]
 [illegible]             [illegible]   [illegible]   [illegible]
 ---------- ---- End of Frost Penetration --- - ----------

 TOTAL FROST PENETRATION     [illegible]   inches



 Do you want a hard copy of this data (  or        [illegible])?
```

1987

```
C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

            Summary: MODIFIED BERGGREN SOLUTION

        Design Freezing Index (AIR)      =  225 F-days
        Design Freezing Index (SURFACE)  =  225 F-days
        Mean Annual Temperature          = 53.7 °F
        Length of Freezing Season        =   51 Days

-------------------------------------------------------------
                          LAYER     FREEZING INDEX DISTRIBUTION
     LAYER              THICKNESS
     #: Type             (inches)    Each Layer     Accumulated
-------------------    ---------    ------------   -------------
1: Fine-grained          6.0            48             48
2: Fine grained          6.0           145            193
3: Fine grained          0.8            26            219
---------------- End of Frost Penetration ------------------

TOTAL FROST PENETRATION =  12.8 inches



Do you want a hard copy of this data (Y or [illegible] N)?
```

1988

```
C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

            Summary: MODIFIED BERGGREN SOLUTION

        Design Freezing Index (AIR)      =  632 F-days
        Design Freezing Index (SURFACE)  =  372 F-days
        Mean Annual Temperature          = [illegible] °F
        Length of Freezing Season        =   74 Days

-------------------------------------------------------------
                          LAYER     FREEZING INDEX DISTRIBUTION
     LAYER              THICKNESS
     #: Type             (inches)    Each Layer     Accumulated
-------------------    ---------    ------------   -------------
[illegible]
---------------- End of Frost Penetration ------------------

TOTAL FROST PENETRATION =  [illegible] inches

Do you want a hard copy of this data (Y or [illegible] N)?
```

1989

```
C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

            Summary: MODIFIED BERGGREN SOLUTION

        Design Freezing Index (AIR)      =  714 F-days
        Design Freezing Index (SURFACE)  =  714 F-days
        Mean Annual Temperature          =  [illegible] °F
        Length of Freezing Season        =   88 Days

-------------------------------------------------------------------
                          LAYER     FREEZING INDEX DISTRIBUTION
     LAYER              THICKNESS
     #: Type             (inches)    Each Layer     Accumulated
-----------------------  ---------   -------------  -------------
1: Fine grained          12.0        151            151
2: Fine grained           6.0        135            [illegible]
3: Fine grained           [illegible] 284           [illegible]
4: Fine grained           1.9        192            [illegible]
---------------- End of Frost Penetration ------------------

TOTAL FROST PENETRATION =  25.9 inches


Do you want a hard copy of this data (Y or [illegible] N)?
```

1990

```
C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

            Summary: MODIFIED BERGGREN SOLUTION

        Design Freezing Index (AIR)      =  [illegible] F-days
        Design Freezing Index (SURFACE)  =  [illegible] F-days
        Mean Annual Temperature          =  [illegible] °F
        Length of Freezing Season        =  [illegible] Days

-------------------------------------------------------------------
                          LAYER     FREEZING INDEX DISTRIBUTION
     LAYER              THICKNESS
     #: Type             (inches)    Each Layer     Accumulated
-----------------------  ---------   -------------  -------------
[illegible]              [illegible] [illegible]    [illegible]
[illegible]              [illegible] [illegible]    [illegible]
[illegible]              [illegible] [illegible]    [illegible]
[illegible]              [illegible] [illegible]    [illegible]
---------- End of Frost Penetration -----

TOTAL FROST PENETRATION -        inches


Do you want a hard copy of this data (  or          )?
```

1991

```
C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

                Summary: MODIFIED BERGGREN SOLUTION

          Design Freezing Index (AIR)      =  696 F-days
          Design Freezing Index (SURFACE)  =  696 F-days
          Mean Annual Temperature          = 52.0 °F
          Length of Freezing Season        =   77 Days

-----------------------------------------------------------------
                          LAYER     FREEZING INDEX DISTRIBUTION
     LAYER              THICKNESS
     #: Type             (inches)    Each Layer     Accumulated
-------------------     ---------   ------------   -------------
1: Fine-grained           6.0            34             34
2: Fine grained           6.0           103            137
3: Fine grained           6.0           172            309
4: Fine-grained           6.0           241            550
5: Fine grained           2.8           138            688
---------------- End of Frost Penetration ------------------

TOTAL FROST PENETRATION =  26.8 inches


Do you want a hard copy of this data (Y or default N)?
```

1992

```
C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

                Summary: MODIFIED BERGGREN SOLUTION

          Design Freezing Index (AIR)      =  718 F-days
          Design Freezing Index (SURFACE)  =  718 F-days
          Mean Annual Temperature          = 52.0 °F
          Length of Freezing Season        =   74 Days

-----------------------------------------------------------------
                          LAYER     FREEZING INDEX DISTRIBUTION
     LAYER              THICKNESS
     #: Type             (inches)    Each Layer     Accumulated
-------------------     ---------   ------------   -------------
1: Fine grained           12.0           138            138
2: Fine grained           12.0           413            551
3: Fine grained            3.4           167            718
---------------- End of Frost Penetration ------------------

TOTAL FROST PENETRATION =  27.4 inches


Do you want a hard copy of this data (Y or default N)?
```

C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

```
                Summary: MODIFIED BERGGREN SOLUTION

          Design Freezing Index (AIR)      =  284 F-days
          Design Freezing Index (SURFACE)  =  284 F-days
          Mean Annual Temperature          = [illegible] oF
          Length of Freezing Season        =   [illegible] Days

-------------------------------------------------------------------
                          LAYER     FREEZING INDEX DISTRIBUTION
     LAYER                THICKNESS
     #: Type              (inches)   Each Layer     Accumulated
-----------------------   --------   ------------   ------------
1: Fine-grained            5.0        5[illegible]      [illegible]
2: Fine grained            [illegible]  1[illegible]      [illegible]
3: Fine grained            2.[illegible]  8[illegible]      [illegible]
----------------- End of Frost Penetration -----------------

TOTAL FROST PENETRATION = [illegible]  inches


Do you want a hard copy of this data (Y or [illegible]N)?
```

```
C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

                Summary: MODIFIED BERGGREN SOLUTION

          Design Freezing Index (AIR)      =  970 F-days
          Design Freezing Index (SURFACE)  =  776 F-days
          Mean Annual Temperature          = 50.1 °F
          Length of Freezing Season        =   83 Days

                                LAYER      FREEZING INDEX DISTRIBUTION
       LAYER                  THICKNESS
     #: Type                   (inches)    Each Layer    Accumulated
  ------------------          ---------    ----------    -----------
  1: Fine-grained               12.0          129           129
  2: Fine grained               12.0          387           516
  3: Fine grained                5.5          263           779
  ---------------- End of Frost Penetration ----------------

  TOTAL FROST PENETRATION =  29.5 inches


  Do you want a hard copy of this data (Y or [illegible] N)?
```

1937, N=0.8

```
C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

                Summary: MODIFIED BERGGREN SOLUTION

          Design Freezing Index (AIR)      =  970 F-days
          Design Freezing Index (SURFACE)  =  873 F-days
          Mean Annual Temperature          = 50.1 °F
          Length of Freezing Season        =   83 Days

                                LAYER      FREEZING INDEX DISTRIBUTION
       LAYER                  THICKNESS
     #: Type                   (inches)    Each Layer    Accumulated
  ------------------          ---------    ----------    -----------
  1: Fine grained               12.0          126           126
  2. Fine grained               12.0          379           505
  3: Fine grained                7.5          373           878
  ---------------- End of Frost Penetration ----------------

  TOTAL FROST PENETRATION =  31.5 inches


  Do you want a hard copy of this data (Y or [illegible] N)?
```

1937, N=0.9

```
C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

                Summary: MODIFIED BERGGREN SOLUTION

          Design Freezing Index (AIR)      =  970 F-days
          Design Freezing Index (SURFACE)  =  970 F-days
          Mean Annual Temperature          = 50.1 °F
          Length of Freezing Season        =   83 Days

                                LAYER      FREEZING INDEX DISTRIBUTION
       LAYER                  THICKNESS
     #: Type                   (inches)    Each Layer    Accumulated
  ------------------          ---------    ----------    -----------
  1: Fine grained               12.0          [illegible]   [illegible]
  2: Fine grained               [illegible]   170           [illegible]
  3: Fine grained               [illegible]   480           [illegible]
  ---------------- End of Frost Penetration ----------------

  TOTAL FROST PENETRATION =  [illegible] inches


  Do you want a hard copy of this data (Y or [illegible] N)?
```

1937, N=1.0

```
C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

                Summary: MODIFIED BERGGREN SOLUTION

          Design Freezing Index (AIR)       - 1112 F-days
          Design Freezing Index (SURFACE)   -  966 F-days
          Mean Annual Temperature           - 41.1 oF
          Length of Freezing Season         -   [illegible] Days

                                LAYER      FREEZING INDEX DISTRIBUTION
      LAYER                   THICKNESS
     #: Type                   (inches)    Each Layer     Accumulated
-------------------------------------------------------------------------
1: Fine grained                 12.6          134            134
2: Fine grained                 12.6          483            617
3: Fine grained                 [illegible]   [illegible]    [illegible]
---------------- End of Frost Penetration ----------------

TOTAL FROST PENETRATION =  [illegible] inches


Do you want a hard copy of this data (Y or        N)?
```

1979, N=0.8

```
C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

                Summary: MODIFIED BERGGREN SOLUTION

          Design Freezing Index (AIR)       - 1112 F-days
          Design Freezing Index (SURFACE)   - [illegible] F-days
          Mean Annual Temperature           - [illegible] oF
          Length of Freezing Season         -   [illegible] Days

                                LAYER      FREEZING INDEX DISTRIBUTION
      LAYER                   THICKNESS
     #: Type                   (inches)    Each Layer     Accumulated
-------------------------------------------------------------------------
1: Fine grained                 [illegible]   [illegible]    [illegible]
2: Fine grained                 [illegible]   [illegible]    [illegible]
3: Fine grained                 [illegible]   [illegible]    [illegible]
---------------- End of Frost Penetration

TOTAL FROST PENETRATION -        inches


Do you want a hard copy of this data (Y or        N)?
```

1979, N=0.9

```
C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

                [illegible]

          Design Freezing Index (AIR)       - [illegible] F days
          Design Freezing Index (SURFACE)   - [illegible] F days
          Mean Annual Temperature           - [illegible] oF
          Length of Freezing Season         - [illegible] Days

                                LAYER      FREEZING INDEX DISTRIBUTION
      LAYER                   THICKNESS
     #: Type                   (inches)    Each Layer     Accumulated
-------------------------------------------------------------------------
[illegible]
[illegible]
[illegible]
---------------- End of Frost Penetration

TOTAL FROST PENETRATION          inches


Do you want a hard copy of this data (  or          )?
```

1979, N=1.0

```
C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

                Summary: MODIFIED BERGGREN SOLUTION

          Design Freezing Index (AIR)      = 1141 F-days
          Design Freezing Index (SURFACE)  =  913 F-days
          Mean Annual Temperature          = 48.8 °F
          Length of Freezing Season        =   83 Days

                                  LAYER     FREEZING INDEX DISTRIBUTION
       LAYER                    THICKNESS
     #: Type                     (inches)    Each Layer    Accumulated
1: Fine grained                   12.0          116           116
2: Fine grained                   12.0          349           465
3: Fine grained                    9.7          452           917
---------------- End of Frost Penetration ----------------

TOTAL FROST PENETRATION =  33.7 inches

Do you want a hard copy of this data (Y or      N)?
```

1933, N=0.8

```
C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

                Summary: MODIFIED BERGGREN SOLUTION

          Design Freezing Index (AIR)      = 1141 F-days
          Design Freezing Index (SURFACE)  = 1027 F-days
          Mean Annual Temperature          = 48.8 °F
          Length of Freezing Season        =   83 Days

                                  LAYER     FREEZING INDEX DISTRIBUTION
       LAYER                    THICKNESS
     #: Type                     (inches)    Each Layer    Accumulated
1: Fine grained                   12.0          116           116
2: Fine grained                   12.0          147           263
3: Fine grained                   [illegible]   [illegible]   [illegible]
---------------- End of Frost Penetration ----------------

TOTAL FROST PENETRATION =  [illegible] inches

Do you want a hard copy of this data (Y or      N)?
```

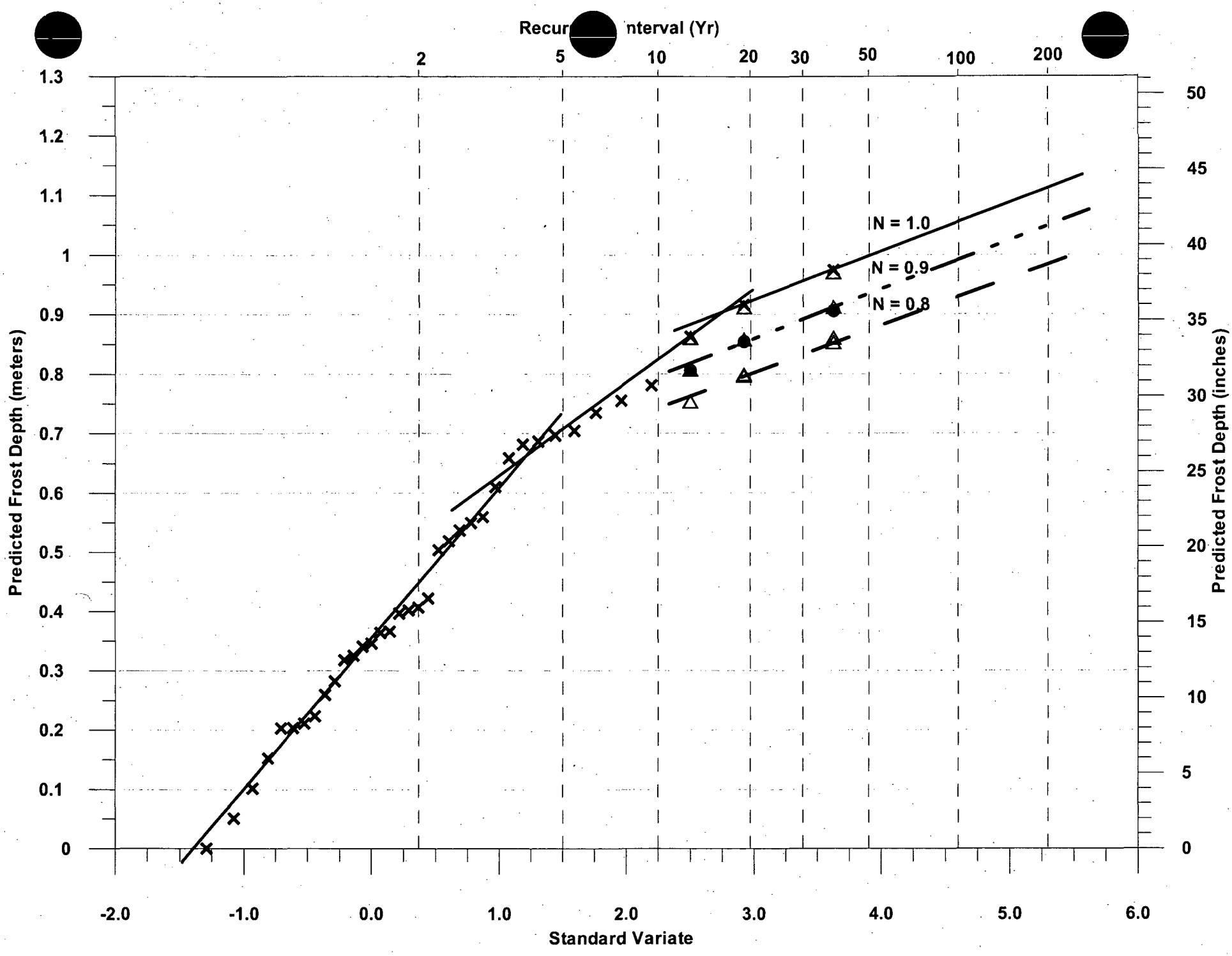
1933, N=0.9

```
C:\PROGRA~1\DOSPRG~1\frost\GO2.exe

                Summary: MODIFIED BERGGREN SOLUTION

          Design Freezing Index (AIR)      = [illegible] F-days
          Design Freezing Index (SURFACE)  = [illegible] F-days
          Mean Annual Temperature          = [illegible] °F
          Length of Freezing Season        = [illegible] Days

                                  LAYER     FREEZING INDEX DISTRIBUTION
       LAYER                    THICKNESS
     #: Type                     (inches)    Each Layer    Accumulated
[illegible]
---------------- End of Frost Penetration ----------------

TOTAL FROST PENETRATION = [illegible] inches

Do you want a hard copy of this data (Y or      N)?
```

1933, N=1.0

Appendix C

Results of Extreme Frost Depth Analysis


Recur nterval (Yr)
2
5
10
20
30
50
100
200
N = 1.0
N = 0.9
N = 0.8
Predicted Frost Depth (meters)
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Predicted Frost Depth (inches)
50
45
40
35
30
25
20
15
10
5
0
-2.0
-1.0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
Standard Variate

End of current text

U.S. Department of Energy—Grand Junction, Colorado

Calculation Cover Sheet

Calc. No.: MOA-02-08-2006-5-13-01 Discipline: Geology No. of Sheets: 16
Doc No.: X0175600

Location: Attachment 1, Appendix B

Project: Moab UMTRA Project

Site: Crescent Junction Disposal Site

Feature: Radon Barrier Design Remedial Action Plan

Sources of Data:

RAP calculations as referenced in text.

Sources of Formulae and References:

See "References" section.

Preliminary Calc. ☐ Final Calc. ☒ Supersedes Calc. No. MOA-02-05-2006-3-13-00

	Name	Date		Name	Date
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Problem Statement:

- Part 40 of the United States *Code of Federal Regulations*, section 192.02 (40 CFR 192.02) requires that control of radioactive materials and their listed constituents shall be designed to provide reasonable assurance that release of radon-222 from residual radioactive material (RRM) to the atmosphere will not exceed an average of 20 picocuries per square meter per second (pCi/m^2/sec), averaged over the entire cover top slope.
- The cover of the Crescent Junction Disposal Cell must be sufficient to provide isolation of tailings and control of radon emanation for the period of up to one thousand years, to the extent reasonably achievable, and, in any case, for at least 200 years.
- This calculation establishes the dimensions and input parameters for design of the Crescent Junction Disposal Cell radon barrier that will provide the requisite reasonable assurance of performance.

Method of Solution:

- Site-specific data for the RRM, which includes tailings, contaminated soils, mill debris, and other contaminated materials, and for the native cover materials were developed through thorough field investigations and laboratory testing programs (Golder 2006a, Remedial Action Plan calculations referenced herein). These site-specific data are presented in summary tables in Appendix B.
- Two conceptual design configurations were evaluated: one using a compacted-clay radon barrier (Uranium Mill Tailings Remedial Action [UMTRA] checklist cover), and one using a monolithic soil cover (alternative cover).
- The Nuclear Regulatory Commission (NRC) computer code RADON (NRC 1989a) was used to calculate the optimum radon-barrier thickness, given the specific input parameters for each model run.

Assumptions:

- Tailings activity will be relatively homogeneous as placed; no layers of different radium-226 activity were modeled. This is conservative, as placement of contaminated soils of lower activity may be placed in the upper portions of the pile. It is anticipated that the cover design will be re-evaluated during construction using actual as-placed source material activities and properties to ensure the cover is optimized for as-built conditions.
- Bottom-boundary radon flux is equal to zero, as per the Technical Approach Document (TAD) (DOE 1989).
- Ambient air radon concentrations were assumed to equal the conservative default value of zero, no local ambient air radon concentration data were available. Should these data become available prior to construction, these measured values should be considered in evaluation of the final cover design.
- The cell side slopes will be constructed of dikes made from clean fill to thicknesses far in excess of the cover and with properties comparable to the cover material; therefore, radon flux through the side slopes was not modeled.
- Following UMTRA precedence, materials above the radon barrier (e.g., frost protection layers, riprap, or rock mulch erosion-protection layers) were not modeled. These overlying materials provide additional radon attenuation. This conservative assumption enhances the reasonable assurance that the barrier as designed will provide the requisite protection and long-term performance.
- A clean-fill interim cover with a minimum thickness of 1 foot (ft) will be placed over the tailings as a best management practice.
- Physical properties of the cover materials are adequately represented by the characterization data.
- RADON model (NRC 1989a) default values for radon-emanation coefficient (0.35) are assumed conservative and appropriate.

- Capillary breaks, drainage layers/ biointrusion layers were assumed to have insignificant impact on radon attenuation, given their large pore size and low long-term moisture content. Therefore, these layers have conservatively been omitted from the RADON model runs.

Calculation:

- The mean value (x_{mean}) of any parameter is calculated by the equation:

$$x_{mean} = \sum x_i / n$$

where: x_i = the ith value, and
n = the total number of values.

- The standard deviation (s) of a set of values is calculated by the equation:

$$s = \text{sqrt}((\sum(x_i - x_{mean})^2 / [n-1]))$$

where: sqrt = the square root of the value.

- Porosity (η) of a sample is calculated from the equation:

$$(\eta = (1 - [\text{dry bulk density} \div (\text{specific gravity} \times \text{unit weight of water})])$$

where the unit weight of water is 62.4 pounds per cubic foot (pcf), or 1 gram per cubic centimeter (g/cc).

- Radon (^{222}Rn) Diffusion coefficients were calculated using equation 9 from Rogers and Nielson (1991) as follows:

$$D=Da*p*\exp(-6Sp-6S14p)$$

where: D = the calculated ^{222}Rn diffusion coefficient
Da = the ^{222}Rn diffusion coefficient in air (1.10×10^{-5} m^2/s)
p = the porosity of the individual material (also represented by the symbol η, as above)
S = the degree of material saturation, represented the following equation:

Saturation (S) = Long-term water content/((unit weight of water/material dry density) – (1 – material specific gravity))

- The density of a sample in g/cc is converted to pcf by multiplying the unit weight of water (62.4 pcf).
- The Rawls & Brakensiek equation referenced in the NRC Regulatory Guide 3.64 (NRC 1989b) can be used to estimate the 15 bar moisture content as a reasonable lower bound of long-term moisture content. The equation is:

$$\text{15 bar moisture content} = 0.026 + 0.005z + 0.0158y$$

where: z = percent clay in the soil
y = percent organic matter in the soil

For example, the calculated 15 bar moisture content of the alluvial site materials, which have a mean clay content of 18.63 percent and a mean organic matter content of 0.28 percent is:

$$\text{15 bar moisture content} = 0.026 + 0.005(18.23) + 0.0158(0.28)$$
$$\text{15 bar moisture content} \doteq 0.075\text{, or 7.5 percent}$$

The individual RADON model (NRC 1989a) output files, which include the input parameter values for each model layer, are included in Appendix A. Appendix B provides additional calculations and data supporting development of the input parameters.

Discussion:

Two general cover configurations were considered: a "typical" UMTRA-style cover consisting of a compacted, native-clay radon barrier (see Figure 1), and an alternative cover design using a monolithic cover of loosely compacted native materials (see Figure 2). It has been assumed as a best management practice that a 1-ft-thick interim cover of clean native materials will be placed on the RRM to control wind transport of fine material and to provide for a relatively clean and uniform work surface on which the radon barrier will be constructed.

The radon barrier layers have been optimized by the RADON model to limit the radon flux to 20 pCi/m^2/sec under long-term moisture content conditions. As with previous UMTRA Title I cover designs, the attenuation of radon by the drainage layer or frost protection layers are not considered in these analyses, though these layers will further reduce the radon flux rate at the Disposal Cell surface. An additional model run was performed for the UMTRA cover to illustrate the calculated radon barrier thickness required, should the attenuation of radon by the frost protection layer be considered.

Clean fill embankments made of native materials will be used around the perimeter of the new disposal cell constructed with 5H:1V exterior side slopes and a minimum 30-ft-wide crest. Consequently, the tailings side slope thicknesses will be far in excess of the cover requirements.

Several model sensitivity runs were performed for the UMTRA cover design to illustrate the sensitivity of the calculated radon barrier thickness to the thickness of the interim cover and to the long-term tailings moisture content. Model sensitivity runs were also performed for the alternative cover to illustrate the sensitivity of the calculated radon barrier thickness to the long-term tailings moisture content.

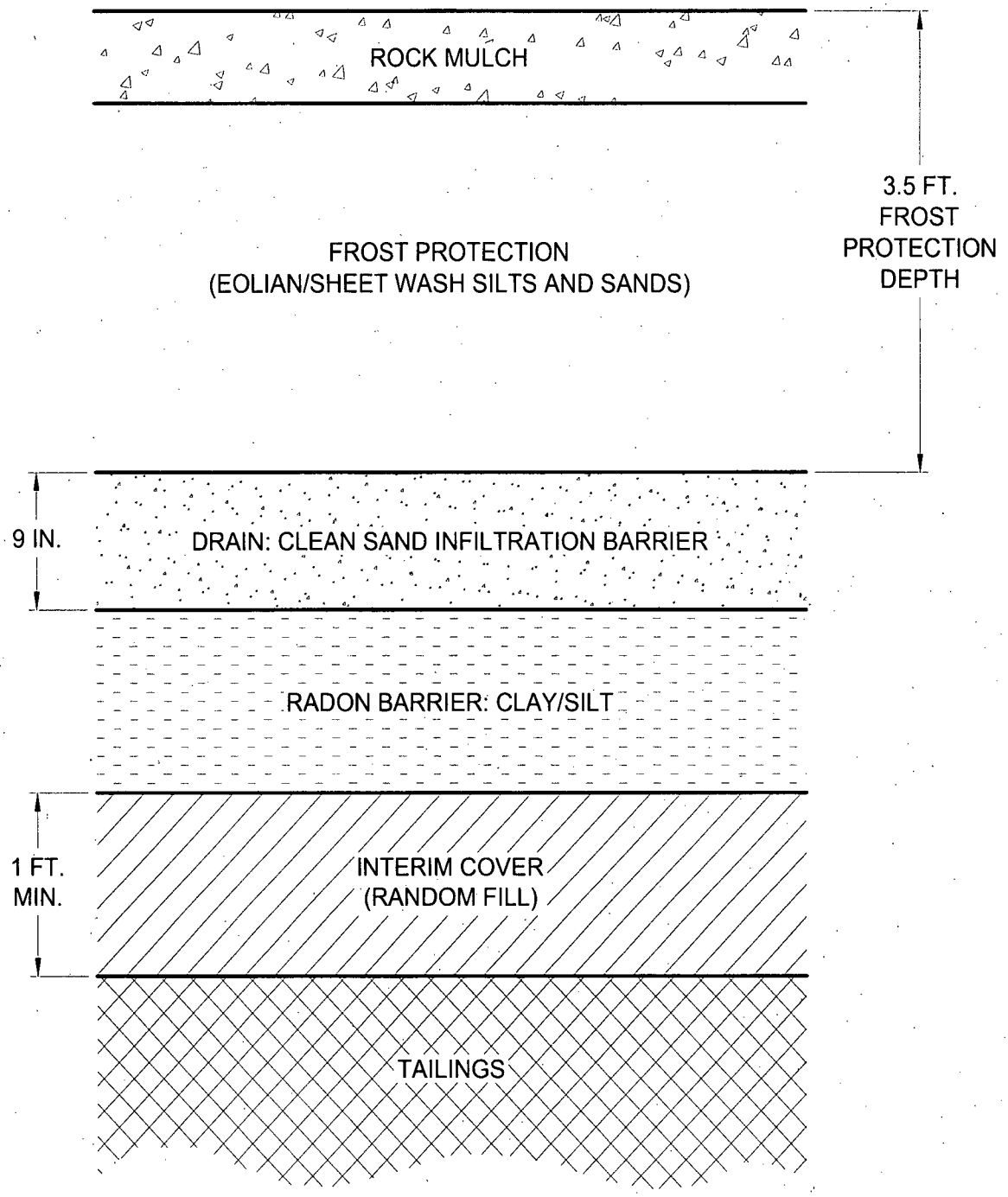

Figure 1. UMTRA Checklist Top Cover

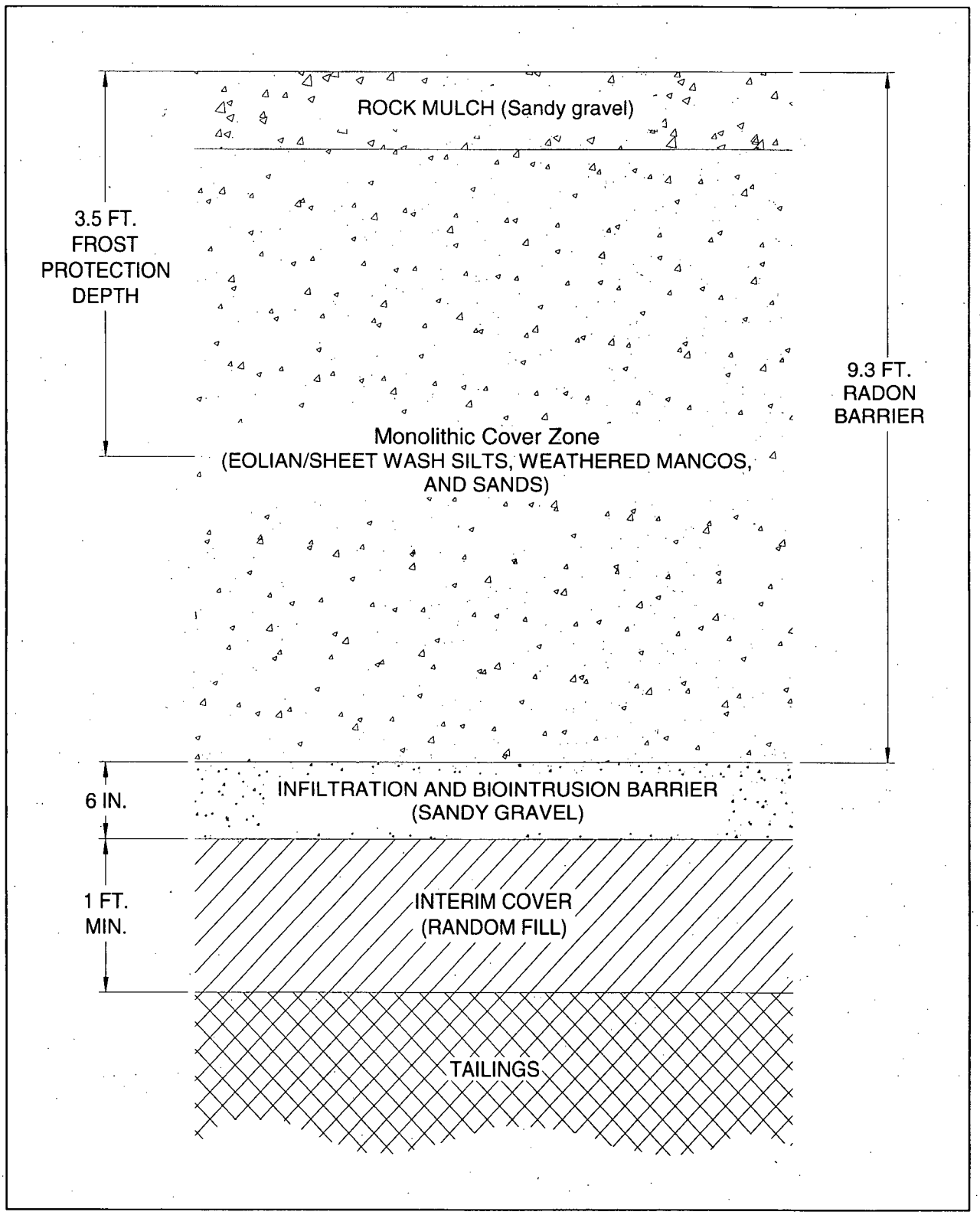

Figure 2. Alternative Top Cover

UMTRA-Style Cover

The current conceptual design of the UMTRA cover system consists of 1 ft of interim cover on the tailings surface below the compacted-clay radon barrier consisting of clean, native materials placed as a best management practice to control wind transport of fine material and to provide for a relatively clean, uniform work surface upon which to construct the radon barrier. The model is used to optimize the layer thickness of the compacted-clay radon barrier. Several model runs were performed to assess model sensitivity to certain variables as described below.

- Model run UMTRA 1a uses mean input values for the UMTRA style cover with a 1-ft-thick interim cover.
- Model runs UMTRA 1b through UMTRA 1d are sensitivity runs to illustrate the effect of the interim cover thickness on the calculated radon barrier thickness to meet the 20 pCi/m^2/s flux requirement.
  - Model run UMTRA 1b is the same as run UMTRA 1a but with a 3-ft-thick interim cover.
  - Model run UMTRA 1c is the same as run UMTRA 1a but with a 5-ft-thick interim cover.
  - Model run UMTRA 1d is the same as run UMTRA 1a but with a 7-ft-thick interim cover.
- Model run UMTRA 2a is a sensitivity run illustrating the calculated radon barrier thickness required should the attenuation of radon by the freeze/thaw protection layer be considered.
- Model runs UMTRA 3a and UMTRA 3b are sensitivity runs illustrating the effect of tailings moisture content on the calculated radon barrier thickness.
  - Model run UMTRA 3a is the same as UMTRA 1a but with the tailings moisture content set to 10 percent.
  - Model run UMTRA 3a is the same as UMTRA 1a but with the tailings moisture content set to 20 percent.

Alternative Cover

The alternative cover system design consists of 1 ft of interim cover, a 6-inch-thick capillary break layer and a monolithic radon-barrier layer. However, because the capillary barrier is very coarse grained and will have very low long-term moisture content, experience has shown that its influence on radon attenuation is minimal. Therefore, it has conservatively been omitted from the model runs.

The alternative cover uses a monolithic soil layer placed at a density similar to existing native soils conditions and is modeled under conservative long-term soil moisture conditions. Therefore, a frost protection layer is not needed to protect it from changes due to seasonal freeze/thaw cycles.

This monolithic soil layer will also be covered by a rock mulch designed to resist wind and surface water runoff erosional forces under the Probable Maximum Flow (PMF) event, ensuring that the layer endures as an integral unit for the design life of the disposal cell. Several model runs were performed to assess model sensitivity to certain variables as described below.

- Model run Alt 1a uses mean input values for the alternative cover.
- Model runs Alt 1b and Alt 1c are sensitivity runs illustrating the effect of tailings moisture content on the calculated radon barrier thickness.
  - Model run Alt 1b is the same as Alt 1a but with the tailings moisture content set to 10 percent.
  - Model run Alt 1b is the same as Alt 1a but with the tailings moisture content set to 20 percent.

Description of Model and Input Values

Radon emanation calculations from a multilayered cover system were made with the RADON model, a one-dimensional model that calculates radon flux from decay of a radium-226 (Ra-226) source (such as the tailings). The key input parameters to the model include:

- Layer thickness.
- Porosity.
- Mass density.
- Ra-226 activity concentration.
- Emanation coefficient.
- Weight percent moisture.
- Coefficient of radon diffusion.

Only those material layers including the radon barrier and below are modeled. This ensures that the radon barrier alone can meet the long-term average radon flux requirement of 20 $pCi/m^2/s$, without the additional attenuation provided by overlying layers such as freeze/thaw protection layers or rock mulch layers. The input parameters and values used in the model are outlined below. Table 1 summarizes the individual input parameters used for all of the models run and their bases and the results of the model runs. Figure 1 and Figure 2 illustrate the UMTRA checklist cover and the alternative cover design configurations. Appendix A presents the RADON model output files. Appendix B presents all raw data used in developing the model input parameters.

Layer Thickness

The layers and material sequences for the UMTRA cover and the alternative cover are illustrated in Figure 1 and Figure 2, respectively, and represent the geometries of the tailings and of each cover-layer component. Therefore, radon flux through the side slopes was not modeled. For all model runs, a tailings thickness of 500 centimeters (cm) is used; the model output is insensitive to source term thicknesses greater than 500 cm.

The UMTRA cover design evaluated for radon flux consists of an a 1-ft-thick interim cover constructed of clean native alluvium and a compacted clay radon barrier constructed from conditioned on-site weathered Mancos Shale. The overlying sand drainage/biointrusion layer, frost protection layer and rock mulch erosion protection layer are not considered in the base-line modeling consistent with the historic UMTRA design approach. However, an additional model run was performed for the UMTRA cover to illustrate the calculated radon barrier thickness required should the attenuation of radon by the 3.5-ft-thick frost protection layer be considered.

The alternative cover design evaluated for radon flux consists of the same interim cover as used for the UMTRA cover. A monolithic radon barrier consisting of the same materials as the interim cover placed at the same densities overlies the interim cover. The sand drainage layer is not considered in the modeling as it has a high porosity, low long-term moisture content and would not significantly add to the attenuation characteristics of the cover.

Table 1. Crescent Junction Disposal Cell Radon Barrier Design, RADON Model Runs Summary

Model Run	Layer Type	Layer Thickness (cm)	Layer Thickness (ft)	Porosity	Density (g/cc)	Ra-226 Activity (pCi/g)	Gravimetric Moisture Content (%)	Moisture Saturation Fraction (%)	Calculated Diffusion Coefficient (m^2/s)	Notes
(Appendix B data reference)		Prescribed	Prescribed	Table 2	Table 2	Table 3	Table 4	Table 5	Table 5	
Alt 1a	Tailings	500	16.4	0.44	1.57	707	15	53.4%	1.044E-02	Alt. cover, baseline model run, mean input parameters
	Interim Cover	30.5	1.0	0.38	1.66	1.9	9	39.4%	1.629E-02	
	Radon Barrier	**284.4**	**9.3**	0.38	1.66	1.9	9	39.4%	1.629E-02	
Alt 1b	Tailings	500	16.4	0.44	1.57	707	10	35.6%	1.873E-02	Alt. Cover, sensitivity Run, baseline model w/ Tailings Moisture content = 10%
	Interim Cover	30.5	1.0	0.38	1.66	1.9	9	39.4%	1.629E-02	
	Radon Barrier	**288.5**	**9.5**	0.38	1.66	1.9	9	39.4%	1.629E-02	
Alt 1c	Tailings	500	16.4	0.44	1.57	707	20	71.2%	3.541E-03	Alt. Cover, sensitivity Run, baseline model w/ Tailings Moisture content = 20%
	Interim Cover	30.5	1.0	0.38	1.66	1.9	9	39.4%	1.629E-02	
	Radon Barrier	**261**	**8.6**	0.38	1.66	1.9	9	39.4%	1.629E-02	
UMTRA 1a	Tailings	500	16.4	0.44	1.57	707	15	53.4%	1.044E-02	UMTRA Cover, baseline model run, mean input parameters Interim Cover = 1-ft thick
	Interim Cover	30.5	1.0	0.38	1.66	1.9	9	39.4%	1.629E-02	
	Radon Barrier	**119.8**	**3.9**	0.33	1.77	2.3	12	64.4%	4.636E-03	
UMTRA 1b	Tailings	500	16.4	0.44	1.57	707	15	53.4%	1.044E-02	UMTRA Cover, sensitivity run, baseline model w/ Interim Cover = 3-ft thick
	Interim Cover	91.5	3.0	0.38	1.66	1.9	9	39.4%	1.629E-02	
	Radon Barrier	**86.4**	**2.8**	0.33	1.77	2.3	12	64.4%	4.636E-03	
UMTRA 1c	Tailings	500	16.4	0.44	1.57	707	15	53.4%	1.044E-02	UMTRA Cover, sensitivity run, baseline model w/ Interim Cover = 5-ft thick
	Interim Cover	152.5	5.0	0.38	1.66	1.9	9	39.4%	1.629E-02	
	Radon Barrier	**55.1**	**1.8**	0.33	1.77	2.3	12	64.4%	4.636E-03	

Table 1 (continued). Crescent Junction Disposal Cell Radon Barrier Design, RADON Model Runs Summary

Model Run	Layer Type	Layer Thickness (cm)	Layer Thickness (ft)	Porosity	Density (g/cc)	Ra-226 Activity (pCi/g)	Gravimetric Moisture Content (%)	Moisture Saturation Fraction (%)	Calculated Diffusion Coefficient (m^2/s)	Notes
(Appendix B data reference)		Prescribed	Prescribed	Table 2	Table 2	Table 3	Table 4	Table 5	Table 5	
UMTRA 1d	Tailings	500	16.4	0.44	1.57	707	15	53.4%	1.044E-02	UMTRA Cover, sensitivity run, baseline model w/ Interim Cover = 5 ft. thick
	Interim Cover	213.5	7.0	0.38	1.66	1.9	9	39.4%	1.629E-02	
	Radon Barrier	**27.9**	**0.9**	0.33	1.77	2.3	12	64.4%	4.636E-03	
UMTRA 2a	Tailings	500	16.4	0.44	1.57	707	15	53.4%	1.044E-02	UMTRA Cover, sensitivity run, baseline model w/ freeze/thaw layer Radon barrier optimized to make radon flux at the surface of the freeze/thaw layer = 20 $pCi/m^2/sec$
	Interim Cover	30.5	1.0	0.38	1.66	1.9	9	39.4%	1.629E-02	
	Radon Barrier	**81.72**	**2.7**	0.33	1.77	2.3	12	64.4%	4.636E-03	
	Freeze/ Thaw Layer	106.8	3.5	0.38	1.66	1.9	9	39.4%	1.629E-02	
UMTRA 3a	Tailings	500	16.4	0.44	1.57	707	10	35.6%	1.873E-02	UMTRA Cover, sensitivity Run, baseline model w/ Tailings Moisture content = 10%
	Interim Cover	30.5	1.0	0.38	1.66	1.9	9	39.4%	1.629E-02	
	Radon Barrier	**119.1**	**3.9**	0.33	1.77	2.3	12	64.4%	4.636E-03	
UMTRA 3b	Tailings	500	16.4	0.44	1.57	707	20	71.2%	3.541E-03	UMTRA Cover, sensitivity Run, baseline model w/ Tailings Moisture content = 20%
	Interim Cover	30.5	1.0	0.38	1.66	1.9	9	39.4%	1.629E-02	
	Radon Barrier	**111.7**	**3.7**	0.33	1.77	2.3	12	64.4%	4.636E-03	

Porosity (n)

The porosity of the layer materials have been calculated based on the dry density and the specific gravity of the specific materials according to the equation identified in the previous section.

The porosity of the tailings was modeled as 0.44, given a mean specific gravity of 2.8 for the tailings based on the data in the "Geotechnical Laboratory Testing Results for the Moab Processing Site" calculation (RAP Attachment 5, Vol. I, Appendix J), and a designed placement density of 1.57 g/cc (98 pcf).

The porosity of the interim cover and the monolithic layer of the alternative cover, to be developed from the alluvial silty sands and sheetwash deposits overlying the in-situ weathered Mancos Shale, was modeled as 0.38, given a mean specific gravity of 2.65—based on nine samples presented in the "Geotechnical Properties of Native Materials" calculation (RAP Attachment 5, Vol. I, Appendix E) and Appendix B—and a designed placement density of 1.66 g/cc (103 pcf). These two layers will be constructed of the same on-site materials from the Crescent Junction Site and will be placed in the same conditions. The porosity of the frost protection layer was modeled assuming the same conditions as the interim cover material.

The porosity of the compacted Mancos Shale was modeled as 0.33, given a mean specific gravity for the Mancos Shale of 2.65—based on the data in the "Geotechnical Properties of Native Materials" calculation (RAP Attachment 5, Vol. I, Appendix E) and Appendix B—and a designed placement density of 1.77 g/cc (111 pcf).

Mass Density

The dry density of the tailings as placed has been modeled as 1.57 g/cc (98 pcf), which is 90 percent of the mean standard Proctor maximum dry density of transition tailings materials as reported in the Draft Tech Memo by Golder Associates (2006b).

The density of the interim cover materials and the alternative cover monolithic layer, as placed, has been modeled as 1.66 g/cc (103 pcf), which is 85 percent of the mean modified Proctor dry density value (121.8 pcf) for these materials as developed in the "Geotechnical Properties of Native Materials" calculation (RAP Attachment 5, Vol. I, Appendix E). The density of the frost protection layer has been modeled as the same as the interim cover materials. Because these materials will be installed using more energy and in a different manner than the native in-situ alluvial materials, it is anticipated that the frost protection layer will have long-term density more representative of the as-placed conditions than the native in-situ material conditions.

The density of the compacted clay materials and the UMTRA-style cover, as placed, has been modeled as 1.77 g/cc (111 pcf), which is 90 percent of the mean modified Proctor dry density value (123 pcf) for these materials, as developed in the "Geotechnical Properties of Native Materials" calculation (RAP Attachment 5, Vol. I, Appendix E).

Radium Activity Concentration

The Ra-226 activity concentration values used in the model for each specific material are outlined below.

<u>Tailings</u>

Radium-226 concentrations for the tailings pile materials were assessed based on 94 samples of tailings sands, slimes, transitional tailings and other contaminated materials. Radium-226 analyses were performed by gamma spectroscopy from these locations. The estimated volumes of tailings material are provided in the "Volume Calculation for the Moab Tailings Pile," calculation (RAP Attachment 1, Appendix I). The average Ra-226 activity for the contaminated materials is 707 picocuries per gram (pCi/g), with values ranging from 2 to 2,195 pCi/g, as developed in the "Average Radium-226 Concentrations for the Moab Tailings Pile," calculation (RAP Attachment 1, Appendix K) (see also Appendix B of this calculation).

The current conceptual plan for tailings removal and placement would entail a significant amount of blending of lower-activity beach sands and higher-activity slimes. Therefore, no layering of the tailings

source term has been modeled, and a single activity value has been used. However, it is highly likely that lower-activity contaminated sub-pile soils and contaminated soils from the mill site and cleanup of peripheral and vicinity properties will be placed above the higher activity tailings, which would serve to further reduce Ra-226 activity at the base of the cover. The tailings source term activity, as well as the actual cover materials properties site, should be reevaluated once delivered to ensure that the cover design is optimized for the actual as-built conditions of the cell contents.

Interim Cover and Alternative Cover Monolithic Layer

The Ra-226 activity of the alluvial materials to be used for the interim cover, alternative cover, and the clean-fill perimeter dikes is based on five samples of native materials collected from the Crescent Junction Site as developed in the "Geotechnical Properties of Native Materials" calculation (RAP Attachment 5, Vol. I, Appendix E) (see also Appendix B of this calculation). Samples were collected from alluvial materials and weathered Mancos Shale with depths ranging from 4 to 22 ft below the surface. The Ra-226 activity of the alluvial material ranged from 1.4 to 2.3 pCi/g, with a mean value of 1.9 pCi/g.

Compacted Clay Layer

The Ra-226 activity value for the compacted clay layer is based on two samples of Mancos Shale collected from the Crescent Junction Site that will be used to construct the compacted-clay radon barrier and clean-fill perimeter dikes (see Appendix B). Samples were collected from weathered Mancos Shale samples with depths of approximately 20 to 22 ft below the surface. The Ra-226 activity of the weathered Mancos Shale ranged from 1.6 to 3.0 pCi/g, with a mean value of 2.3 pCi/g.

Radon Emanation Coefficient

A radon-emanation coefficient of 0.35 was used for all of the tailings, random fill, and cover materials. This is the conservative default value used in the RADON model.

Long-Term Weight Percent Moisture

The mean weight percent moisture of the tailings has been modeled as 15 percent, which is in the typical range for tailings and is below that value used for the modeling of the Grand Junction UMTRA Site (18 percent). Sensitivity analyses for the influence of long-term tailings moisture content were used to evaluate the influence of this parameter on predicted radon barrier thicknesses. Values of 10 percent moisture content and 20 percent moisture content were modeled. The results of the sensitivity analyses are discussed in the "Conclusion and Recommendations" section.

The mean long-term gravimetric moisture content of the interim cover and the alternative cover monolithic layer is modeled as 9 percent. This value is based on the mean of 20 measured 15 bar tests as determined by ASTM Method D3152 and presented in the "Supplemental Geotechnical Properties of Native Materials" calculation (Attachment 5, Vol. I, Appendix K). This mean measured value was evaluated for reasonableness using the Rawls and Brakensiek equation as presented in the NRC Regulatory Guide 3.64 (NRC 1989b). The Rawls and Brakensiek equation is a simplified empirical relationship based on the correlation of measured 15-bar moisture contents to the percent clay and organic matter in a range of soils. However, this relationship is not considered as reliable as the site-specific test data, and is considered as confirmatory information only. The calculated value, using the mean percent clay of eight alluvial samples and the percent organic matter of six alluvial samples, is 7.5 percent, which agrees well with the measured value of site-specific soils, or 9 percent. These data and calculations are summarized in Appendix B.

The mean long-term moisture content of the compacted clay derived from the on-site weathered Mancos Shale is modeled as 12 percent. This value is based on the mean of 12 measured 15 bar moisture content (12.1 percent) as determined by ASTM Method D3152 and presented in "Supplemental Geotechnical Properties of Native Materials" calculation (Attachment 5, Vol. I, Appendix K). This mean measured value was also evaluated for reasonableness using the Rawls and Brakensiek equation as presented in the NRC Regulatory Guide 3.64 (NRC 1989b). The calculated value is 12.4 percent, which agrees well with the

measured value of site-specific soils, or 9 percent. These data and calculations are summarized in Appendix B.

In-situ moisture content for weathered Mancos was not included in the calculation of the mean, as in-situ moisture contents are not representative of remolded weathered Mancos. Long-term moisture content of the remolded weathered Mancos are better represented by the calculated and measured 15 bar moisture content test values due to the significantly different fabric the material will have as placed in the cell cover.

Radon-Diffusion Coefficient

The radon-diffusion coefficient used in the RADON model can either be calculated within the model (based on an empirical relationship with degree of saturation and porosity) or input directly into the model using values measured from laboratory testing. However, the radon diffusion equations in the 1989 version of RADON are not consistent with the later equations based on a much larger set of data correlating radon diffusion with soil cover materials. Therefore, this evaluation calculated the layer specific radon diffusion coefficients based on equation 9 from Rogers and Nielson (1991) as described in the "Calculation" section, above. The applied diffusion coefficients are presented in Table 1. These calculations are presented in Appendix B.

Radon in Ambient Air

The ambient air radon concentrations above the radon-barrier layer are assumed to be zero (0) in absence of site-specific data.

Conclusion and Recommendations:

- Based on the model runs developed in this evaluation, both design approaches are capable of meeting the requisite reasonable assurance of providing long-term control of radon flux to the specific average of 20 pCi/m^2/sec.
- As shown in Table 1, the compacted-clay radon barrier of the UMTRA checklist-type cover under the modeled conditions can vary from 0.9 to 3.9 ft, depending on the thickness of the interim cover. Model runs UMTRA 1a through UMTRA 1d varied the thickness of the interim cover from 1 ft to 7 ft in 2-ft increments. Figure 3 illustrates the relationship between interim cover thickness and calculated compacted clay radon barrier thickness. These data are also summarized in Appendix B.
- The compacted-clay radon barrier of the UMTRA checklist-type cover is relatively insensitive to the long-term moisture content of the tailings. Model run UMTRA 3a used a long-term tailings moisture contents of 10 percent and resulted in essentially no change in calculated cover thickness, indicating that potential drying of the contaminated materials below the anticipated baseline moisture content of 15 percent would not result in radon flux in excess of the standard. In addition, Model run UMTRA 3a used a long-term tailings moisture content of 20 percent and resulted in 8 percent decrease in the calculated radon barrier thickness.
- The alternative cover radon barrier thickness is calculated to be 9.3 ft, assuming a 1-ft-thick interim cover. The interim cover materials and the alternative cover materials are essentially the same and are to be placed to essentially the same conditions. Therefore, the relationship between interim cover thickness and calculated alternative cover radon barrier thickness is of little value, and no sensitivity runs to evaluate this relationship were performed.
- Like the UMTRA checklist cover, the alternative cover radon barrier is also relatively insensitive to the long-term moisture content of the tailings. Model run Alt 1b used a long-term tailings moisture contents of 10 percent and resulted in an approximate 1 percent increase in calculated cover thickness, indicating that potential drying of the contaminated materials below the anticipated baseline moisture content of 15 percent would not significantly result in radon flux in excess of the standard. In addition, Model run Alt 1c used a long-term tailings moisture content of 20 percent and resulted in 7 percent decrease in the calculated radon barrier thickness.

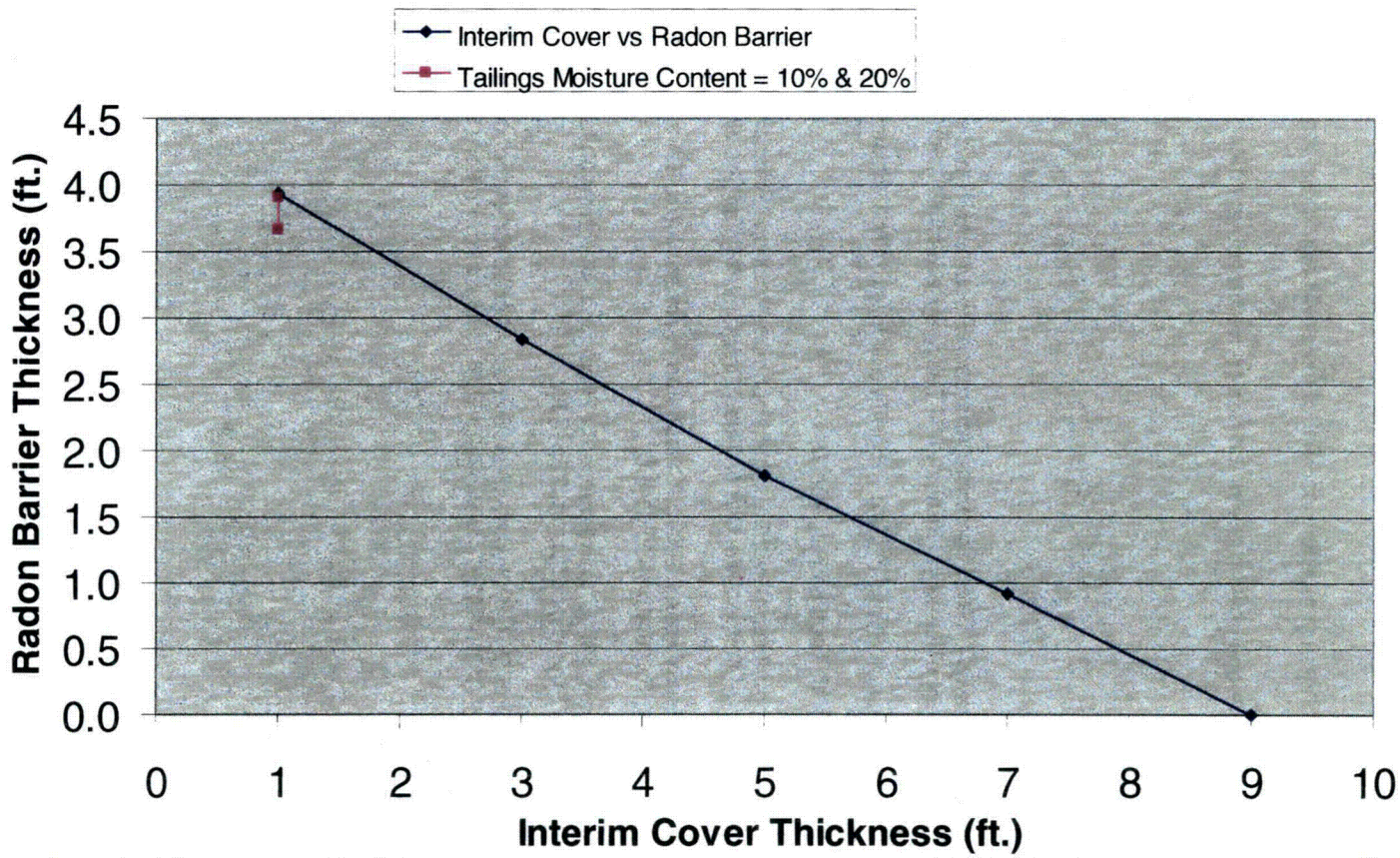

Figure 3. UMTRA Cover Design: Radon Barrier Thickness vs. Interim Cover Thickness

- Because the geometry and material properties (e.g., activity, grain size distribution, etc.) of contaminated materials placed in the cell may differ from that considered herein, it is recommended that three actions occur during construction and prior to placement of the radon barrier:
  - Additional testing of Ra-226 activity for the contaminated materials placed in the upper 10 ft of the cell.
  - Additional testing of long-term moisture content of materials stockpiled for construction of the radon barrier.
  - The radon barrier be re-optimized if any of the design assumptions differ from those considered herein.

Computer Source:

See NRC 1989a, below.

References:

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NRC (Nuclear Regulatory Commission), 1989b. *Calculation of Radon Flux Attenuation by Earthen Uranium Mill Tailings Covers,* Regulatory Guide 3.64.

Rogers, V.C., and K.K. Nielson, 1991. "Correlations for Predicting Air Permeabilities and ^{222}Rn Diffusion Coefficients of Soils," *Health Physics*, 61(2), pp. 235–230.

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Appendix A

RADON Model Output Files

-----*****! RADON !*****-----

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RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS ARE CALCULATED FOR MULTIPLE LAYERS

OUTPUT FILE: Alt 1a

DESCRIPTION: alternative cover, mean input values, 1-ft thick interim cover

CONSTANTS

RADON DECAY CONSTANT .0000021 s^-1
RADON WATER/AIR PARTITION COEFFICIENT .26
DEFAULT SPECIFIC GRAVITY OF COVER & TAILINGS 2.65

GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS 3
DEFAULT RADON FLUX LIMIT 20 pCi m^-2 s^-1
NO. OF THE LAYER TO BE OPTIMIZED 3
DEFAULT SURFACE RADON CONCENTRATION 0 pCi l^-1
SURFACE FLUX PRECISION .001 pCi m^-2 s^-1

LAYER INPUT PARAMETERS

LAYER 1 Tailings

THICKNESS 500 cm
POROSITY .44
MEASURED MASS DENSITY 1.57 g cm^-3
MEASURED RADIUM ACTIVITY 868 pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT .35
CALCULATED SOURCE TERM CONCENTRATION 2.276D-03 pCi cm^-3 s^-1
WEIGHT % MOISTURE 15 %
MOISTURE SATURATION FRACTION .535
MEASURED DIFFUSION COEFFICIENT .01044 cm^2 s^-1

LAYER 2 Interim Cover

THICKNESS 30.5 cm
POROSITY .38
MEASURED MASS DENSITY 1.66 g cm^-3
MEASURED RADIUM ACTIVITY 1.95 pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT .35
CALCULATED SOURCE TERM CONCENTRATION 6.261D-06 pCi cm^-3 s^-1
WEIGHT % MOISTURE 9 %
MOISTURE SATURATION FRACTION .393
MEASURED DIFFUSION COEFFICIENT .01637 cm^2 s^-1

LAYER 3 Radon Barrier

THICKNESS 10 cm
POROSITY .38
MEASURED MASS DENSITY 1.66 g cm^-3
MEASURED RADIUM ACTIVITY 1.95 pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT .35
CALCULATED SOURCE TERM CONCENTRATION 6.261D-06 pCi cm^-3 s^-1
WEIGHT % MOISTURE 9 %
MOISTURE SATURATION FRACTION .393
MEASURED DIFFUSION COEFFICIENT .01637 cm^2 s^-1

DATA SENT TO THE FILE `RNDATA' ON DRIVE A:

N	F01	CN1	ICOST	CRITJ	ACC
3	-1.000D+00	0.000D+00	3	2.000D+01	1.000D-03

LAYER	DX	D	P	Q	XMS	RHO
1	5.000D+02	1.044D-02	4.400D-01	2.276D-03	5.352D-01	1.570
2	3.050D+01	1.637D-02	3.800D-01	6.261D-06	3.932D-01	1.660
3	1.000D+01	1.637D-02	3.800D-01	6.261D-06	3.932D-01	1.660

BARE SOURCE FLUX FROM LAYER 1: 7.056D+02 pCi m^-2 s^-1

RESULTS OF THE RADON DIFFUSION CALCULATIONS

LAYER	THICKNESS (cm)	EXIT FLUX (pCi m^-2 s^-1)	EXIT CONC. (pCi l^-1)
1	5.000D+02	3.943D+02	4.786D+05
2	3.050D+01	2.793D+02	3.984D+05
3	3.038D+02	1.998D+01	0.000D+00

-----*****! RADON !*****-----

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RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS ARE CALCULATED FOR MULTIPLE LAYERS

OUTPUT FILE: Alt 1b

DESCRIPTION: alternative cover, Sensitivity run, mean input values, Tailings moisture content = 10%

CONSTANTS

RADON DECAY CONSTANT .0000021 s^-1
RADON WATER/AIR PARTITION COEFFICIENT .26
DEFAULT SPECIFIC GRAVITY OF COVER & TAILINGS 2.65

GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS 3
DEFAULT RADON FLUX LIMIT 20 pCi m^-2 s^-1
NO. OF THE LAYER TO BE OPTIMIZED 3
DEFAULT SURFACE RADON CONCENTRATION 0 pCi l^-1
SURFACE FLUX PRECISION .001 pCi m^-2 s^-1

LAYER INPUT PARAMETERS

LAYER 1 Tailings

THICKNESS 500 cm
POROSITY .44
MEASURED MASS DENSITY 1.57 g cm^-3
MEASURED RADIUM ACTIVITY 707 pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT .35
CALCULATED SOURCE TERM CONCENTRATION 1.854D-03 pCi cm^-3 s^-1
WEIGHT % MOISTURE 10 %
MOISTURE SATURATION FRACTION .357
MEASURED DIFFUSION COEFFICIENT .01873 cm^2 s^-1

LAYER 2 Interim Cover

THICKNESS 30.5 cm
POROSITY .38
MEASURED MASS DENSITY 1.66 g cm^-3
MEASURED RADIUM ACTIVITY 1.9 pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT .35
CALCULATED SOURCE TERM CONCENTRATION 6.100D-06 pCi cm^-3 s^-1
WEIGHT % MOISTURE 9 %
MOISTURE SATURATION FRACTION .393
MEASURED DIFFUSION COEFFICIENT .01629 cm^2 s^-1

LAYER 3 Radon Barrier

THICKNESS 10 cm
POROSITY .38
MEASURED MASS DENSITY 1.66 g cm^-3
MEASURED RADIUM ACTIVITY 1.9 pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT .35
CALCULATED SOURCE TERM CONCENTRATION 6.100D-06 pCi cm^-3 s^-1
WEIGHT % MOISTURE 9 %
MOISTURE SATURATION FRACTION .393
MEASURED DIFFUSION COEFFICIENT .01629 cm^2 s^-1

DATA SENT TO THE FILE `RNDATA' ON DRIVE A:

N	F01	CN1	ICOST	CRITJ	ACC
3	-1.000D+00	0.000D+00	3	2.000D+01	1.000D-03

LAYER	DX	D	P	Q	XMS	RHO
1	5.000D+02	1.873D-02	4.400D-01	1.854D-03	3.568D-01	1.570
2	3.050D+01	1.629D-02	3.800D-01	6.100D-06	3.932D-01	1.660
3	1.000D+01	1.629D-02	3.800D-01	6.100D-06	3.932D-01	1.660

BARE SOURCE FLUX FROM LAYER 1: 7.666D+02 pCi m^-2 s^-1

RESULTS OF THE RADON DIFFUSION CALCULATIONS

LAYER	THICKNESS (cm)	EXIT FLUX (pCi m^-2 s^-1)	EXIT CONC. (pCi l^-1)
1	5.000D+02	3.358D+02	4.981D+05
2	3.050D+01	2.377D+02	3.400D+05
3	2.885D+02	1.998D+01	0.000D+00

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RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS ARE CALCULATED FOR MULTIPLE LAYERS

OUTPUT FILE: Alt 1c

DESCRIPTION: alternative cover, Sensitivity run, mean input values, Tailings moisture content = 20%

CONSTANTS

RADON DECAY CONSTANT .0000021 s^-1
RADON WATER/AIR PARTITION COEFFICIENT .26
DEFAULT SPECIFIC GRAVITY OF COVER & TAILINGS 2.65

GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS 3
DEFAULT RADON FLUX LIMIT 20 pCi m^-2 s^-1
NO. OF THE LAYER TO BE OPTIMIZED 3
DEFAULT SURFACE RADON CONCENTRATION 0 pCi l^-1
SURFACE FLUX PRECISION .001 pCi m^-2 s^-1

LAYER INPUT PARAMETERS

LAYER 1 Tailings

THICKNESS 500 cm
POROSITY .44
MEASURED MASS DENSITY 1.57 g cm^-3
MEASURED RADIUM ACTIVITY 707 pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT .35
CALCULATED SOURCE TERM CONCENTRATION 1.854D-03 pCi cm^-3 s^-1
WEIGHT % MOISTURE 20 %
MOISTURE SATURATION FRACTION .714
MEASURED DIFFUSION COEFFICIENT .003541 cm^2 s^-1

LAYER 2 Interim Cover

THICKNESS 30.5 cm
POROSITY .38
MEASURED MASS DENSITY 1.66 g cm^-3
MEASURED RADIUM ACTIVITY 1.9 pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT .35
CALCULATED SOURCE TERM CONCENTRATION 6.100D-06 pCi cm^-3 s^-1
WEIGHT % MOISTURE 9 %
MOISTURE SATURATION FRACTION .393
MEASURED DIFFUSION COEFFICIENT .01629 cm^2 s^-1

LAYER 3 Radon Barrier

THICKNESS 10 cm
POROSITY .38
MEASURED MASS DENSITY 1.66 g cm^-3
MEASURED RADIUM ACTIVITY 1.9 pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT .35
CALCULATED SOURCE TERM CONCENTRATION 6.100D-06 pCi cm^-3 s^-1
WEIGHT % MOISTURE 9 %
MOISTURE SATURATION FRACTION .393
MEASURED DIFFUSION COEFFICIENT .01629 cm^2 s^-1

DATA SENT TO THE FILE `RNDATA' ON DRIVE A:

N	F01	CN1	ICOST	CRITJ	ACC
3	-1.000D+00	0.000D+00	3	2.000D+01	1.000D-03

LAYER	DX	D	P	Q	XMS	RHO
1	5.000D+02	3.541D-03	4.400D-01	1.854D-03	7.136D-01	1.570
2	3.050D+01	1.629D-02	3.800D-01	6.100D-06	3.932D-01	1.660
3	1.000D+01	1.629D-02	3.800D-01	6.100D-06	3.932D-01	1.660

BARE SOURCE FLUX FROM LAYER 1: 3.350D+02 pCi m^-2 s^-1

RESULTS OF THE RADON DIFFUSION CALCULATIONS

LAYER	THICKNESS (cm)	EXIT FLUX (pCi m^-2 s^-1)	EXIT CONC. (pCi l^-1)
1	5.000D+02	2.461D+02	2.342D+05
2	3.050D+01	1.743D+02	2.494D+05
3	2.610D+02	1.998D+01	0.000D+00

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RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS ARE CALCULATED FOR MULTIPLE LAYERS

OUTPUT FILE: UMTRA 1a

DESCRIPTION: UMTRA Cover, mean input parameters, 1-ft thick interim cover

CONSTANTS

RADON DECAY CONSTANT .0000021 s^-1
RADON WATER/AIR PARTITION COEFFICIENT .26
DEFAULT SPECIFIC GRAVITY OF COVER & TAILINGS 2.65

GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS 3
DEFAULT RADON FLUX LIMIT 20 pCi m^-2 s^-1
NO. OF THE LAYER TO BE OPTIMIZED 3
DEFAULT SURFACE RADON CONCENTRATION 0 pCi l^-1
SURFACE FLUX PRECISION .001 pCi m^-2 s^-1

LAYER INPUT PARAMETERS

LAYER 1 Tailings

THICKNESS 500 cm
POROSITY .44
MEASURED MASS DENSITY 1.57 g cm^-3
MEASURED RADIUM ACTIVITY 707 pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT .35
CALCULATED SOURCE TERM CONCENTRATION 1.854D-03 pCi cm^-3 s^-1
WEIGHT % MOISTURE 15 %
MOISTURE SATURATION FRACTION .535
MEASURED DIFFUSION COEFFICIENT .01044 cm^2 s^-1

LAYER 2 Interim Cover

THICKNESS 30.5 cm
POROSITY .38
MEASURED MASS DENSITY 1.66 g cm^-3
MEASURED RADIUM ACTIVITY 1.9 pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT .35
CALCULATED SOURCE TERM CONCENTRATION 6.100D-06 pCi cm^-3 s^-1
WEIGHT % MOISTURE 9 %
MOISTURE SATURATION FRACTION .393
MEASURED DIFFUSION COEFFICIENT .01629 cm^2 s^-1

LAYER 3 Radon Barrier

THICKNESS 10 cm
POROSITY .33
MEASURED MASS DENSITY 1.77 g cm^-3
MEASURED RADIUM ACTIVITY 2.3 pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT .35
CALCULATED SOURCE TERM CONCENTRATION 9.067D-06 pCi cm^-3 s^-1
WEIGHT % MOISTURE 12 %
MOISTURE SATURATION FRACTION .644
MEASURED DIFFUSION COEFFICIENT .004636 cm^2 s^-1

DATA SENT TO THE FILE `RNDATA' ON DRIVE A:

N	F01	CN1	ICOST	CRITJ	ACC
3	-1.000D+00	0.000D+00	3	2.000D+01	1.000D-03

LAYER	DX	D	P	Q	XMS	RHO
1	5.000D+02	1.044D-02	4.400D-01	1.854D-03	5.352D-01	1.570
2	3.050D+01	1.629D-02	3.800D-01	6.100D-06	3.932D-01	1.660
3	1.000D+01	4.636D-03	3.300D-01	9.067D-06	6.436D-01	1.770

BARE SOURCE FLUX FROM LAYER 1: 5.748D+02 pCi m^-2 s^-1

RESULTS OF THE RADON DIFFUSION CALCULATIONS

LAYER	THICKNESS (cm)	EXIT FLUX (pCi m^-2 s^-1)	EXIT CONC. (pCi l^-1)
1	5.000D+02	2.496D+02	4.998D+05
2	3.050D+01	1.197D+02	4.967D+05
3	1.198D+02	1.999D+01	0.000D+00

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RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS ARE CALCULATED FOR MULTIPLE LAYERS

OUTPUT FILE: UMTRA 1b

DESCRIPTION: UMTRA Cover, Sensitivity run, mean input parameters, 3 feet thick interim cover

CONSTANTS

RADON DECAY CONSTANT .0000021 s^-1
RADON WATER/AIR PARTITION COEFFICIENT .26
DEFAULT SPECIFIC GRAVITY OF COVER & TAILINGS 2.65

GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS 3
DEFAULT RADON FLUX LIMIT 20 pCi m^-2 s^-1
NO. OF THE LAYER TO BE OPTIMIZED 3
DEFAULT SURFACE RADON CONCENTRATION 0 pCi l^-1
SURFACE FLUX PRECISION .001 pCi m^-2 s^-1

LAYER INPUT PARAMETERS

LAYER 1 Tailings

THICKNESS 500 cm
POROSITY .44
MEASURED MASS DENSITY 1.57 g cm^-3
MEASURED RADIUM ACTIVITY 707 pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT .35
CALCULATED SOURCE TERM CONCENTRATION 1.854D-03 pCi cm^-3 s^-1
WEIGHT % MOISTURE 15 %
MOISTURE SATURATION FRACTION .535
MEASURED DIFFUSION COEFFICIENT .01044 cm^2 s^-1

LAYER 2 Interim Cover

THICKNESS 91.5 cm
POROSITY .38
MEASURED MASS DENSITY 1.66 g cm^-3
MEASURED RADIUM ACTIVITY 1.9 pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT .35
CALCULATED SOURCE TERM CONCENTRATION 6.100D-06 pCi cm^-3 s^-1
WEIGHT % MOISTURE 9 %
MOISTURE SATURATION FRACTION .393
MEASURED DIFFUSION COEFFICIENT .01629 cm^2 s^-1

LAYER 3 Radon Barrier

THICKNESS 10 cm
POROSITY .33
MEASURED MASS DENSITY 1.77 g cm^-3
MEASURED RADIUM ACTIVITY 2.3 pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT .35
CALCULATED SOURCE TERM CONCENTRATION 9.067D-06 pCi cm^-3 s^-1
WEIGHT % MOISTURE 12 %
MOISTURE SATURATION FRACTION .644
MEASURED DIFFUSION COEFFICIENT .004636 cm^2 s^-1

DATA SENT TO THE FILE `RNDATA' ON DRIVE A:

N	F01	CN1	ICOST	CRITJ	ACC
3	-1.000D+00	0.000D+00	3	2.000D+01	1.000D-03

LAYER	DX	D	P	Q	XMS	RHO
1	5.000D+02	1.044D-02	4.400D-01	1.854D-03	5.352D-01	1.570
2	9.150D+01	1.629D-02	3.800D-01	6.100D-06	3.932D-01	1.660
3	1.000D+01	4.636D-03	3.300D-01	9.067D-06	6.436D-01	1.770

BARE SOURCE FLUX FROM LAYER 1: 5.748D+02 pCi m^-2 s^-1

RESULTS OF THE RADON DIFFUSION CALCULATIONS

LAYER	THICKNESS (cm)	EXIT FLUX (pCi m^-2 s^-1)	EXIT CONC. (pCi l^-1)
1	5.000D+02	3.037D+02	4.168D+05
2	9.150D+01	6.024D+01	2.422D+05
3	8.643D+01	2.001D+01	0.000D+00

```
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     RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS            ARE
CALCULATED FOR MULTIPLE LAYERS

OUTPUT FILE: UMTRA 1c

DESCRIPTION: UMTRA Cover, Sensitivity run, mean input parameters, 5 feet
thick              interim cover


       CONSTANTS

RADON DECAY CONSTANT            .0000021   s^-1
RADON WATER/AIR PARTITION COEFFICIENT   .26
DEFAULT SPECIFIC GRAVITY OF COVER & TAILINGS       2.65


       GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS        3
DEFAULT RADON FLUX LIMIT          20      pCi m^-2 s^-1
NO. OF THE LAYER TO BE OPTIMIZED      3
DEFAULT SURFACE RADON CONCENTRATION    0      pCi l^-1
SURFACE FLUX PRECISION           .001     pCi m^-2 s^-1


       LAYER INPUT PARAMETERS

LAYER 1    Tailings


THICKNESS                  500     cm
POROSITY                   .44
MEASURED MASS DENSITY           1.57     g cm^-3
MEASURED RADIUM ACTIVITY          707     pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT    .35
CALCULATED SOURCE TERM CONCENTRATION    1.854D-03  pCi cm^-3 s^-1
WEIGHT % MOISTURE             15      %
MOISTURE SATURATION FRACTION        .535
MEASURED DIFFUSION COEFFICIENT       .01044    cm^2 s^-1


LAYER 2    Interim Cover


THICKNESS                  152.5    cm
POROSITY                   .38
MEASURED MASS DENSITY           1.66     g cm^-3
MEASURED RADIUM ACTIVITY          1.9     pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT    .35
CALCULATED SOURCE TERM CONCENTRATION    6.100D-06  pCi cm^-3 s^-1
WEIGHT % MOISTURE             9      %
MOISTURE SATURATION FRACTION        .393
MEASURED DIFFUSION COEFFICIENT       .01629    cm^2 s^-1
```

LAYER 3 Radon Barrier

THICKNESS 10 cm
POROSITY .33
MEASURED MASS DENSITY 1.77 g cm^-3
MEASURED RADIUM ACTIVITY 2.3 pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT .35
CALCULATED SOURCE TERM CONCENTRATION 9.067D-06 pCi cm^-3 s^-1
WEIGHT % MOISTURE 12 %
MOISTURE SATURATION FRACTION .644
MEASURED DIFFUSION COEFFICIENT .004636 cm^2 s^-1

DATA SENT TO THE FILE `RNDATA' ON DRIVE A:

N	F01	CN1	ICOST	CRITJ	ACC
3	-1.000D+00	0.000D+00	3	2.000D+01	1.000D-03

LAYER	DX	D	P	Q	XMS	RHO
1	5.000D+02	1.044D-02	4.400D-01	1.854D-03	5.352D-01	1.570
2	1.525D+02	1.629D-02	3.800D-01	6.100D-06	3.932D-01	1.660
3	1.000D+01	4.636D-03	3.300D-01	9.067D-06	6.436D-01	1.770

BARE SOURCE FLUX FROM LAYER 1: 5.748D+02 pCi m^-2 s^-1

RESULTS OF THE RADON DIFFUSION CALCULATIONS

LAYER	THICKNESS (cm)	EXIT FLUX (pCi m^-2 s^-1)	EXIT CONC. (pCi l^-1)
1	5.000D+02	3.169D+02	3.965D+05
2	1.525D+02	3.339D+01	1.171D+05
3	5.511D+01	2.002D+01	0.000D+00

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RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS ARE CALCULATED FOR MULTIPLE LAYERS

OUTPUT FILE: UMTRA 1d

DESCRIPTION: UMTRA Cover, Sensitivity run, mean input parameters, 7 feet thick interim cover

CONSTANTS

RADON DECAY CONSTANT .0000021 s^-1
RADON WATER/AIR PARTITION COEFFICIENT .26
DEFAULT SPECIFIC GRAVITY OF COVER & TAILINGS 2.65

GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS 3
DEFAULT RADON FLUX LIMIT 20 pCi m^-2 s^-1
NO. OF THE LAYER TO BE OPTIMIZED 3
DEFAULT SURFACE RADON CONCENTRATION 0 pCi l^-1
SURFACE FLUX PRECISION .001 pCi m^-2 s^-1

LAYER INPUT PARAMETERS

LAYER 1 Tailings

THICKNESS 500 cm
POROSITY .44
MEASURED MASS DENSITY 1.57 g cm^-3
MEASURED RADIUM ACTIVITY 707 pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT .35
CALCULATED SOURCE TERM CONCENTRATION 1.854D-03 pCi cm^-3 s^-1
WEIGHT % MOISTURE 15 %
MOISTURE SATURATION FRACTION .535
MEASURED DIFFUSION COEFFICIENT .01044 cm^2 s^-1

LAYER 2 Interim Cover

THICKNESS 213.5 cm
POROSITY .38
MEASURED MASS DENSITY 1.66 g cm^-3
MEASURED RADIUM ACTIVITY 1.9 pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT .35
CALCULATED SOURCE TERM CONCENTRATION 6.100D-06 pCi cm^-3 s^-1
WEIGHT % MOISTURE 9 %
MOISTURE SATURATION FRACTION .393
MEASURED DIFFUSION COEFFICIENT .01629 cm^2 s^-1

LAYER 3 Radon Barrier

THICKNESS 10 cm
POROSITY .33
MEASURED MASS DENSITY 1.77 g cm^-3
MEASURED RADIUM ACTIVITY 2.3 pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT .35
CALCULATED SOURCE TERM CONCENTRATION 9.067D-06 pCi cm^-3 s^-1
WEIGHT % MOISTURE 12 %
MOISTURE SATURATION FRACTION .644
MEASURED DIFFUSION COEFFICIENT .004636 cm^2 s^-1

DATA SENT TO THE FILE `RNDATA' ON DRIVE A:

N	F01	CN1	ICOST	CRITJ	ACC
3	-1.000D+00	0.000D+00	3	2.000D+01	1.000D-03

LAYER	DX	D	P	Q	XMS	RHO
1	5.000D+02	1.044D-02	4.400D-01	1.854D-03	5.352D-01	1.570
2	2.135D+02	1.629D-02	3.800D-01	6.100D-06	3.932D-01	1.660
3	1.000D+01	4.636D-03	3.300D-01	9.067D-06	6.436D-01	1.770

BARE SOURCE FLUX FROM LAYER 1: 5.748D+02 pCi m^-2 s^-1

RESULTS OF THE RADON DIFFUSION CALCULATIONS

LAYER	THICKNESS (cm)	EXIT FLUX (pCi m^-2 s^-1)	EXIT CONC. (pCi l^-1)
1	5.000D+02	3.201D+02	3.916D+05
2	2.135D+02	2.276D+01	5.130D+04
3	2.790D+01	2.001D+01	0.000D+00

-----*****! RADON !*****-----

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RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS ARE CALCULATED FOR MULTIPLE LAYERS

OUTPUT FILE: UMTRA 2a

DESCRIPTION: UMTRA Cover, Sensitivity run, mean input parameters, frost protection layer contributes to radon attenuation

CONSTANTS

RADON DECAY CONSTANT .0000021 s^-1
RADON WATER/AIR PARTITION COEFFICIENT .26
DEFAULT SPECIFIC GRAVITY OF COVER & TAILINGS 2.65

GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS 4
DEFAULT RADON FLUX LIMIT 20 pCi m^-2 s^-1
NO. OF THE LAYER TO BE OPTIMIZED 3
DEFAULT SURFACE RADON CONCENTRATION 0 pCi l^-1
SURFACE FLUX PRECISION .001 pCi m^-2 s^-1

LAYER INPUT PARAMETERS

LAYER 1 Tailings

THICKNESS 500 cm
POROSITY .44
MEASURED MASS DENSITY 1.57 g cm^-3
MEASURED RADIUM ACTIVITY 707 pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT .35
CALCULATED SOURCE TERM CONCENTRATION 1.854D-03 pCi cm^-3 s^-1
WEIGHT % MOISTURE 15 %
MOISTURE SATURATION FRACTION .535
MEASURED DIFFUSION COEFFICIENT .01044 cm^2 s^-1

LAYER 2 Interim Cover

THICKNESS 30.5 cm
POROSITY .38
MEASURED MASS DENSITY 1.66 g cm^-3
MEASURED RADIUM ACTIVITY 1.9 pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT .35
CALCULATED SOURCE TERM CONCENTRATION 6.100D-06 pCi cm^-3 s^-1
WEIGHT % MOISTURE 9 %
MOISTURE SATURATION FRACTION .393
MEASURED DIFFUSION COEFFICIENT .01629 cm^2 s^-1

LAYER 3 Radon Barrier

THICKNESS 10 cm
POROSITY .33
MEASURED MASS DENSITY 1.77 g cm^-3
MEASURED RADIUM ACTIVITY 2.3 pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT .35
CALCULATED SOURCE TERM CONCENTRATION 9.067D-06 pCi cm^-3 s^-1
WEIGHT % MOISTURE 12 %
MOISTURE SATURATION FRACTION .644
MEASURED DIFFUSION COEFFICIENT .004636 cm^2 s^-1

LAYER 4 Frost Protection

THICKNESS 106.8 cm
POROSITY .38
MEASURED MASS DENSITY 1.66 g cm^-3
MEASURED RADIUM ACTIVITY 1.9 pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT .35
CALCULATED SOURCE TERM CONCENTRATION 6.100D-06 pCi cm^-3 s^-1
WEIGHT % MOISTURE 9 %
MOISTURE SATURATION FRACTION .393
MEASURED DIFFUSION COEFFICIENT .01629 cm^2 s^-1

DATA SENT TO THE FILE `RNDATA' ON DRIVE A:

N	F01	CN1	ICOST	CRITJ	ACC
4	-1.000D+00	0.000D+00	3	2.000D+01	1.000D-03

LAYER	DX	D	P	Q	XMS	RHO
1	5.000D+02	1.044D-02	4.400D-01	1.854D-03	5.352D-01	1.570
2	3.050D+01	1.629D-02	3.800D-01	6.100D-06	3.932D-01	1.660
3	1.000D+01	4.636D-03	3.300D-01	9.067D-06	6.436D-01	1.770
4	1.068D+02	1.629D-02	3.800D-01	6.100D-06	3.932D-01	1.660

BARE SOURCE FLUX FROM LAYER 1: 5.748D+02 pCi m^-2 s^-1

RESULTS OF THE RADON DIFFUSION CALCULATIONS

LAYER	THICKNESS (cm)	EXIT FLUX (pCi m^-2 s^-1)	EXIT CONC. (pCi l^-1)
1	5.000D+02	2.509D+02	4.978D+05
2	3.050D+01	1.217D+02	4.936D+05
3	8.172D+01	3.348D+01	3.043D+04
4	1.068D+02	2.000D+01	0.000D+00

```
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     RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS            ARE
CALCULATED FOR MULTIPLE LAYERS

OUTPUT FILE: UMTRA 3a

DESCRIPTION: UMTRA Cover, Sensitivity run, mean input parameters, tailings
             moisture content = 10%

       CONSTANTS

RADON DECAY CONSTANT              .0000021   s^-1
RADON WATER/AIR PARTITION COEFFICIENT   .26
DEFAULT SPECIFIC GRAVITY OF COVER & TAILINGS       2.65


       GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS         3
DEFAULT RADON FLUX LIMIT          20      pCi m^-2 s^-1
NO. OF THE LAYER TO BE OPTIMIZED      3
DEFAULT SURFACE RADON CONCENTRATION    0      pCi l^-1
SURFACE FLUX PRECISION           .001     pCi m^-2 s^-1


       LAYER INPUT PARAMETERS

LAYER 1    Tailings


THICKNESS                 500     cm
POROSITY                  .44
MEASURED MASS DENSITY          1.57     g cm^-3
MEASURED RADIUM ACTIVITY          707     pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT    .35
CALCULATED SOURCE TERM CONCENTRATION    1.854D-03  pCi cm^-3 s^-1
WEIGHT % MOISTURE             10      %
MOISTURE SATURATION FRACTION        .357
MEASURED DIFFUSION COEFFICIENT       .01873    cm^2 s^-1


LAYER 2    Interim Cover


THICKNESS                 30.5     cm
POROSITY                  .38
MEASURED MASS DENSITY          1.66     g cm^-3
MEASURED RADIUM ACTIVITY          1.9     pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT    .35
CALCULATED SOURCE TERM CONCENTRATION    6.100D-06  pCi cm^-3 s^-1
WEIGHT % MOISTURE              9      %
MOISTURE SATURATION FRACTION        .393
MEASURED DIFFUSION COEFFICIENT       .01629    cm^2 s^-1
```

LAYER 3 Radon Barrier

THICKNESS 10 cm
POROSITY .33
MEASURED MASS DENSITY 1.77 g cm^-3
MEASURED RADIUM ACTIVITY 2.3 pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT .35
CALCULATED SOURCE TERM CONCENTRATION 9.067D-06 pCi cm^-3 s^-1
WEIGHT % MOISTURE 12 %
MOISTURE SATURATION FRACTION .644
MEASURED DIFFUSION COEFFICIENT .004636 cm^2 s^-1

DATA SENT TO THE FILE `RNDATA' ON DRIVE A:

N	F01	CN1	ICOST	CRITJ	ACC
3	-1.000D+00	0.000D+00	3	2.000D+01	1.000D-03

LAYER	DX	D	P	Q	XMS	RHO
1	5.000D+02	1.873D-02	4.400D-01	1.854D-03	3.568D-01	1.570
2	3.050D+01	1.629D-02	3.800D-01	6.100D-06	3.932D-01	1.660
3	1.000D+01	4.636D-03	3.300D-01	9.067D-06	6.436D-01	1.770

BARE SOURCE FLUX FROM LAYER 1: 7.666D+02 pCi m^-2 s^-1

RESULTS OF THE RADON DIFFUSION CALCULATIONS

LAYER	THICKNESS (cm)	EXIT FLUX (pCi m^-2 s^-1)	EXIT CONC. (pCi l^-1)
1	5.000D+02	2.462D+02	6.007D+05
2	3.050D+01	1.181D+02	4.899D+05
3	1.191D+02	1.999D+01	0.000D+00

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RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS ARE CALCULATED FOR MULTIPLE LAYERS

OUTPUT FILE: UMTRA 3b

DESCRIPTION: UMTRA Cover, Sensitivity run, mean input parameters, tailings moisture content = 20%

CONSTANTS

RADON DECAY CONSTANT .0000021 s^-1
RADON WATER/AIR PARTITION COEFFICIENT .26
DEFAULT SPECIFIC GRAVITY OF COVER & TAILINGS 2.65

GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS 3
DEFAULT RADON FLUX LIMIT 20 pCi m^-2 s^-1
NO. OF THE LAYER TO BE OPTIMIZED 3
DEFAULT SURFACE RADON CONCENTRATION 0 pCi l^-1
SURFACE FLUX PRECISION .001 pCi m^-2 s^-1

LAYER INPUT PARAMETERS

LAYER 1 Tailings

THICKNESS 500 cm
POROSITY .44
MEASURED MASS DENSITY 1.57 g cm^-3
MEASURED RADIUM ACTIVITY 707 pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT .35
CALCULATED SOURCE TERM CONCENTRATION 1.854D-03 pCi cm^-3 s^-1
WEIGHT % MOISTURE 20 %
MOISTURE SATURATION FRACTION .714
MEASURED DIFFUSION COEFFICIENT .003541 cm^2 s^-1

LAYER 2 Interim Cover

THICKNESS 30.5 cm
POROSITY .38
MEASURED MASS DENSITY 1.66 g cm^-3
MEASURED RADIUM ACTIVITY 1.9 pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT .35
CALCULATED SOURCE TERM CONCENTRATION 6.100D-06 pCi cm^-3 s^-1
WEIGHT % MOISTURE 9 %
MOISTURE SATURATION FRACTION .393
MEASURED DIFFUSION COEFFICIENT .01629 cm^2 s^-1

LAYER 3 Radon Barrier

THICKNESS 10 cm
POROSITY .33
MEASURED MASS DENSITY 1.77 g cm^-3
MEASURED RADIUM ACTIVITY 2.3 pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT .35
CALCULATED SOURCE TERM CONCENTRATION 9.067D-06 pCi cm^-3 s^-1
WEIGHT % MOISTURE 12 %
MOISTURE SATURATION FRACTION .644
MEASURED DIFFUSION COEFFICIENT .004636 cm^2 s^-1

DATA SENT TO THE FILE `RNDATA' ON DRIVE A:

N	F01	CN1	ICOST	CRITJ	ACC
3	-1.000D+00	0.000D+00	3	2.000D+01	1.000D-03

LAYER	DX	D	P	Q	XMS	RHO
1	5.000D+02	3.541D-03	4.400D-01	1.854D-03	7.136D-01	1.570
2	3.050D+01	1.629D-02	3.800D-01	6.100D-06	3.932D-01	1.660
3	1.000D+01	4.636D-03	3.300D-01	9.067D-06	6.436D-01	1.770

BARE SOURCE FLUX FROM LAYER 1: 3.350D+02 pCi m^-2 s^-1

RESULTS OF THE RADON DIFFUSION CALCULATIONS

LAYER	THICKNESS (cm)	EXIT FLUX (pCi m^-2 s^-1)	EXIT CONC. (pCi l^-1)
1	5.000D+02	2.103D+02	3.287D+05
2	3.050D+01	1.011D+02	4.179D+05
3	1.117D+02	1.998D+01	0.000D+00

Appendix B

Supporting Calculations and Data

Table B–1. Moab Project, Crescent Junction Native Materials Index Test Results Summary

Geotechnical Testing Data from the "Geotechnical Properties of Native Materials" Calculation (RAP Attachment 5, Appendix E)

Sample	No.	Field Description	Test Depth (ft)	Natural Moisture (%)	Dry Density (pcf)	Liquid Limit (%)	Plasticity Index (%)	Passing No. 200 (%)	Specific Gravity	□max (Modified Proctor) (pcf)	□max (Modified Proctor) (g/cc)	w_{opt} (Modified Proctor) (%)	Sieve			Hydrometer		% Organic Matter	Double Hydro-meter	Ra-226 (pCi/g)
													% Gravel	% Sand	% Fines	% silt	% clay			
BH	031	Clay, sandy, silty L/SC)	12	8.2	96.0	24	4	50												
BH	007	Clay, silty sandy (CL)	7	4.9		23	8	94												
BH	007	Clay, silty sandy (CL)	10.5	4.5	100.0	21	9	62												
BH	045	Clay, silty sandy (CL)	1.5	4.6	84.0	19	7	57												
BH	005	Clay, silty sandy (CL)	2	4.2	91.0	21	4	69												
BH	011	Clay, silty sandy (CL)	2	6.1	83.0	22	9	78												
BH	064	Clay, silty, sandy (CL)	2	12.4	95.0	34	5	74												
BH	068	Clay, silty, sandy (CL)	2	4.2	94.0	21	6	36												
BH	092	Clay, silty, sandy (CL)	2	5.7	87.0	22	9	63												
BH	013	Clay, silty sandy (CL)	2.5	5.8	89.0	24	9	70												
BH	080	Clay, silty, sandy (CL)	3	2.8	95.0	19	5	53												
BH	023	Clay, silty sandy (CL)	3.5	6.0		25	8	72												
BH	043	Clay, silty, sandy (CL)	3.5	6.1	90.0	25	8	53												
BH	051	Clay, silty, sandy (CL)	3.5	3.8	85.0	20	6	57												
BH	066	Clay, silty, sandy (CL)	3.5	4.7	90.0	21	5	53												
BH	100	Clay, silty sandy (CL)	4	8.0		25	5	69												
BH	009	Clay, silty sandy (CL)	4	6.6	83.0	24	9	74												
BH	062	Clay, silty, sandy (CL)	4	7.6	103.0	29	10	69												
BH	094	Clay, silty, sandy (CL)	4	12.2	89.0	31	10	61												
BH	031	Clay, silty, sandy (CL)	5.5	7.0	87.0	25	9	85												
BH	025	Clay, silty, sandy (CL)	6	4.9	89.0	24	9	59												
BH	007	Clay, silty sandy (CL)	6.5	6.5		23	5													
BH	045	Clay, silty, sandy (CL)	6.5	8.6	98.0	32	9	78												
BH	049	Clay, silty, sandy (CL)	6.5	6.0	83.0	20	6	62												
BH	029	Clay, silty, sandy (CL)	7	13.4	77.0	23	6	77												
BH	078	Clay, silty, sandy (CL)	7	5.7	85.0	23	7	70												
BH	080	Clay, silty, sandy (CL)	7	6.0	89.0	24	7	65												
BH	095	Clay, silty, sandy (CL)	7	6.5	85.0	23	7	46												
BH	049	Clay, silty, sandy (CL)	12	5.4	102.0	19	5	80												
BH	082	Clay, silty, sandy (CL)	12	4.7	91.0	21	8	79												
BH	025	Clay, silty sandy (CL)	16.5	7.3	106.0	21	6	66												
BH	027	Clay, silty, sandy (CL)	16.5	8.4	108.0	24	11	87												
BH	094	Clay, silty, sandy (CL)	17	7.1	102.0	20	5	37												
TP	153	Clay, silty, sandy (CL)	3.5	5.7		23	5	72	2.68	120.5	1.93	12.5	0	27	73	60	13			
TP	154	Clay, silty, sandy (CL)	4	7.6		22	4	83		123.0	1.97	12.0	0	16	84	62	22	0.5	79	2.3
TP	151	Clay, silty, sandy (CL)	4.5	5.6		24	5	66		118.5	1.90	13.0	4	30	66					
TP	152	Clay, silty, sandy (CL)	7.5	4.3		26	9	74	2.64	121.0	1.94	13.5	0	25	75	59	16			1.9
TP	154	Clay, silty, sandy (CL)	12	2.7		20	3	63	2.65	122.5	1.96	12.0	0	33	67	40	27	0.2	62	1.6
TP	156	Clay, silty, sandy (CL)	12	2.7		19	2	64	2.64	124.5	1.99	11.0	0	35	65	39	26	0.1	83	2.1
TP	152	Clay, silty, sandy (CL)	15	2.9		21	3	84	2.63	128.0	2.05	10.5	49	22	29	15	14	0.2		1.4

Sample	No.	Field Description	Test Depth (ft)	Natural Moisture (%)	Dry Density (pcf)	Liquid Limit (%)	Plasticity Index (%)	Passing No. 200 (%)	Specific Gravity	□max (Modified Proctor) (pcf)	□max (Modified Proctor) (g/cc)	w_{opt} (Modified Proctor) (%)	Sieve			Hydrometer		% Organic Matter	Double Hydro-meter	Ra-226 (pCi/g)
													% Gravel	% Sand	% Fines	% silt	% clay			
TP	156	Clay, silty, sandy (CL)	4-5	7.2			7	69	2.82	120.0	1.92	11.5	1	29	70	54	16		61	
TP liner	156	Eolian	12.25	7.9	88.0	0	0	50												
TP liner	154	Eolian	13	5.7	82.0	20	2	69												
TP	156	Fluvial/eolian	15															0.2		
BH	027	Sand, clayey, silty (SC)	4	5.9		24	3	44												
BH	099	Sand, clayey, silty (C/SM)	2.5	4.8	87.0	18	3	47												
BH	011	Sand, silty gravelly	11.5	2.6		21	4	19												
BH	013	Sandy silt	7	8.3	113.4	0	0	43												
TP	155	Sheetwash	4															0.4		
TP liner	156	Sheetwash	3.5	9.5	89.0	0	0	79												
TP liner	154	Sheetwash	4	9.5	81.0	22	5	81												
TP liner	156	Sheetwash	7.25	6.0	91.0			63										0.3		
TP	153	Silt, sandy, clayey (ML)	8.5	4.4		0	0	67	2.65	118.0	1.89	11.0	1	32	67	52	15			
BH	064	Weathered shale	3.5	10.0	109.0	31	19	86												
BH	043	Weathered shale	6	5.0	93.0	24	16	47												
BH	009	Weathered shale	6.5	6.6	107.2	28	9	84												
BH	066	Weathered shale	7	12.3	112.0	31	10	90												
BH	079	Weathered shale	10.5	4.4		25	10	78												
BH	033	Weathered shale	10.75	6.7	117.0	34	18	82												
BH	005	Weathered shale	11	6.0	118.0	25	10	79												
BH	090	Weathered shale	12	8.2	99.0	22	5	55												
BH	092	Weathered shale	12	7.7	71.0	26	6	71												
BH	026	Weathered shale	15.5	5.7		24	10	71												
BH	011	Weathered shale	16	7.9	119.4	37	20	96												
BH	082	Weathered shale	17	7.1	118.0	34	14	93												
BH	094	Weathered shale	21.5	6.8	112.0	21	4	33												
BH	029	weathered shale	27	6.4	81.0	29	10	81												
TP	154	weathered shale	20	5.5		38	20	95	2.73	120.5	1.93	13.0	0	5	95	55	40		62	1.6
TP	156	Weathered shale	22			25	7	84	2.56	127.5	2.04	11.0	2	14	84	53	31	0.4	86	3.0
TP	152	Weathered shale	23	5.5		33	12	97		121.0	1.94	12.0	0	3	97	55	42			
		Weathered Mancos Shale	**Max**	12.3	119.4	38.0	20.0	97.0	2.73	127.5	2.04	13.0	2.0	14.0	97.0	55.0	42.0	0.4	86.0	3.0
			Min	4.4	71.0	21.0	4.0	33.0	2.56	120.5	1.93	11.0	0.0	3.0	84.0	53.0	31.0	0.4	62.0	1.6
			Mean	**7.0**	**104.7**	**28.6**	**11.8**	**77.8**	**2.65**	**123.0**	**1.97**	**12.0**	**0.7**	**7.3**	**92.0**	**54.3**	**37.7**	**0.4**	**74.0**	**2.3**
			Median	6.7	110.5	28.0	10.0	82.0	2.65	121.0	1.94	12.0	0.0	5.0	95.0	55.0	40.0	0.4	74.0	2.3
			count	16	12	17	17	17	2	3	3	3	3	3	3	3	3	1	2	2
		Alluvium	**Max**	13.4	113.4	34.0	11.0	94.0	2.82	128.0	2.05	13.5	49.0	35.0	84.0	62.0	27.0	0.5	83.0	2.3
		(All Data w/out Weath. Mancos Shale)	**Min**	2.6	77.0	0.0	0.0	19.0	2.63	118.0	1.89	10.5	0.0	16.0	29.0	15.0	13.0	0.1	61.0	1.4
			Mean	**6.3**	**91.3**	**21.1**	**5.8**	**64.8**	**2.67**	**121.8**	**1.95**	**11.9**	**6.1**	**27.7**	**66.2**	**47.6**	**18.6**	**0.3**	**71.3**	**1.9**
			Median	6.0	89.0	22.0	6.0	66.5	2.65	121.0	1.94	12.0	0.0	29.0	67.0	53.0	16.0	0.2	70.5	1.9
			Count	51	36	49	50	50	7	9	9	9	9	9	9	8	8	7	4	5

liner = Brass Liner samples collected in pit side walls

Table B–2. Radon Barrier Design, RAECOM Model Runs, Summary of Key Parameters

Porosity f (G_s)	No. of Samples	Mean Specific Gravity (G_s)	No. of Samples	Mean Dry Density (g/cc)	Porosity
Alluvium	7	2.67	9	1.66	0.38
Alluvium (in-situ)	7	2.67	36	1.46	0.45
Weathered Mancos	2	2.65	3	1.77	0.33
Tailings	5	2.8	5	1.57	0.44

Long-term Gravimetric Moisture Content (%)	No. of Samples	In Situ	Rawls & Brakensiek[3]	No. of Samples	ASTM D3151 15 bar tests	Used
			Avg		Avg	
Alluvium	51	6.3	7.5	20	9.0	91
Weathered Mancos	16	7.0	12.4	12	12.1	122
Tailings	NA	NA	Not Available	Not Available	Not Available	10 ,15, 20

Ra-226 Activity (pCi/g)	No. of Samples	Mean
Alluvium	5	1.9
Weathered Mancos	2	2.3
Tailings & Contaminated Materials	94	565

Cover Layer	Calculated Diffusion Coefficient (cm^2/s)
Tailings (both cover designs)	1.044E-02
Interim Cover (both cover designs)	1.629E-02
Alternative Cover Radon Barrier	1.629E-02
Frost Protection Layer (Alluvium in-situ)	2.869E-02
UMTRA Cover Radon Barrier	4.636E-03

Note:
NA = Not applicable
Mean Dry density as placed for alluvium = 85% of Maximum Dry Density from Modified Proctor Density Tests
Mean Dry density as placed for weathered Mancos = 90% of Maximum Dry Density from Modified Proctor Density Tests
Mean Dry density as placed for tailings = 90% of Maximum Dry Density from Standard Proctor Density Tests
Porosity (n) is calculated form Gs and Dry density by n = 1 - Dry density/(Gs x Unit weight of water)
Unit weight of water is = 1 g/cc
Mean values developed from raw data presented in Table 1

[1] Long-term moisture content of Alluvium based on 20 ASTM D5131 15 Bar moisture tests, calculated value using Rawls & Brakensiek equation (in NRC 1989b) is approximately 1 standard deviation from the mean test value ands is considered confirmatory of the mean value.
[2] In-situ moisture content for weathered Mancos is not included in the calculation of the mean long-term moisture as in-situ moisture contents are not representative of remolded weathered Mancos. Remolded weathered Mancos long-term moisture contents are better represented by the calculated and 15 bar test values due to the significantly different fabric of the material as placed in the cell cover.
[3] Rawls & Brakensiek equation (in NRC 1989b) based on mean values for each material type.

Table B–3. Moab Project, Crescent Junction Disposal Cell Tailings and Other Contaminated Materials Ra-226

No. of Samples	Sample	Depth	Ra-226 Activity (pCi/g)	Material Type	No. of Samples	Sample	Depth	Ra-226 Activity (pCi/g)	Material Type
Transitional Tailings					**Slimes**				
1	BH-701	0-20	400.9	trans	1	PB-2	34-36	782	slime
2	BH-701	20-40	480.8	trans	2	PB-2	54-56	2070	slime
3	BH-703	0-20	457.6	trans	3	437	40.75-41	2194.9	slime
4	BH-703	20-40	610.1	trans	4	438	72.75-73	1891.7	slime
5	BH-705	20-40	616.9	trans	5	439	82-82.25	2157.5	slime
6	BH-709	20-40	546.6	trans	6	AR-10	75-86	588.8	slime
7	BH-713	20-36.5	631.1	trans	7	BH-700	30-60	466.5	slime
8	BH-715	20-40	278.9	trans	8	BH-701	40-60	758.9	slime
9	BH-718	0-20	717.8	trans	9	BH-701	60-80	1215.8	slime
10	BH-718	20-40	917.3	trans	10	BH-703	40-60	1396.3	slime
11	BH-719	0-20	357.4	trans	11	BH-703	65-73	1333	slime
12	PB-1	39-41	335	trans	12	BH-705	40-60	1232.8	slime
13	PB-1	44-46	464	trans	13	BH-709	40-60	1195.3	slime
14	PB-1	49-51	566	trans	14	BH-709	60-65	1205.8	slime
15	PB-1	64-66	418	trans	15	BH-715	0-20	1000.5	slime
16	PB-1	74-76	605	trans	16	BH-715	40-60	1225.9	slime
17	PB-1	76-81	220	trans	17	BH-715	60+	1518.6	slime
18	PB-1	81-83	201	trans	18	BH-718	40-43	1601.7	slime
19	PB-2	9-11	803	trans	19	BH-719	20-40	1117.7	slime
20	PB-2	29-31	192	trans	20	BH-719	40-51.5	1669.7	slime
21	PB-2	39-41	325	trans	21	PB-1	59-61	236	slime
22	PB-2	49-51	816	trans	22	PB-1	69-71	748	slime
23	PB-2	59-61	781	trans	23	PB-1	83-85	1600	slime
24	PB-2	61-66	711	trans	24	PB-1	85-87	2040	slime
25	PB-2	69-71	614	trans	25	PB-1	87-89	1640	slime
26	AR-4S	20-21	530.6	unconsol	26	PB-1	89-91	1690	slime
27	AR-8	21-22	594.8	unconsol	27	PB-2	44-46	1740	slime
28	AR-8	25-35	639.9	unconsol	28	PB-2	71-73	1390	slime
					29	PB-2	73-75	1280	slime
Sands					30	PB-2	75-77	1130	slime
1	Impound 2	imp	12.7	imp	31	PB-2	77-79	1240	slime
2	Impound 3	imp	87.4	imp	32	PB-2	79-81	1550	slime
3	AR-10	3-4	311.8	sand	33	PB-2	84-86	1620	slime
4	AR-10	20-25	98	sand					
5	AR-6	35-40	100.4	sand	**Alluvium**				
6	AR-9	10-11	320.2	sand	1	437	44-44.25	135.5	alluvium
7	AR-9	30-32	87.2	sand	2	438	74-74.25	134.3	alluvium
8	BH-705	0-20	186.2	sand	3	438	75-75.25	92.8	alluvium
9	BH-709	0-20	289.9	sand	4	438	76-76.25	31.3	alluvium
10	PB-1	9-11	215	sand	5	438	78-78.25	118.4	alluvium
11	PB-1	14-16	99.7	sand	6	439	87-87.25	23.9	alluvium
12	PB-1	19-21	202	sand	7	AR-5	0-1	84.3	alluvium
13	PB-1	24-26	148	sand	8	AR-6	0-1	17.3	alluvium
14	PB-1	29-31	153	sand	9	PB-1	94-96	208	alluvium
15	PB-1	34-36	447	sand	10	PB-2	89-91	1.83	alluvium

Table B–3 (continued). Moab Project, Crescent Junction Disposal Cell Tailings and Other Contaminated Materials Ra-226

No. of Samples	Sample	Depth	Ra-226 Activity (pCi/g)	Material Type
16	PB-1	54-56	849	sand
17	PB-2	14-16	269	sand
18	PB-2	19-21	150	sand
19	PB-2	24-26	100	sand
20	AR-2	5.5-10	786.5	silt
21	AR-7	20-25	562.2	silt
22	AR-9	50-55	543.6	silt
23	AR-9	60-62	239.1	silt

	All Data	Sands	Transitional Tailings	Slimes	Off Pile & Sub Pile & Interim Cover Materials (Alluvium)
Max:	2,195	849	917	2,195	208
Min:	2	13	192	236	2
Average:	707	**272**	**530**	**1,349**	**85**
Median:	564	202	556	1,333	89
Std Dev.:	589	224	195	479	66
Count:	94	23	28	33	10
Material Volume (cy)	14,546,054	3,743,474	4,864,651	3,258,910	2,679,019
Volume %:	100%	26%	33%	22%	18%
Weighted Activity (pCi/g)	**565**	70	177	302	16

Table B–4. Moab Project, Crescent Junction Disposal Cell 15 Bar Moisture Content

Sample Description	Soil Type	% Moisture (15 Bar)		
TP-153, 8.5, A	Fluvial/Eolian	6.74	**All Data**	
TP-153, 8.5, A-R	Fluvial/Eolian	6.75	Maximum	14.0
TP-153, 8.5 B	Fluvial/Eolian	6.56	Minimum	6.4
TP-153, 8.5 B-R	Fluvial/Eolian	6.43	Mean	10.1
TP-152, 15, A	Fluvial/Eolian	8.53	Median	10.1
TP-152, 15, A-R	Fluvial/Eolian	8.52	St. Deviation	2.1
TP-152, 15, B	Fluvial/Eolian	8.61	Count	32
TP-152, 15, B-R	Fluvial/Eolian	8.62		
TP-153, 3.5, A	Sheetwash	10.86		
TP-153, 3.5, A-R	Sheetwash	10.6		
TP-153, 3.5 B	Sheetwash	10.49	**Sheetwash/Fluvial/Eolian**	
TP-153, 3.5 B-R	Sheetwash	10.52	Maximum	10.9
TP-152, 7.5 A	Sheetwash	10.08	Minimum	6.4
TP-152, 7.5 A-R	Sheetwash	10.19	Mean	9.0
TP-152, 7.5, B	Sheetwash	9.99	Median	9.0
TP-152, 7.5, B-R	Sheetwash	10.03	St. Deviation	1.4
TP-155, 5, A	Sheetwash	9.56	Count	20
TP-155, 5, A-R	Sheetwash	9.28		
TP-155, 5, B	Sheetwash	8.75		
TP-155, 5, B-R	Sheetwash	8.72		
TP-154, 20, A	Weathered Shale	12.1	**Weathered Shale**	
TP-154, 20, A-R	Weathered Shale	12.33	Maximum	14.0
TP-154, 20, B	Weathered Shale	12.19	Minimum	9.3
TP-154, 20, B-R	Weathered Shale	12.22	Mean	12.1
TP-152, 23, A	Weathered Shale	13.99	Median	12.2
TP-152, 23, A-R	Weathered Shale	13.73	St. Deviation	1.6
TP-152, 23, B	Weathered Shale	13.47	Count	12
TP-152, 23, B-R	Weathered Shale	13.56		
TP-156, 22, A	Weathered Shale	11.16		
TP-156, 22, A-R	Weathered Shale	11.16		
TP-156, 22, B	Weathered Shale	9.28		
TP-156, 22, B-R	Weathered Shale	9.52		

Note: values are gravimetric moisture content on a dry unit weight basis

Table B–5. Moab Project, Crescent Junction Disposal Cell Calculation of Radon Diffusion Coefficients Using Updated Equation (Rogers and Nielson, 1991)

Cover Layer	Mass Density (g/cm3)	Dry Density (pcf)	Long-Term Water Content (w)	Specific Gravity (G_s)	Porosity[1] (p)	Calculated Saturation[2] (S)	Calculated Diffusion Coefficient[3] (cm^2/s)
Tailings (both cover designs)	1.57	97.8	0.15	2.8	0.44	53.4%	1.044E-02
(moisture content = 10%)	1.57	97.8	0.10	2.8	0.44	35.6%	1.873E-02
(moisture content = 20%)	1.57	97.8	0.20	2.8	0.44	71.2%	3.541E-03
Interim Cover (both cover designs)	1.66	103.5	0.09	2.67	0.38	39.4%	1.629E-02
Alternative Cover Radon Barrier	1.66	103.5	0.09	2.67	0.38	39.4%	1.629E-02
UMTRA Cover Radon Barrier	1.77	110.7	0.12	2.65	0.33	64.4%	4.636E-03

[1]Porosity (p) = 1 - dry density/(specific gravity x unit weight of water)
[2]Saturation (S) = Long-term water content/((unit weight of water/dry density) - (1 - specific gravity))
[3]D=Da*p*exp(-6Sp-6S14p) Source: Rogers and Nielson, 1991, equation 9

unit weight of water	62.4	pcf
^{222}Rn diffusion coefficient in air (Da)	1.10E-05	m^2/s

Rogers and Nielson, 1991. Correlations for Predicting Air Permeabilities and ^{222}Rn Diffusion Coefficients of Soils, Health Physics, Vol. 61, No. 2, pp. 225-230, August.

Table B–6. Moab Project, Crescent Junction Disposal Cell Calculation of 15 bar Moisture Content Using Empirical Relationship Rawls & Brakensiek (in NRC 1989b): 15 bar Vol. moisture content = 0.026 + 0.005z + 0.0158y (where z = % of Clay in the soil and y = % of organic matter in the soil)

Alluvium			
Mean Max. Dry Density as placed =	103.4	lbs/cu. ft.	(1.66 g/cc; 85% of Max Dry Density from Modified Proctor Tests)
Mean % Clay =	18.6		
Mean % Organic Matter =	0.3		
15 bar vol. moisture content = 0.026 + 0.005(18.63) + 0.0158(0.3)			
	Volumetric (%)	**Gravimetric (%)**	
15 bar Vol. Moisture Content =	12.3	7.5	Using mean values
Weathered Mancos			
Mean Max. Dry Density as placed =	110.7	lbs/cu. ft.	(1.77 g/cc; 90% of Max. Dry Density from Modified Proctor Tests)
Mean % Clay =	37.7		
Mean % Organic Matter =	0.4		
15 bar vol. moisture content = 0.026 + 0.005(37.67) + 0.0158(0.4)			
	Volumetric (%)	**Gravimetric (%)**	
15 bar Vol. Moisture Content =	22.1	12.4	Using mean values

Table B–7. Tailings Density

Tailings Maximum Dry Density				
Source: Golder Associates 4/3/06 Draft Tech Memo				
Standard Proctor Maximum Dry Density of Transition Tailings				
Sample Number	**Max Dry Density (pcf)**			
GABT-05	113.3			
GABT-07	107.3			
GABT-08	112.8			
GABT-09	102			
GABT-10	107.8		**90% of Mean**	
	108.6	**Mean**	98	pcf
	5	**Count**	1.57	g/cc

U.S. Department of Energy—Grand Junction, Colorado

Calculation Cover Sheet

Calc. No.: MOA-02-05-2007-5-17-02 **Discipline:** Geotechnical **No. of Sheets:** 20
Doc. No.: X0175900

Location: Attachment 1, Appendix C

Project: Moab UMTRA Project

Site: Crescent Junction Disposal Site

Feature: Slope Stability of Crescent Junction Disposal Cell

Sources of Data:

Remedial Action Plan (RAP) calculation sets as referenced in text.

Purpose of Revision:

Revision was made to address the Nuclear Regulatory Commission comments GT4 and GT9 (see Appendix A of the Remedial Action Selection Report) to clarify materials to be used in various components of proposed covers, and to analyze the stability of the UMTRA cover.

Sources of Formulae and References:

See list of references at end of calculation set

Preliminary Calc. ☐ **Final Calc.** ☒ **Supersedes Calc. No.** MOA-02-05-2006-05-17-01

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Problem Statement:

The purpose of this calculation is to assess the stability of the disposal cell at the Crescent Junction Site. Both the short-term (end-of-construction) and long-term conditions were evaluated under static and seismic conditions.

Method of Solution:

Slope stability analyses were performed using limit equilibrium methods with the aid of the computer program SLOPE/W (Geo-Slope/W 2004). The SLOPE/W program calculates factors of safety by a variety of methods. Spencer's method was used for these analyses because it considers both force equilibrium and moment equilibrium in the factor of safety calculation.

Failure surfaces represented the most likely modes of failure, including circular, non-circular, and infinite slope failure surfaces. Circular failure surface analyses were analyzed by targeting deeper, full-slope failures. Small shallow failures were not considered. In both cases, a number of failure surfaces were analyzed to find the lowest factor of safety.

In addition, the analysis of the infinite slope scenario (slope length much longer than thickness of critical layer) was conducted on the side slopes. This conservative analysis minimizes any stabilization effects of a passive resistive wedge at the base of the slope.

Slope stability analyses were performed to analyze both the UMTRA cover and the proposed alternative cover.

Assumptions:

See "Discussion."

Calculation:

See "Discussion."

Discussion:

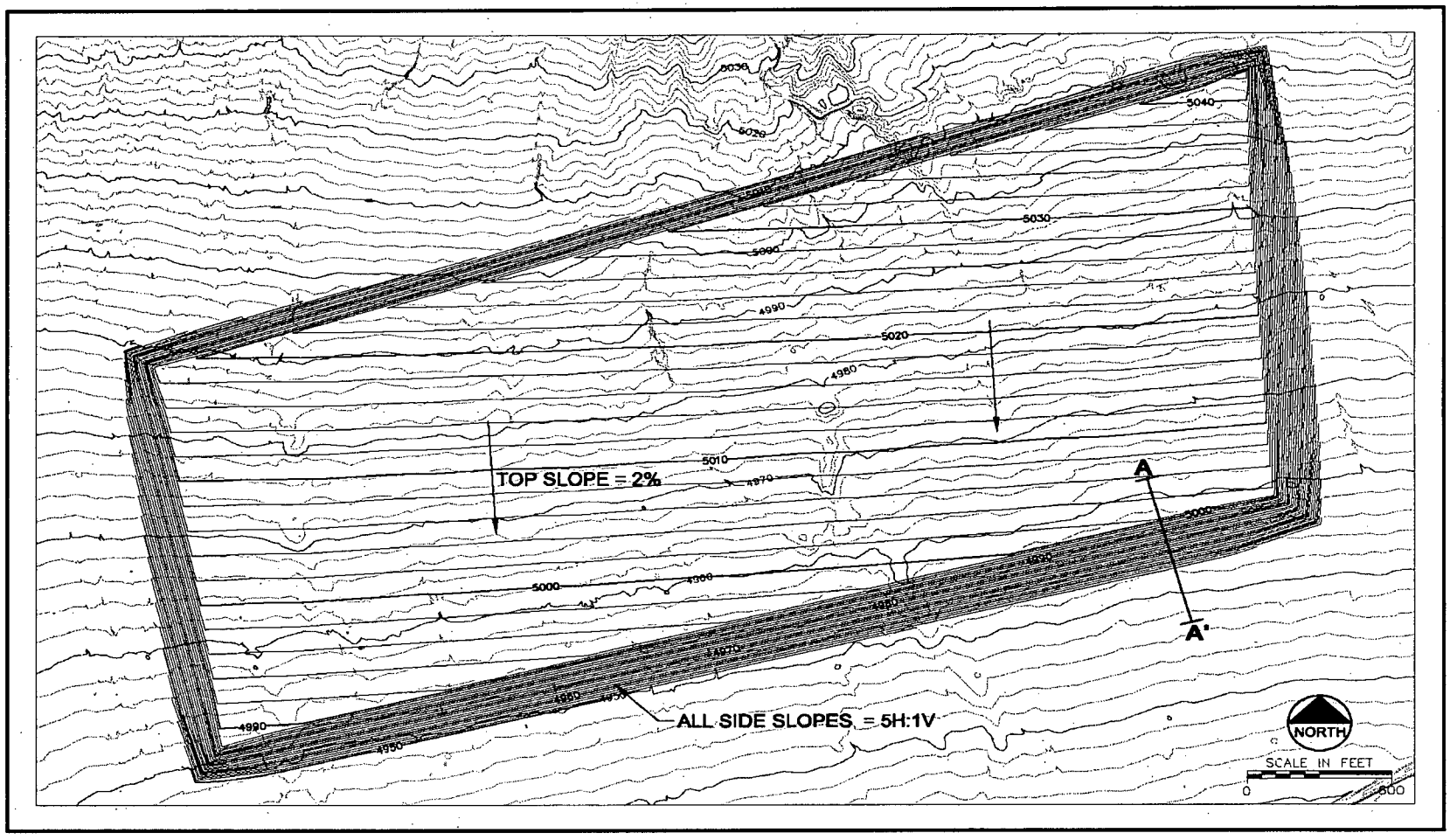
Critical Conditions

Slope-stability analyses are typically conducted under scenarios that represent the critical conditions for construction and operation. For the disposal cell, these conditions include: (1) the period immediately after construction, and (2) the long-term period after cell construction.

Key factors during construction are development of excess porewater pressures in foundation, dike, tailings, or cover materials due to equipment or fill placement, or displacement of low-strength fill materials (such as slime tailings) in response to covering fill placement. These factors are not of concern for slope stability during cell construction. The foundation materials (unsaturated weathered Mancos Shale) are not susceptible to development of excess porewater pressures since they are not likely to be saturated. Tailings will be placed and compacted at optimum or slightly (up to 2 percent) wet of optimum water content. This placement procedure will minimize future settlement. Because of this placement method, it is likely that only the bottom portion of the tailings below natural grade will become saturated due to consolidation and draindown during construction. The development of some excess pore pressures at the base of the tailings is not expected to affect long-term stability.

Critical Geometry

The critical cross-section location used in the analysis is shown in Figure 1. The profile at this location is shown in Figure 2. This section was chosen for analysis because it represents a combination of both highest slope face of the disposal cell and down-sloping natural grade.



MFG, Inc. *consulting scientists and engineers*	FIGURE 1 CRITICAL SECTION FOR SLOPE STABILITY TOP OF COVER	Date: JULY 2006 Project: 181268 File: CELL-DESIGN..07-2

Figure 1.Critical Section for Slope Stability, Top of Tailings

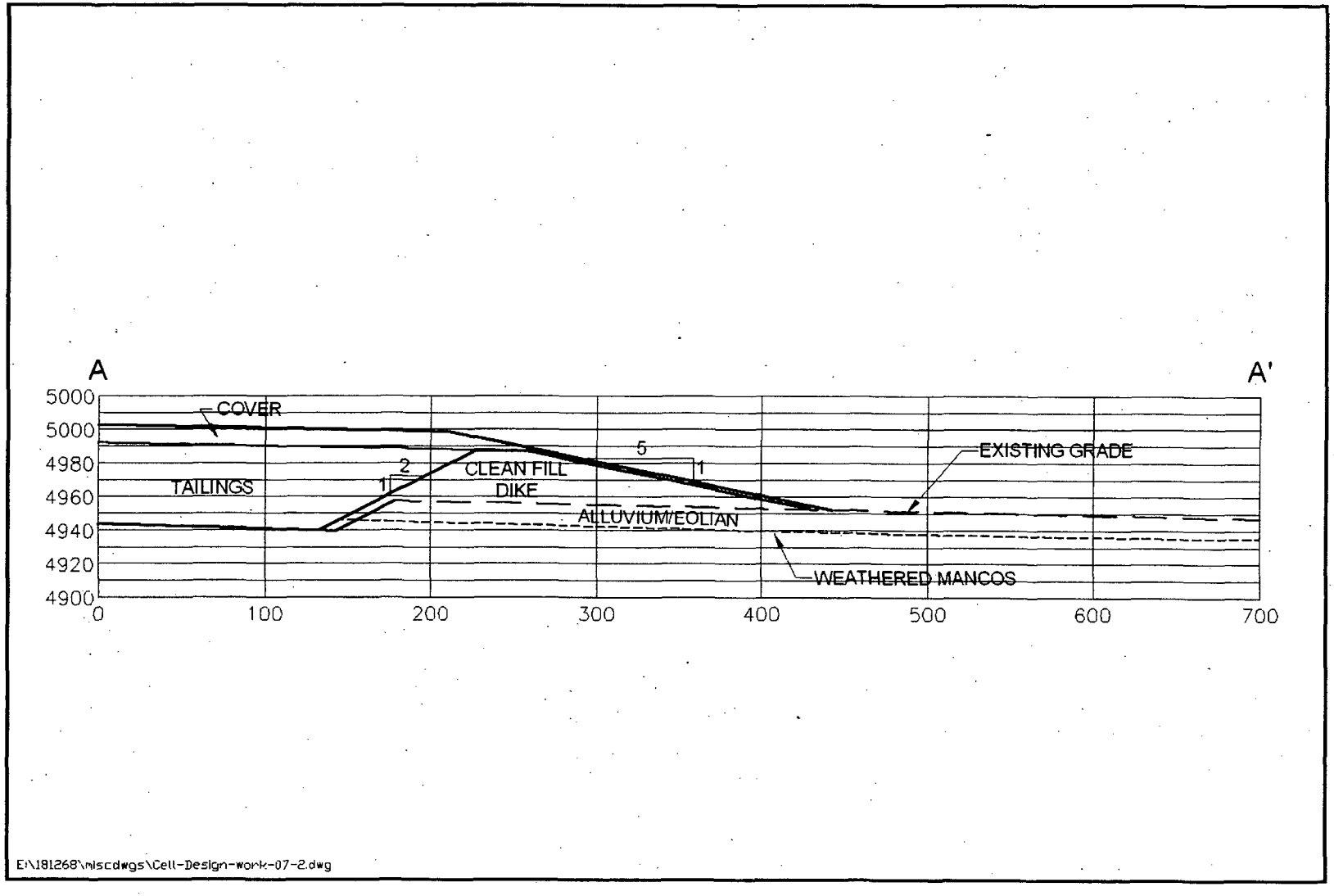


Figure 2. Cross Section A–A'

The cell profile geometry was based on the current cell excavation plan and final cell configuration. This configuration includes excavating existing soils within the footprint of the disposal cell to a depth of approximately 16 ft. Tailings will be compacted, along with the construction of a clean-fill dike, to grades as shown on Figure 1.

The proposed alternative cover consists (from bottom to top) of approximately 6 inches of infiltration and biointrusion barrier (clean sands and gravels), approximately 10 ft of recompacted native alluvial and weathered Mancos shale soils excavated from within the disposal cell footprint, and 6 inches of rock mulch.

The UMTRA cover consists (from bottom to top) of approximately 4 ft of compacted Radon Barrier consisting of recompacted weathered Mancos shale, 6 inches of infiltration/biointrusion material, 3 ft of frost protection consisting of recompacted native alluvial and weathered Mancos Shale soils, and 6 inches of rock mulch. The stability of the UMTRA cover was conservatively analyzed by assuming a 10-ft cover (using the same model geometry as the alternative cover for ease of computation) constructed of the recompacted weathered Mancos shale, which represents the weakest layer of the UMTRA cover system.

Pore Water Conditions

Site investigations (RAP Attachment 5, Vol. I, "Test Pit Logs" [Appendix B], "Borehole Logs" [Appendix D] and "Geotechnical Properties of Native Materials" [Appendix E]) indicate that the foundation soils are dry. The shallowest water encountered in piezometer wells was at a depth of approximately 100 ft (see "Hydrologic Characterization–Vertical Travel Time to Uppermost (Dakota) Aquifer," RAP Attachment 3, Appendix E); therefore, the foundation materials are not expected to be saturated from naturally occurring ground water during construction.

Due to the placement procedure of the tailings (placed between 2 percent dry and 2 percent wet of optimum water content and compacted to 90 percent of maximum dry density of Standard Proctor), it is unlikely that a phreatic surface will exist above natural grade within the tailings. Permeability testing of the tailings is ongoing; however, preliminary results conducted under low confining pressures (2 psi) indicate the permeability of the tailings is approximately 3.0E-5 cm/sec (see "Supplemental Geotechnical Properties of Tailings Materials from the Moab Processing Site," RAP Attachment 5, Vol. II, Appendix N). This compares with estimates of the permeability of the tailings based on literature values for sandy silt tailings of 7E-5 centimeters per second (cm/sec) (Geo-Slope/W) and between 1E-5 and 1E-6 cm/sec (Keshian and Rager 1988). Packer tests performed within the weathered Mancos zone indicate the foundation materials immediately underlying the tailings have an average hydraulic conductivity of approximately 1E-4 cm/sec (see "Hydrologic Characterization–Vertical Travel Time to Uppermost (Dakota) Aquifer," RAP Attachment 3, Appendix E). Because the foundation is more permeable than the tailings, saturation within the tailings is expected to be minimal and confined to the tailings below natural grade. Due to the construction of the clean-fill dike surrounding the tailings, below-grade saturation of tailings will have minimal impact on slope stability. Therefore, potentiometric water surface within the foundation, tailings, cover, or dike material was not considered.

Material Properties

The soil properties used in the stability analyses are summarized in Table 1.

Erosion Protection

The current cell configuration requires rock mulch with a D_{50} of 2.2 inches along the 2 percent top slope of the cell to protect against erosion from action of wind and water. The south side slope requires riprap with a minimum D_{50} of 8.2 inches. This rock will have little impact on the slope stability because it is a relatively thin layer, and the rock will have relatively strong shear strength in relation to other components of the cover. Densities for the rock mulch are assumed from literature values for silty or clayey gravel and sand (Carter and Bentley 1991), and for the riprap, from typical values based on experience. Shear strength values are estimated from Figure 4.8 of NUREG/CR-4620 (Nelson et al. 1986). As the erosion protection will not be subject to excess pore water pressures, shear strength values are modeled as being the same for all three loading cases.

Table 1. Material Properties

Soil Layer	Description	In-Place Dry Density (pcf)	In-Place Moist Density (pcf)	In-Place Saturated Density (pcf)	Short Term		Long Term		Long-Term Seismic	
					Cohesion (psf)	Angle of Internal Friction (degrees)	Cohesion (psf)	Angle of Internal Friction (degrees)	Cohesion (psf)	Angle of Internal Friction (degrees)
Erosion Protection, Top Slope	Angular rock mulch with D_{50} = 2.2 inches	109	123	130	0	37	0	37	0	37
Erosion Protection, Side Slope	Angular riprap with D_{50} = 8.2 inches	135	135	146	0	37	0	37	0	37
Alternative Cover	On-site weathered Mancos shale, alluvial and eolian soils recompacted to 85% maximum dry density from Modified Proctor	103	115	127	0	29	0	29	0	24
UMTRA Cover	On-site weathered Mancos shale recompacted to 90% maximum dry density from Modified Proctor	111	124	132	0	26	0	26	0	21
Clean-fill Dike	On-site weathered Mancos shale, alluvial and eolian soils recompacted to 90% maximum dry density from Modified Proctor	111	124	132	0	19	0	26	0	21
Tailings	Compacted to a minimum of 90% standard Proctor	98	115	125	615	0	0	32	0	27
Sheet wash/eolian soils	In-situ foundational soil outside of tailings footprint	91	97	119	0	26	0	26	0	22
Weathered Mancos Shale	In-situ foundational soil	103	114	127	0	25	0	25	0	21

Alternative Cover

The alternative cover consists of approximately 10 ft of relatively lightly recompacted native alluvial and eolian soils and weathered Mancos shale excavated from the disposal cell footprint. Densities are estimated based on 85 percent of the average of maximum dry densities from Modified Proctor tests performed on these soils (see "Geotechnical Properties of Native Materials," RAP Attachment 5, Vol I, Appendix E). Shear strength parameters used in the model are an average of triaxial shear strength values that were performed on these materials (see "Supplemental Geotechnical Properties of Native Materials," RAP Attachment 5, Vol. I, Appendix K). Cohesion is neglected. Because the cover will not be placed or loaded under saturated conditions, short-term shear strength parameters are estimated to be equivalent to long-term drained conditions. Under seismic loading, the shear strength parameters are estimated to be 80 percent of long-term shear strength ($\tan(\phi)_{seismic} = 0.8 \times \tan(\phi)_{long\text{-}term}$) to account for strain softening during a seismic event. Although conditions do not exist that would cause liquefaction of materials, a reduction of up to 80 percent of peak shear strength under cyclical loading is conservatively considered (Makdisi and Seed 1978) under seismic loading.

UMTRA Cover

The UMTRA cover is conservatively modeled as consisting entirely of recompacted weathered Mancos shale, the weakest component of the cover system. Densities are estimated based on 90 percent of the average of maximum dry densities from Modified Proctor tests performed on the weathered Mancos (see "Geotechnical Properties of Native Materials," RAP Attachment 5, Vol. I, Appendix E). Shear strength parameters used in the model are an average of the triaxial shear strength values that were performed on the weathered Mancos (see "Supplemental Geotechnical Properties of Native Materials," RAP Attachment 5, Vol. I, Appendix K). Cohesion is neglected. Short-term and seismic reductions in shear strength are the same as discussed for the alternative cover.

Clean-Fill Dike

A clean-fill dike will be constructed around the perimeter of the disposal cell. The height of the dike will be the same as that of the tailings, and will vary from 10 to 30 ft. The dike will be constructed from recompacted weathered Mancos Shale, alluvial, and eolian soils that are excavated from the disposal cell footprint. Densities are based on 90 percent of the average of maximum dry density from Modified Proctor tests (see "Geotechnical Properties of Native Materials," RAP Attachment 5, Vol. I, Appendix E). Long-term shear strength parameters used in the model are an average of effective triaxial shear strength of the weathered Mancos Shale (the weakest component of the soils used in construction of the dike) (see "Supplemental Geotechnical Properties of Native Materials," RAP Attachment 5, Vol. I, Appendix K). Cohesion is neglected. For short-term analyses, the average total shear strength of the weathered Mancos Shale is used, neglecting cohesion. Under seismic loading, the shear strength is estimated to be 80 percent of long-term shear strength to account for strain softening during a seismic event. The strain-softening approach is used to account for some loss in strength under high strain. An undrained shear strength approach is not considered appropriate because the dike is not expected to be saturated.

Tailings

Tailings will be relocated from the current site in Moab. During the relocation process, tailings will be mixed such that fine-grained particles (slimes) will be combined with coarse-grained particles (sands). The resulting material will consist of transitional tailings, or a mixture of sands and slimes. The tailings will be moisture conditioned and compacted in maximum 12-inch loose lifts within the disposal cell. Densities of the tailings are based on 90 percent of the average of maximum dry density from Standard Proctor tests on transitional tailings (Golder 2006). Shear strength testing on the tailings is ongoing. Literature values for hydraulically placed uranium mill tailings indicate that an effective angle of internal friction of 32 degrees is appropriate for preliminary estimates of the strength of sand/slime mixtures (Keshian and Rager 1988). For short-term, the shear strength of the tailings is estimated based on the average of unconfined compressive strength tests performed on undisturbed samples of the tailings sampled from the current site in Moab (see "Geotechnical Laboratory Testing Results for the Moab Processing Site," RAP Attachment 5, Vol. I, Appendix J). This is considered a conservative approach because the tailings in Moab that were tested for unconfined compressive strength were predominately slimes and have been

hydraulically placed. In contrast, the relocated tailing at the Crescent Junction Site will be mixed in such a manner that percent slimes placed will be minimal. The tailings will also be compacted, thereby increasing the density and shear strength above that currently seen at the Moab Site. Because the tailings will be placed at close to optimum moisture content and compacted, they are not expected to be saturated. Under seismic loading, the shear strength parameters are estimated to be 80 percent of long-term shear strength to account for strain softening during a seismic event. The strain-softening approach is used to account for some loss in strength under high strain during cyclical loading.

Alluvial/Eolian Soil and Weathered Mancos Shale

The native soils outside the footprint of the disposal cell are modeled to check against failures that may incorporate foundation materials. The densities of the alluvial/eolian soils and the weathered Mancos Shale are based on average dry densities measured from respective liner samples taken during the field investigation (see "Geotechnical Properties of Native Materials," RAP Attachment 5, Vol. I, Appendix E). Shear strength parameters for the alluvial/eolian soils are modeled as being 90 percent of the recompacted shear strength of the same material to reflect lower shear strength due to less compaction. The in-situ weathered shale has essentially the same dry density as the recompacted samples and is therefore estimated to have similar shear strength parameters.

Seismic Coefficient

As per the "Site and Regional Seismicity – Results of Maximum Credible Earthquake Estimation and Peak Horizontal Acceleration" calculation (RAP Attachment 2, Appendix F), the predicted peak horizontal acceleration (PHA) is estimated to be 0.22 g. In accordance with guidance given in the Technical Approach Document (TAD) (DOE 1989), the seismic coefficient for a pseudostatic analysis is equivalent to 1/2 of PHA (0.11 g) for end-of-construction analyses, and is equivalent to 2/3 of PHA (0.15 g) for the long-term analyses.

Stability Criteria

The required safety factors as given in the TAD are as follows:

Loading Condition	Minimum Factor of Safety
End-of-construction:	
Static	1.3
Pseudostatic (kh=0.11 g)*	1.0
Long-term:	
Static	1.5
Pseudostatic (kh=0.15 g)	1.0

*kh = seismic coefficient

Results from Stability Analyses

Based on the input parameters outlined previously, critical failure surfaces and the associated factor of safety are shown in Figures 3 through 10. The stability results are summarized below:

Loading Condition	Results of Analysis	
	Alternative Cover	UMTRA Cover
End-of-construction:		
Static	1.7	1.7
Pseudostatic (kh=0.11g)	1.1	1.1
Infinite Slope (Static)	1.7	1.7
Infinite Slope (Pseudostatic)	1.1	1.1
Long-term:		
Static	2.4	2.4
Pseudostatic (kh=0.15 g)	1.0	1.0
Infinite Slope (Static)	2.4	2.4
Infinite Slope (Pseudostatic)	1.1	1.1

*kh = seismic coefficient

Name: short-term seismic.gsz

Comments: End-of-Construction

Comments: End-of-ConstructionHorz Seismic Load: 0.11

Material #: 1 Description: Alternative Cover Wt: 115 Cohesion: 0 Phi: 29
Material #: 2 Description: Clean-Fill Dike Wt: 124 Cohesion: 0 Phi: 19
Material #: 3 Description: Tailings Wt: 115 Cohesion: 615
Material #: 4 Description: Alluvium/Eolian Wt: 97 Cohesion: 0 Phi: 26
Material #: 5 Description: Weathered Mancos Wt: 114 Cohesion: 0 Phi: 25

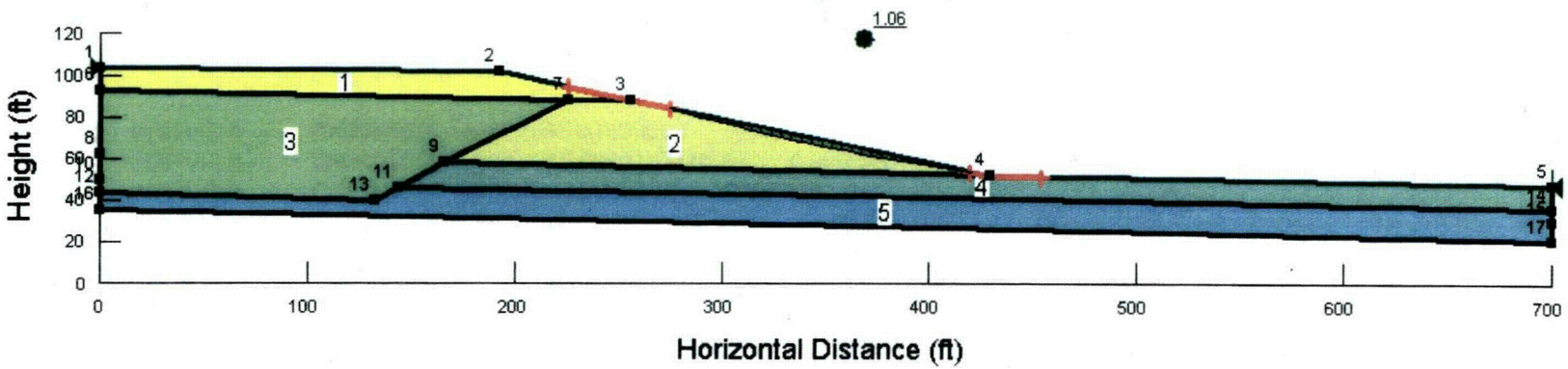


Figure 3. Short-Term Seismic (Alternative Cover)

Name: short-term static.gsz

Comments: End-of-Construction

Comments: End-of-ConstructionHorz Seismic Load: 0

Material #: 1 Description: Alternative Cover Wt: 115 Cohesion: 0 Phi: 29
Material #: 2 Description: Clean-Fill Dike Wt: 124 Cohesion: 0 Phi: 19
Material #: 3 Description: Tailings Wt: 115 Cohesion: 615
Material #: 4 Description: Alluvium/Eolian Wt: 97 Cohesion: 0 Phi: 26
Material #: 5 Description: Weathered Mancos Wt: 114 Cohesion: 0 Phi: 25

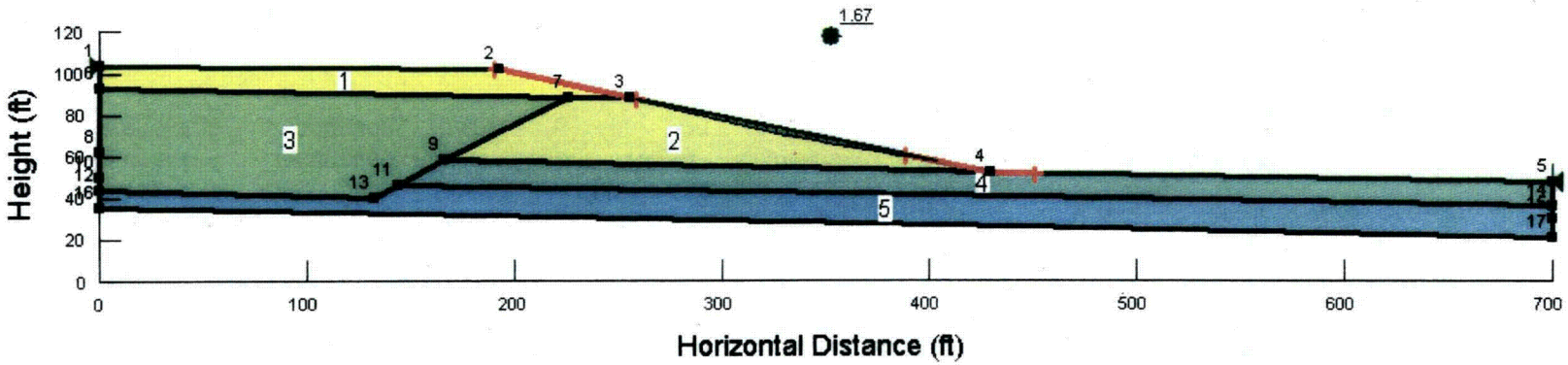


Figure 4. Short-Term Static (Alternative Cover)

Name: long-term seismic.gsz

Comments: Long-term

Comments: Long-termHorz Seismic Load: 0.15

Material #: 1 Description: Alternative Cover Wt: 115 Cohesion: 0 Phi: 24
Material #: 2 Description: Clean-Fill Dike Wt: 124 Cohesion: 0 Phi: 21
Material #: 3 Description: Tailings Wt: 115 Cohesion: 0 Phi: 27
Material #: 4 Description: Alluvium/Eolian Wt: 97 Cohesion: 0 Phi: 22
Material #: 5 Description: Weathered Mancos Wt: 114 Cohesion: 0 Phi: 21

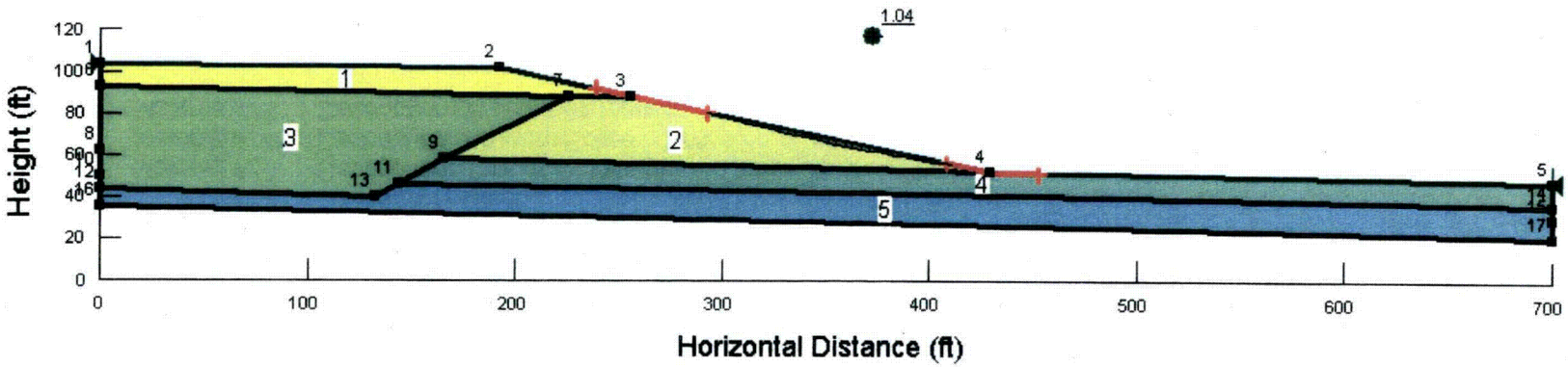


Figure 5. Long-Term Seismic (Alternative Cover)

Name: long-term static.gsz
Comments: Long-term
Comments: Long-termHorz Seismic Load: 0

Material #: 1 Description: Alternative Cover Wt: 115 Cohesion: 0 Phi: 29
Material #: 2 Description: Clean-Fill Dike Wt: 124 Cohesion: 0 Phi: 26
Material #: 3 Description: Tailings Wt: 115 Cohesion: 0 Phi: 32
Material #: 4 Description: Alluvium/Eolian Wt: 97 Cohesion: 0 Phi: 26
Material #: 5 Description: Weathered Mancos Wt: 114 Cohesion: 0 Phi: 25

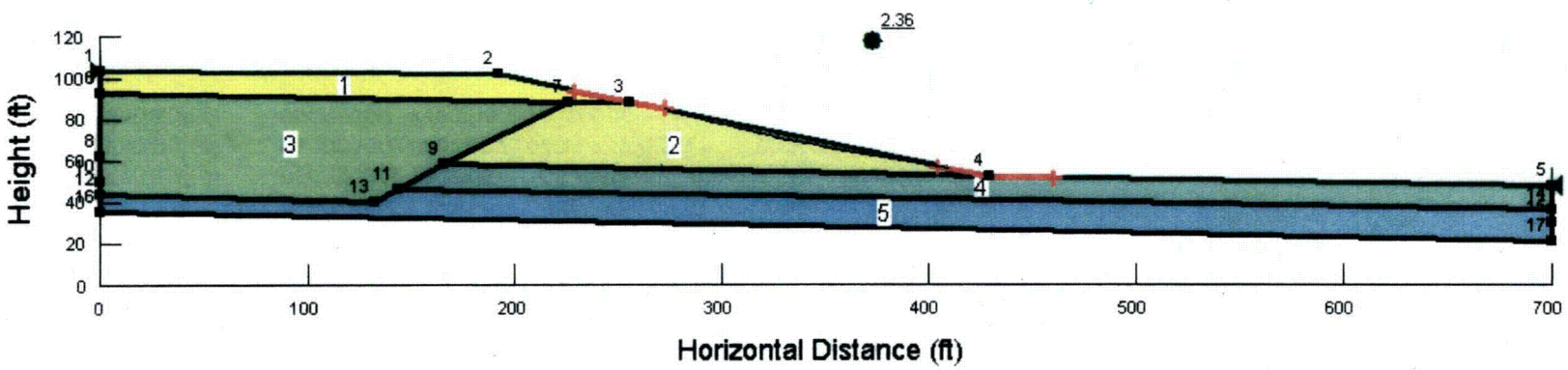


Figure 6. Long-Term Static (Alternative Cover)

Name: short-term seismic UMTRA.gsz
Comments: End-of-Construction
Comments: End-of-ConstructionHorz Seismic Load: 0.11

Material #: 1 Description: UMTRA cover Wt: 124 Cohesion: 0 Phi: 26
Material #: 2 Description: Clean-Fill Dike Wt: 124 Cohesion: 0 Phi: 19
Material #: 3 Description: Tailings Wt: 115 Cohesion: 615
Material #: 4 Description: Alluvium/Eolian Wt: 97 Cohesion: 0 Phi: 26
Material #: 5 Description: Weathered Mancos Wt: 114 Cohesion: 0 Phi: 25

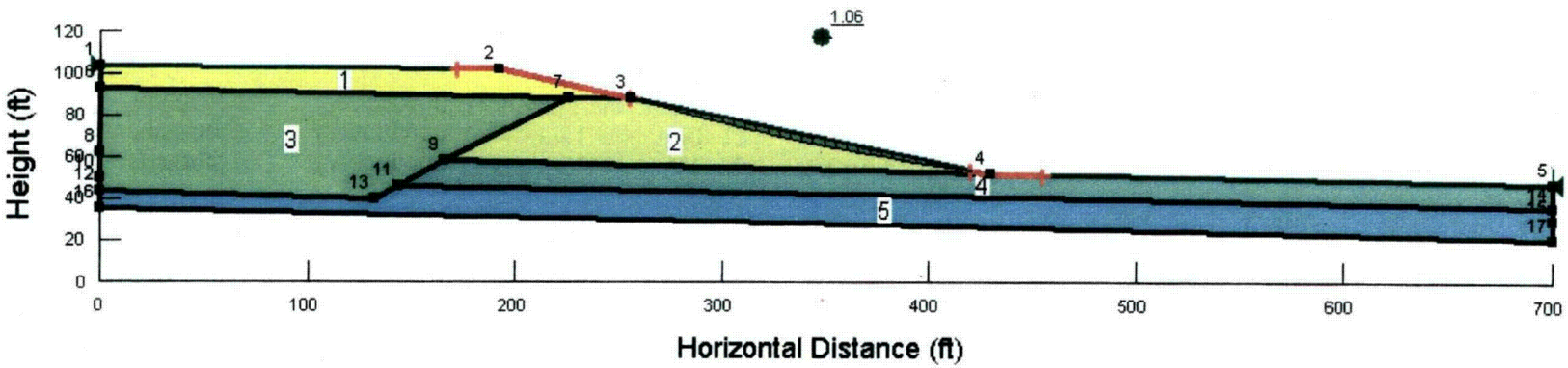


Figure 7. Short-Term Seismic (UMTRA Cover)

Name: short-term static UMTRA.gsz
Comments: End-of-Construction
Comments: End-of-ConstructionHorz Seismic Load: 0

Material #: 1 Description: UMTRA Cover Wt: 124 Cohesion: 0 Phi: 26
Material #: 2 Description: Clean-Fill Dike Wt: 124 Cohesion: 0 Phi: 19
Material #: 3 Description: Tailings Wt: 115 Cohesion: 615
Material #: 4 Description: Alluvium/Eolian Wt: 97 Cohesion: 0 Phi: 26
Material #: 5 Description: Weathered Mancos Wt: 114 Cohesion: 0 Phi: 25

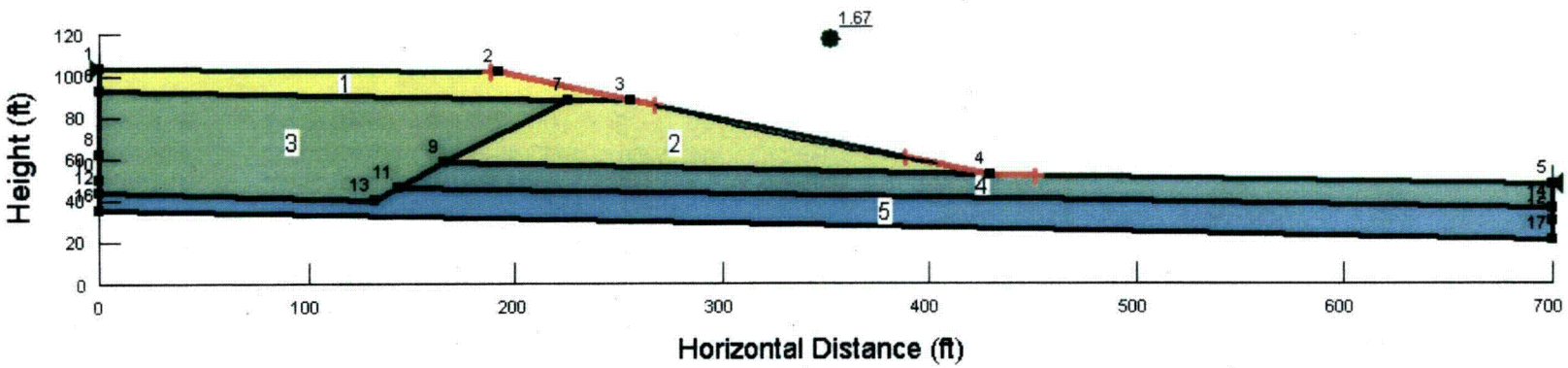


Figure 8. Short-Term Static (UMTRA Cover)

Name: long-term seismic UMTRA.gsz
Comments: Long-term
Comments: Long-termHorz Seismic Load: 0.15

Material #: 1 Description: UMTRA cover Wt: 124 Cohesion: 0 Phi: 21
Material #: 2 Description: Clean-Fill Dike Wt: 124 Cohesion: 0 Phi: 21
Material #: 3 Description: Tailings Wt: 115 Cohesion: 0 Phi: 27
Material #: 4 Description: Alluvium/Eolian Wt: 97 Cohesion: 0 Phi: 22
Material #: 5 Description: Weathered Mancos Wt: 114 Cohesion: 0 Phi: 21

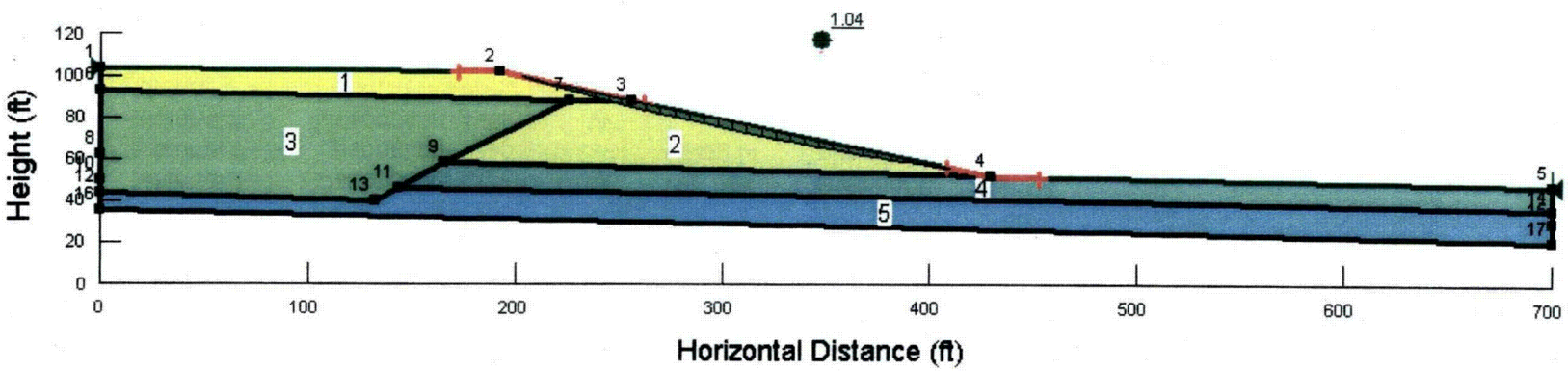


Figure 9. Long-Term Seismic (UMTRA Cover)

Name: long-term static UMTRA.gsz
Comments: Long-term
Comments: Long-termHorz Seismic Load: 0

Material #: 1 Description: UMTRA Cover Wt: 124 Cohesion: 0 Phi: 26
Material #: 2 Description: Clean-Fill Dike Wt: 124 Cohesion: 0 Phi: 26
Material #: 3 Description: Tailings Wt: 115 Cohesion: 0 Phi: 32
Material #: 4 Description: Alluvium/Eolian Wt: 97 Cohesion: 0 Phi: 26
Material #: 5 Description: Weathered Mancos Wt: 114 Cohesion: 0 Phi: 25

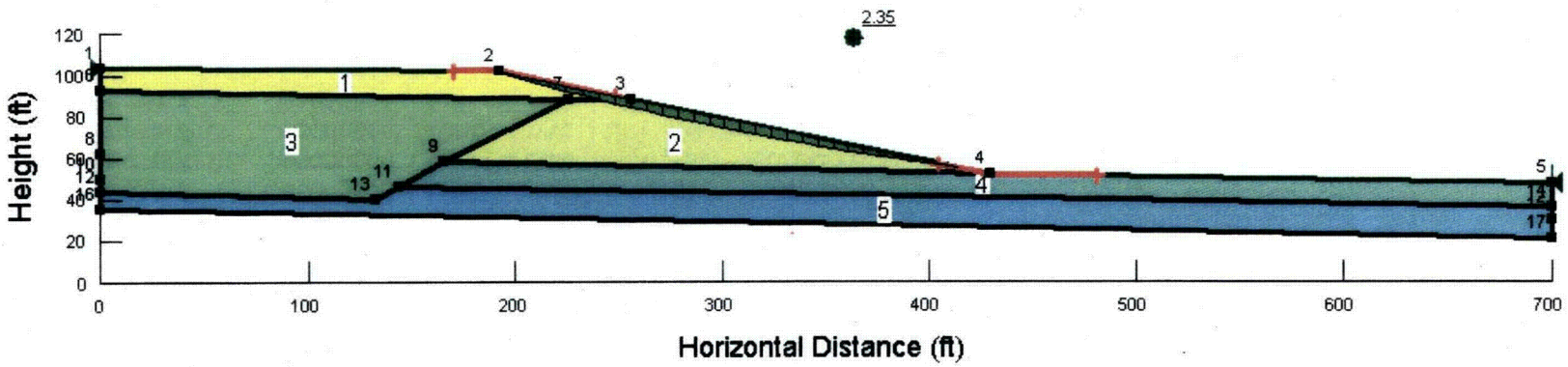


Figure 10. Long-Term Static (UMTRA Cover)

Conclusion and Recommendations:

Based on results of geologic literature review, the Crescent Junction Site appears to be suitable for disposal of the Moab uranium mill tailings and contaminated material. The computed factors of safety for the alternative cover are similar to the UMTRA cover analyses. Critical failure surfaces pass predominately through the perimeter embankment. Therefore, the stability of the disposal cell is relatively insensitive to cover material thickness and to cover material and compacted tailings shear strength. Based on this information, and in conjunction with findings of field investigations, this site is deemed suitable for the intended use.

Computer Source:

Geo-Slope/W International, LTD, 2004. SLOPE/W version 6.19, Calgary, Alberta, Canada.

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Makdisi, F.I., and H.B. Seed, 1978. "Simplified Procedure for Estimating Dam and Embankment Earthquake-Induced Deformations," *Journal of the Geotechnical Engineering Division,* American Society of Civil Engineers, 104(GT7), July.

Nelson, J.D., S.R. Abt, R.L. Volpe, D. van Zyl, N.E. Hinkle, and W.P. Staub, 1986. *Methodologies for Evaluating Long-Term Stabilization Design of Uranium Mill Tailings Impoundments*, NUREG/CR-4620, U.S. Nuclear Regulatory Commission, June.

NRC (U.S. Nuclear Regulatory Commission), 1993. *Final Standard Review Plan for the Review and Remedial Action of Inactive Mill Tailings Sites under Title 1 of the Uranium Mill Tailings Radiation Control Act, Revision I*, U.S. Nuclear Regulatory Commission Office of Nuclear Material Safety and Safeguards, June.

End of current text

Appendix A

Infinite Slope Analysis

Client:	U.S. Department of Energy	Job No. 181268	Page: 1 of 1
Project:	Disposal Cell	Date: 5/19/06	Date Checked: 5/7/07
Detail:	Slope Stability, Seismic Analyses for Infinite Slope	Computed by: RTS	Checked by: CLS

Problem Statement:

Calculate the Factor of Safety assuming infinite slope failure. Analyze side slope at 5H:1V. Critical surface is at the clean-fill dike around the perimeter of the disposal cell. Average properties of borrow material for Mancos Shale soils are LL = 28 and PI = 11. Assume that under moderate loading conditions (10 to 30 feet of material), soils force failure. Use long-term, static friction angle of 26 degrees (average of effective shear strength results for weathered Mancos Shale), long-term pseudostatic friction angle of 21 degrees (80 percent reduction in strength), and short-term friction angle of 19 degrees (average of total shear strength results for weathered Mancos Shale).

Solution:

Use the following equation

$$FS = \frac{\tan(\phi)}{\tan[\beta + \arctan(k_h)]}$$

where FS= Factor of Safety
ϕ= friction angle of clean fill dike
β= slope angle of cover=arctan (1/5)
k_h=horizontal seismic coefficient (g)

For static, short-term conditions, k_h=0.0 g and ϕ=19 degrees:

$$FS = \frac{\tan(19)}{\tan\left[\arctan(\frac{1}{5}) + \arctan(0.0)\right]} = 1.72$$

For pseudostatic, short-term conditions, k_h=0.11 g and ϕ=19 degrees:

$$FS = \frac{\tan(19)}{\tan\left[\arctan(\frac{1}{5}) + \arctan(0.11)\right]} = 1.09$$

For static, long-term conditions, k_h=0.0 g and ϕ=26 degrees:

$$FS = \frac{\tan(26)}{\tan\left[\arctan(\frac{1}{5}) + \arctan(0.0)\right]} = 2.44$$

For pseudostatic, long-term conditions, k_h=0.15g and ϕ=21 degrees:

$$FS = \frac{\tan(21)}{\tan\left[\arctan(\frac{1}{5}) + \arctan(0.15)\right]} = 1.06$$

U.S. Department of Energy—Grand Junction, Colorado

Calculation Cover Sheet

Calc. No.: MOA-02-05-2007-3-16-01 **Discipline:** Engineering Design **No. of Sheets:** 6
Doc. No.: X0176100

Location: RAP Attachment 1, Appendix D

Project: Moab UMTRA Project

Site: Crescent Junction Disposal Site, Disposal Cell Design

Feature: Settlement, Cracking, and Liquefaction Analysis

Sources of Data:

Remedial Action Plan (RAP) calculations as cited in the text.

Purpose of Revision:

Revision to address Nuclear Regulatory Commission comments G15 and GT5 (see Appendix A of the Remedial Action Selection Report) and to include laboratory test results on tailings.

Sources of Formulae and References:

See "References" section.

Preliminary Calc. ☐ **Final Calc.** ☒ **Supersedes Calc. No.** MOA-02-05-2006-3-16-00

	Name	Date		Name	Date
Author:	Clint Strachan	30 May 07	Checked by:	S. Gray Smith	5/30/07
Approved by:	John E Elmer	5/31/07		[illegible]	5/31/07
				[illegible]	May 31, 07

REVIEWED: Frank B Perea 5-31-07

No text for this page

Problem Statement:

Evaluate (1) the potential for post-construction tailings settlement, (2) the potential for cover cracking, and (3) the potential for liquefaction under seismic loading conditions.

Method of Solution:

See "Discussion."

Assumptions:

- Tailings will be placed at approximately 98 pounds per cubic foot (pcf), 17 percent to 21 percent gravimetric moisture content (above 90 percent of average Standard Proctor maximum dry density, and within 2 percent of optimum moisture content).
- Tailings will be placed in thin lifts, compacted, and placed to an ultimate thickness of 38 feet (ft).
- Peak horizontal ground acceleration is 0.22 g (see the "Site and Regional Seismicity–Results of Literature Research" calculation in the Remedial Action Plan [RAP], Attachment 2, Appendix E).

Calculation:

See attached sheets.

Discussion:

The calculations outline the analyses of (1) post-construction tailings settlement, (2) the impact of differential tailings settlement on cover performance (specifically cover cracking), and (3) the potential for tailings liquefaction.

Tailings Settlement

Typical settlement analyses are conducted for uranium tailings reclamation planning, because tailings will settle to varying amounts due to the stress changes from reclamation activity. These stress changes can be caused by: (1) the weight of construction equipment; (2) the loading due to the reclamation cover; and (3) lowering of the zone of saturation in the tailings. These changes have a larger effect with reclamation of tailings deposited as a slurry. In this case, the tailings will be placed in the repository as an unsaturated material, spread in lifts, and rolled with conventional construction equipment. Other Title I sites with relocated tailings have been evaluated for post-construction settlement, and areas of concern for differential settlement are transition zones between tailings and embankment materials or subsoils or zones between tailings and contaminated soils (such as described in Larson and Keshian 1988).

Analysis of tailings settlement is based on the anticipated method of placement and cover system loads on the tailings, and Moab tailings test results, as well as published data on uranium tailings characteristics.

Settlement of the tailings was evaluated to check the magnitude of primary and secondary settlement of the tailings due to the loading of subsequent tailings and cover materials. From data in Keshian and Rager (1988) on Title I tailings samples, the compression index (C_c) for remolded, mixed tailings ranged from 0.01 to 0.1, and the secondary compression index (C_α) ranged from 0.003 to 0.01. From consolidation testing on Moab tailings (Shaw E & I, Inc., 2006b), the median C_c value was approximately 0.2, for transition tailings compacted to 90 percent of Standard Proctor density. Primary settlement of the 38-ft-thick zone of tailings is estimated to be approximately 1.2 ft. Due to the construction schedule, settlement of one area of tailings (due to subsequent tailings placement) may be nearly complete by the time cover construction is started, so that this primary settlement may occur primarily during construction. The secondary settlement (over a 1,000-year period) would range from approximately 0.28 to 0.76 ft for C_α values ranging from 0.003 to 0.01 (using the procedure outlined in Larson and Keshian 1988).

Downward migration of pore water in the tailings may create a saturated zone at the bottom of the compacted tailings. This would be a post-construction effect, and gradual dissipation of pore water pressures over the design period would not significantly change the void ratio of these tailings.

The multi-year construction schedule for the disposal cell provides significant time for tailings drying and settlement prior to cover placement. Tailings will be placed in regions of the cell in lifts, compacted, and covered with interim cover. These regions will subsequently be covered with the soil cover system. The relatively thick cover is sufficiently thick to accommodate differential settlement without detrimental effects. This was evaluated by the calculations described below.

Cover Cracking

Cover cracking was evaluated by comparison of allowable strain for the cover materials with maximum calculated strain due to differential settlement in the cover. The area of the cell with the highest anticipated differential settlement (and associated largest horizontal strain) is inside the perimeter embankment.

The allowable strain for the cover materials was calculated using the equation in Caldwell and Reith (1993) based on soil plasticity index:

$$e_f = 0.05 + 0.003\ PI$$

where e_f = soil tensile strain at failure (in percent)
PI = plasticity index of the cover soil

For the UMTRCA cover, with a weathered Mancos Shale radon barrier with a PI of 10, the maximum allowable strain is approximately 0.08 percent. For the alternative cover with slopewash soils with a plasticity index of 5 or less, the maximum allowable strain is approximately 0.06 percent. These allowable strain values are consistent with the allowable strains presented in Larson and Keshian (1988) and EPA (1991).

The differential settlement of tailings along the perimeter embankment would be zero near the embankment crest to as much as 2.0 ft at the inside edge of the cell excavation (conservatively adding primary and secondary settlement). This amount of differential settlement over the inside embankment slope distance (76 ft) is equivalent to a horizontal tensile strain of approximately 0.03 percent. This calculated strain is lower than the allowable tensile strain for the soil, indicating acceptable cover performance.

Liquefaction

Although the tailings will be placed in the repository in an unsaturated condition, downward migration of porewater or inclusion of meteoric water may create zones in the tailings with saturated conditions. The potential liquefaction of saturated zones of the tailings was checked with standard procedures outlined in Day (1999), based on the classic paper by Seed and Idriss (1971). This involves comparison of the seismic stress ratio due to the design seismic event with the seismic stress ratio that would cause liquefaction of the tailings at a specific depth of analysis. The analysis was performed assuming the entire tailings thickness is saturated. This situation is extremely unlikely, but was used to conservatively analyze the liquefaction potential.

These stress ratios were calculated at the top and bottom of the tailings. The stress ratio due to the design seismic event was calculated from the peak estimated acceleration at the ground surface of 0.22 g. The stress ratio required for liquefaction was based a conservatively estimated relative density of the tailings of 50 percent, based on a tailings compaction at 90 percent of Standard Proctor density (using a correlation in Holtz and Kovacs 1981). For this tailings relative density, fines content values ranging from 17 to 46 percent (representing the minimum and mean measured values), and the two depths of analysis, the stress ratio required to cause liquefaction was higher than the seismic stress ratio from the design earthquake. This indicates that if the tailings were to become saturated, the tailings would not liquefy under peak seismic ground acceleration conditions.

Conclusion and Recommendations:

- The cover for the disposal cell should not undergo significant settlement due to (1) the placement characteristics (density and moisture content of the tailings), and (2) the compaction energies applied by the equipment used to place the material. Due to the multi-year construction schedule and dry site climate, considerable tailings settlement would be expected before the cover is constructed over the cell.
- In the event of differential settlement of tailings, an analysis of cover cracking shows that the maximum calculated tensile stresses in the cover due to differential settlement are less than the allowable stresses in the cover. In addition, the cover thickness (roughly 10 to 14 ft for the UMTRCA and alternative cover designs) would accommodate cracking without affecting the performance of the entire cover system.
- Tailings liquefaction is not likely because of the placement of unsaturated tailings in the cell (as described above), the density that the tailings will achieve with placement in lifts and rolling with construction equipment, and the fines content of the tailings. In the event of zones of tailings becoming saturated, the calculated stress ratio required to cause liquefaction of the tailings is higher than the seismic stress ratio for all of the cases considered, indicating that liquefaction would not occur.

Computer Source:

Not applicable.

References:

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Shaw E & I Inc., 2006b. Geotechnical test results on tailings samples, November 7.

End of current text

Appendix A

Liquefaction Analysis

ANALYSIS METHOD OUTLINED IN DAY (1999) AND OTHER REFERENCES

1. CALCULATION OF SEISMIC SHEAR STRESS RATIO (caused by peak acceleration)

$$SSR_a = 0.65\, r_d \left(\frac{a_{max}}{g}\right)\left(\frac{\sigma_{vo}}{\sigma_{vo}'}\right)$$

where: a_{max} = peak acceleration at the ground surface for Crescent Valley. $a_{max}/g = 0.22$

σ_{vo} = total vertical stress at depth of analysis

σ_{vo}' = effective vertical stress at depth of analysis

r_d = depth reduction factor = $1 - 0.012\, z$

z = depth (in meters) below ground surface at depth of analysis

ASSUMPTIONS:

tailings thickness = 38 feet
cover thickness = 13 feet
saturated thickness = 38 feet (tailings saturated)

cover unit weight = 103 pcf dry
110.2 pcf at 7% water content

tailings unit weight = 98 pcf dry
124.1 pcf at 266% water content (saturated)

tailings fines content = 17% (minimum)
46% (mean)

CALCULATING r_d:

- at top of tailings: $z = 13/3.28 = 3.96$ m

  $r_d = 1 - 0.012 \cdot 3.96 = 0.952$

- at bottom of tailings: $z = 51/3.28 = 15.55$ m

  $r_d = 1 - 0.012 \cdot 15.55 = 0.813$

CALCULATION OF SSR_a (cont'd)

A. At top of tailings :

$\sigma_{vo} = 13 \cdot 110.2 = 1433$ psf

$\sigma_{vo}' = 13 \cdot 110.2 = 1433$ psf

$\sigma_{vo}/\sigma_{vo}' = 1.0$

B. At bottom of tailings : $\sigma_{vo} = 13 \cdot 110.2 + 38 \cdot 124.1 = 1433 + 4716 = 6149$ psf

$\sigma_{vo}' = \sigma_{vo} - u = 6149 - 38 \cdot 62.4 = 6149 - 2371 = 3778$ psf

$\sigma_{vo}/\sigma_{vo}' = 1.63$

At top of tailings: $SSR_a = 0.65\, r_d \left(\frac{a_{max}}{g}\right)\left(\frac{\sigma_{vo}}{\sigma_{vo}'}\right)$

$= 0.65 \cdot 0.952 \cdot 0.22 \cdot 1.0 = 0.136$

At bottom of tailings: $SSR_a = 0.65 \cdot 0.813 \cdot 0.22 \cdot 1.63 = 0.190$

2. CALCULATION OF STRESS RATIO CAUSING LIQUEFACTION, SSR_ℓ

SSR_ℓ determined from Figure 11.8 of Day (1999), using calculated values of corrected blow count $(N_1)_{60}$ and fines content of tailings.

$(N_1)_{60}$ represents the resistance to liquefaction in terms of a corrected SPT blow count. The corrections are made for 60% rod energy ratio and for overburden pressure, as outlined in National Research Council (1985) and Carter and Bentley (1991).

For tailings compacted to 90% relative compaction, the equivalent relative density is 50% (Holtz and Kovacs, 1981). A relative density of 50% is equivalent to an SPT blow count of 20 blows/foot (Lambe and Whitman, 1969; Carter and Bentley, 1991). This is equivalent to an $(N_1)_{60}$ value of 15 (Carter and Bentley, 1991).

CALCULATING SSR_ℓ (cont'd)

The range of tailings fines content (from the Shaw test data) is 17 to 46 %. The $(N_1)_{60}$ value for compacted tailings is 15 throughout the tailings profile. Using Figure 11.8 of Day (1999) or Figure 4-7 of National Research Council (1985), the SSR_ℓ value for 17% fines is 0.23, and SSR_ℓ for 46% fines is 0.27.

3. COMPARING CALCULATED STRESS RATIO VALUES

Location in profile	% Fines	SSR_a	SSR_ℓ	Comment
Top of tailings	17	0.136	0.23	No liquefaction
	46	0.136	0.27	"
Bottom of tailings	17	0.190	0.23	"
	46	0.190	0.27	"

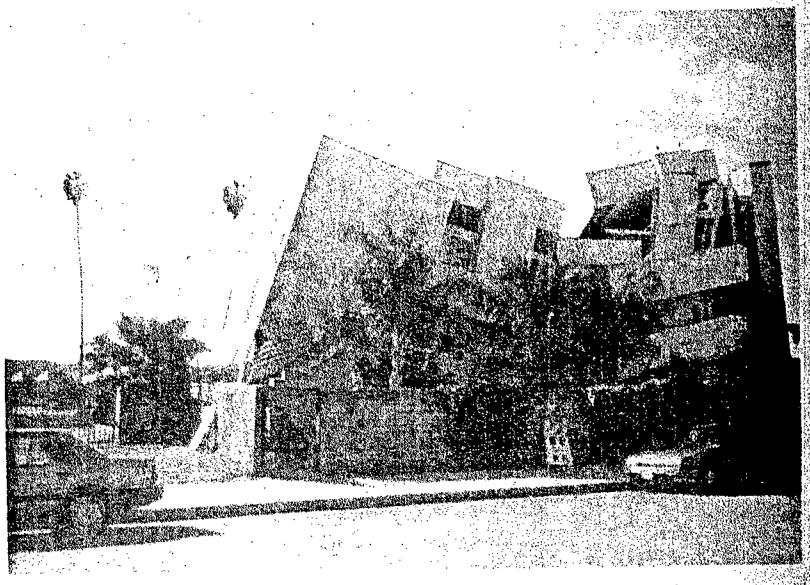

FIGURE 11.1 Building collapse caused by the 1994 Northridge, California, earthquake.

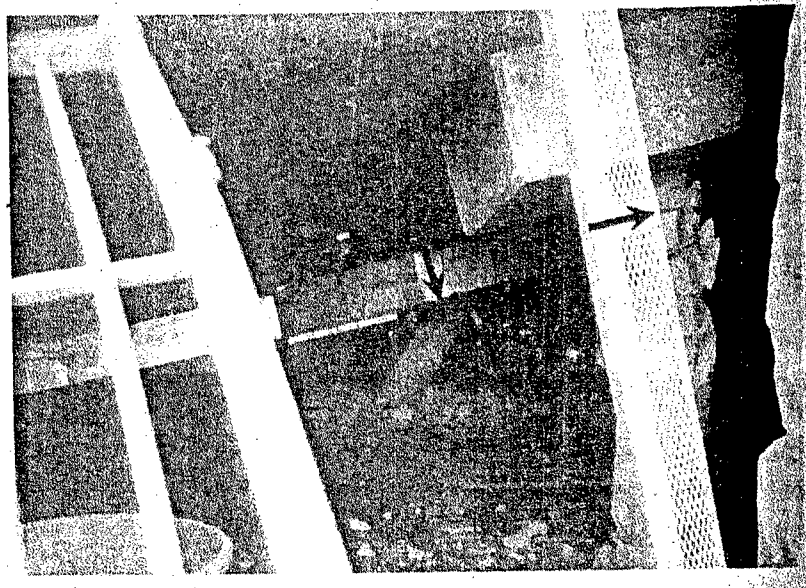

FIGURE 11.2 View inside the collapsed first floor parking garage (arrows point to columns).

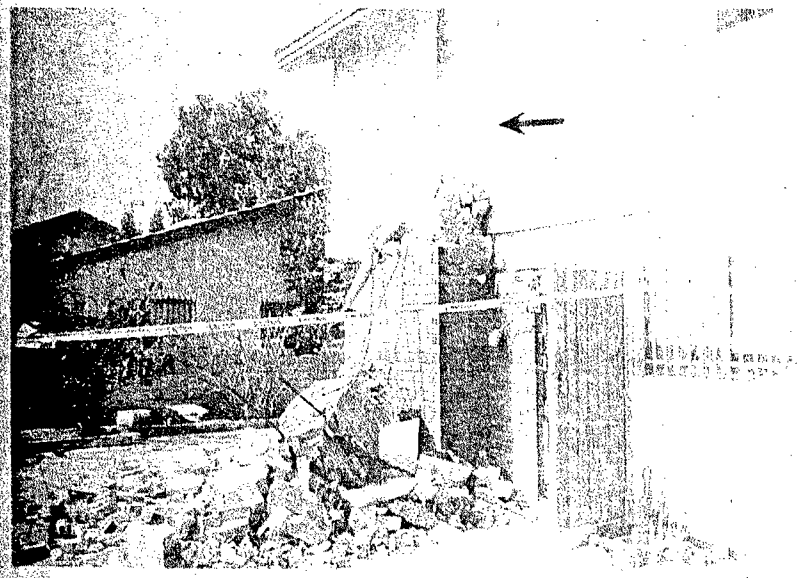

FIGURE 11.3 Collapse of brick chimney, 1994 Northridge, California, earthquake.

two primary types of damage have developed: (1) longitudinal cracks at the top of the dam and (2) crest settlement. In the case of the Sheffield Dam, a complete failure did occur, probably due to liquefaction of the very loose and saturated lower portion of the embankment (Sherard et al., 1963).

11.2 EARTHQUAKES

A structure can be damaged by many different earthquake effects. Examples previously provided include a lack of shear resistance (Figs. 11.1 and 11.2) and poor construction practices (Fig. 11.3). The purpose of the following sections is to provide a brief summary of the common earthquake effects that need to be considered by the geotechnical engineer.

11.2.1 Fault and Ground Rupture Zone

Surface fault rupture caused by the earthquake is important because it has caused severe damage to buildings, bridges, dams, tunnels, canals, and underground utilities (Lawson et al., 1908; Ambraseys, 1960; Duke, 1960; California Department of Water Resources, 1967; Bonilla, 1970; Steinbrugge, 1970). Fault displacement is defined as the relative movement of the two sides of a fault, measured in a specific direction (Bonilla, 1970). Figure 11.4 shows the displacement of rock strata caused by the Carmel Valley Fault, located at Torry Pines, California.

Examples of very large surface fault rupture are the 11 m (35 ft) of vertical displacement in the Assam earthquake of 1897 (Oldham, 1899) and the 9 m (29 ft) of horizontal

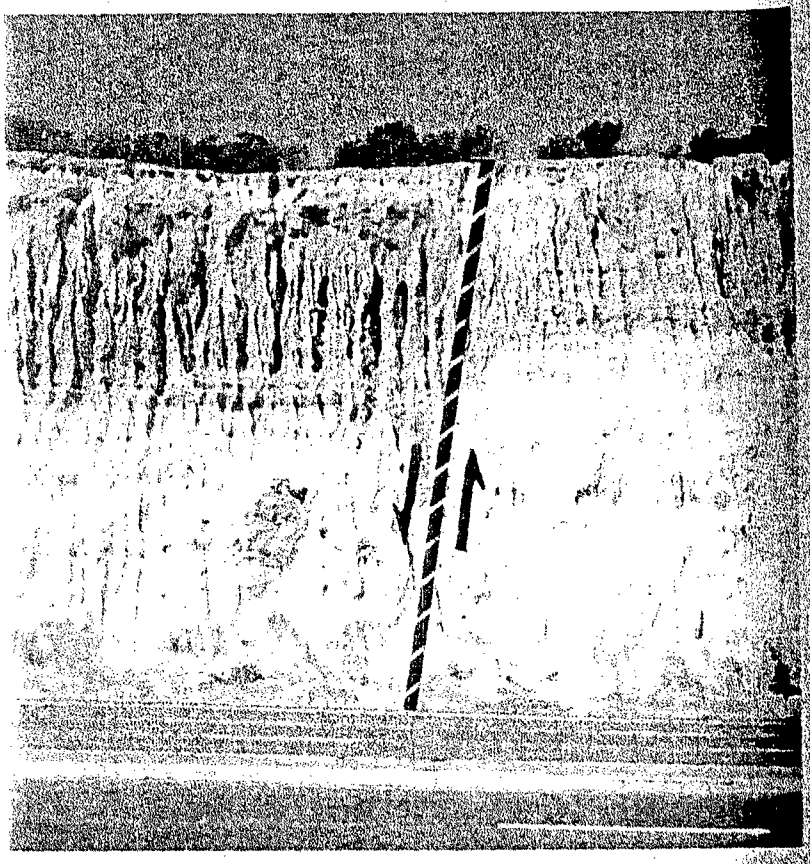

FIGURE 11.4 Carmel Valley Fault, located at Torry Pines, California.

movement during the Gobi-Altai earthquake of 1957 (Florensov and Solonenko, 1965). The length of the fault rupture can be quite significant. For example, the estimated length of surface faulting in the 1964 Alaskan earthquake varied from 600 to 720 km (Savage and Hastie, 1966; Housner, 1970).

A recent (geologically speaking) earthquake caused the fault rupture shown in Fig. 11.5. The fault is located at the base of the Black Mountains, in California. The vertical fault displacement caused by the earthquake is the vertical distance between the two arrows in Fig. 11.5. The fault displacement occurred in an alluvial fan being deposited at the base of the Black Mountains. Most structures would be unable to accommodate the huge vertical displacement shown in Fig. 11.5.

In addition to fault rupture, there can also be ground rupture away from the main trace of the fault. These ground cracks could be caused by many different factors, such as movement of subsidiary faults, auxiliary movement that branches off from the main fault trace, or ground rupture caused by the differential or lateral movement of underlying soil deposits. For example, Fig. 11.6 shows ground rupture during the 1994 Northridge,

California, earthquake. The direction of the ground shear movement shown in Fig. 11.6 is toward the northwest. The ground movement sheared both the concrete patio and adjacent pool and knocked the house off its foundation.

Since most structures will be unable to resist the shear movement associated with surface faulting and ground rupture, one design approach is to simply restrict construction in the active fault shear zone. The best individual to determine the location and width of the active fault shear zone is the engineering geologist. Seismic study maps, such as the *State of California Special Studies Zones Maps* (1982), which were developed as part of the Alquist-Priolo Special Studies Zones Act, delineate the approximate location of active fault zones that require special geologic studies. These maps also indicate the approximate locations of historic fault offsets, which are indicated by year of earthquake-associated event, as well as the locations of ongoing fault displacement due to fault creep. There are many other geologic references, such as the cross section shown in Fig. 4.2, that can be used to identify active shear fault zones. Trenches, such as shown in Figs. 4.20 and 4.21, can be excavated across the fault zone to more accurately identify the width of the active fault shear zone. Critical structures, such as essential transportation routes (see Sec. 2.2) that must cross the active shear fault zones, will need special designs to resist the earthquake forces induced by ground rupture.

11.2.2 Liquefaction

The typical subsurface condition that is susceptible to liquefaction is a loose or very loose sand that has been newly deposited or placed, with a groundwater table near ground surface. During an earthquake, the ground shaking causes the loose sand to contract, resulting in an increase in pore water pressure. Because the seismic shaking occurs so quickly, the

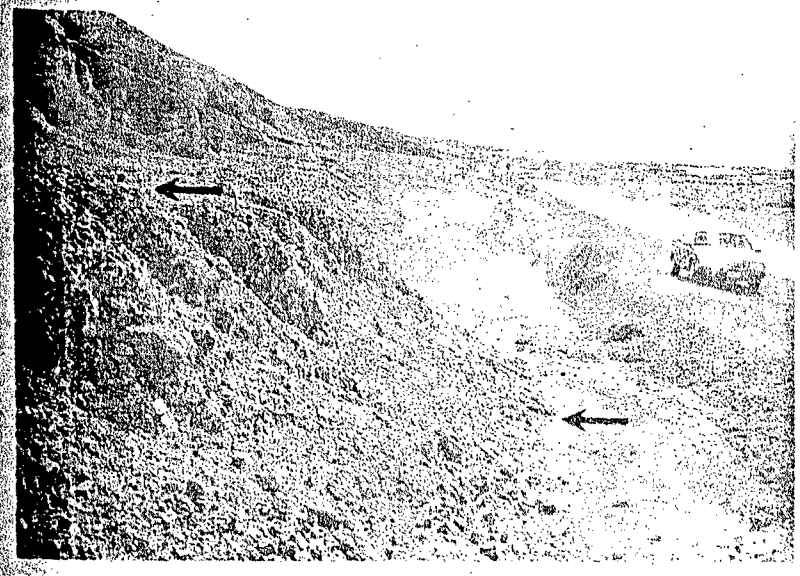

FIGURE 11.5 Fault rupture at the base of the Black Mountains (arrows indicate the amount of vertical displacement caused by the earthquake).

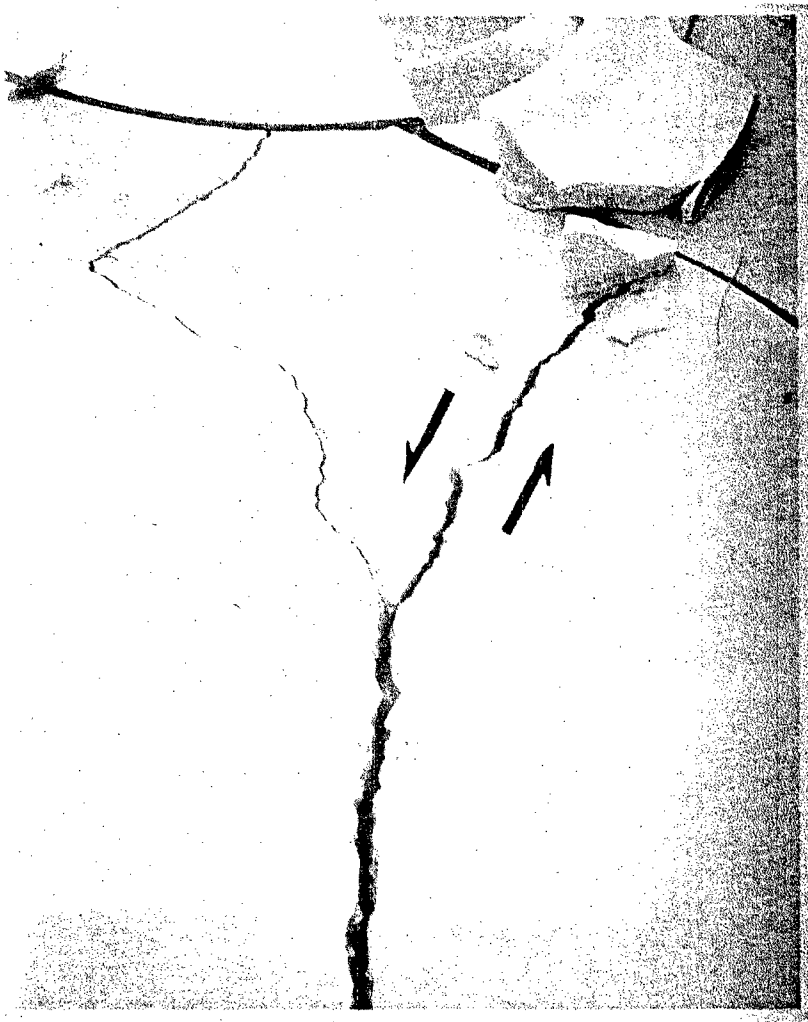

FIGURE 11.6 Ground rupture, 1994 Northridge, California, earthquake.

cohesionless soil is subjected to an undrained loading (total stress analysis). The increase in pore water pressure causes an upward flow of water to the ground surface, where it emerges in the form of mud spouts or sand boils. The development of high pore water pressures due to the ground shaking (i.e., the effective stress becomes zero) and the upward flow of water may turn the sand into a liquefied condition, which has been termed *liquefaction*. Structures on top of the loose sand deposit that has liquefied during an earthquake will sink or fall over, and buried tanks will float to the surface when the loose sand liquefies (Seed, 1970).

Liquefaction can also cause lateral movement of slopes and create flow slides (Ishihara, 1993). Seed (1970) states:

> If liquefaction occurs in or under a sloping soil mass, the entire mass will flow or translate laterally to the unsupported side in a phenomenon termed a flow slide. Such slides also develop in loose, saturated, cohesionless materials during earthquakes and are reported at Chile (1960), Alaska (1964), and Niigata (1964).

An example of lateral movement of liquefied sand is shown in Fig. 11.7 (from Kerwin and Stone, 1997). This damage occurred to a marine facility at Redondo Beach King Harbor during the 1994 Northridge, California, earthquake. The 5.5 m (18 ft) of horizontal displacement was caused by the liquefaction of an offshore sloping fill mass that was constructed as a part of the marine facility.

There can also be liquefaction of seams of loose saturated sands within a slope. This can cause the entire slope to move laterally along the liquefied layer at the base. These types of gross slope failures caused by liquefied seams of soil caused extensive damage during the 1964 Alaskan earthquake (Shannon and Wilson, Inc., 1964; Hansen, 1965). It has been observed that slope movement of this type typically results in little damage to structures located on the main slide mass, but buildings located in the graben area are subjected to large differential settlements and are often completely destroyed (Seed, 1970).

Main Factors for Liquefaction of Cohesionless Soil. There are many factors that govern the liquefaction process. The most important factors are as follows:

1. *Earthquake intensity and duration.* In order to have liquefaction of soil, there must be ground shaking. The character of the ground motion, such as acceleration and frequency content, determines the shear strains that cause the contraction of the soil particles and the development of excess pore water pressures leading to liquefaction. The most common

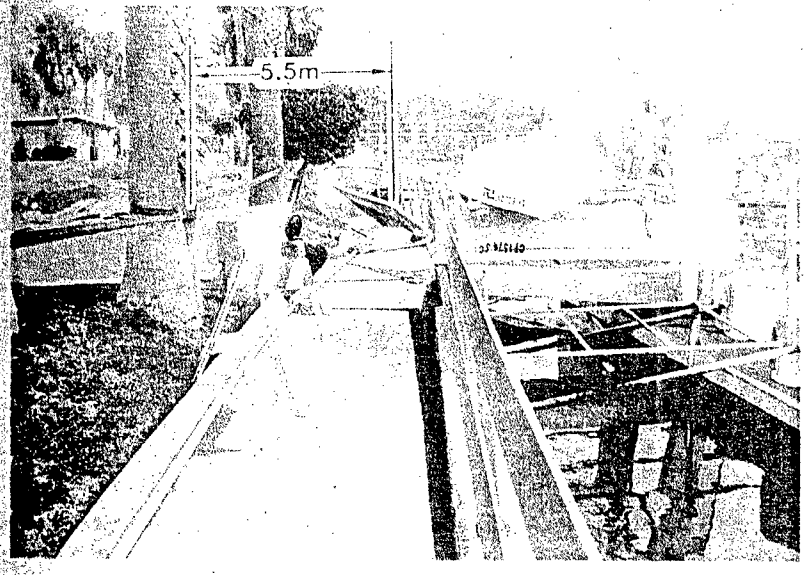

FIGURE 11.7 Damage to marine facility, 1994 Northridge, California, earthquake. (*From Kerwin and Stone, 1997; reprinted with permission from the American Society of Civil Engineers.*)

of liquefaction is the seismic energy released during an earthquake. The potential for liquefaction increases as the earthquake intensity and duration increase. Sites located near the epicenter of major earthquakes will be subjected to the largest intensity and duration of ground shaking (i.e., higher number of applications of cyclic shear strain). Besides earthquakes, other conditions can cause liquefaction, such as subsurface blasting.

2. *Groundwater table.* The condition most conducive to liquefaction is a near-surface groundwater table. Unsaturated soil located above the groundwater table will not liquefy.

3. *Soil type.* The soil types susceptible to liquefaction are nonplastic (cohesionless) soils. Seed et al. (1983) state that, on the basis of both laboratory testing and field performance, the great majority of clayey soils will not liquefy during earthquakes.

An approximate listing of cohesionless soils from least to most resistant to liquefaction are clean sands, nonplastic silty sands, nonplastic silt, and gravels. There could be numerous exceptions to this sequence. For example, Ishihara (1985, 1993) describes the case of tailings derived from the mining industry that were essentially composed of ground-up rocks and were classified as rock flour. Ishihara (1985, 1993) states that the rock flour in a water-saturated state did not possess significant cohesion and behaved as if it were a clean sand. These tailings were shown to exhibit as low a resistance to liquefaction as clean sand.

4. *Soil relative density D_r.* Cohesionless soils in a very loose relative density state are susceptible to liquefaction, while the same soil in a very dense relative density state will not liquefy. Very loose nonplastic soils will contract during the seismic shaking which will cause the development of excess pore water pressures. Very dense soils will dilate during seismic shaking and are not susceptible to liquefaction.

5. *Particle size gradation.* Poorly graded nonplastic soils tend to form more unstable particle arrangements and are more susceptible to liquefaction than well-graded soils.

6. *Placement conditions.* Hydraulic fills (fill placed under water) tend to be more susceptible to liquefaction because of the loose and segregated soil structure created by the soil particles falling through water.

7. *Drainage conditions.* If the excess pore water pressure can quickly dissipate, the soil may not liquefy. Thus gravel drains or gravel layers can reduce the liquefaction potential of adjacent soil.

8. *Confining pressures.* The greater the confining pressure, the less susceptible the soil is to liquefaction. Conditions that can create a higher confining pressure are a deeper groundwater table, soil that is located at a deeper depth below ground surface, and a surcharge pressure applied at ground surface. Case studies have shown that the possible zone of liquefaction usually extends from the ground surface to a maximum depth of about 15 m (50 ft). Deeper soils generally do not liquefy because of the higher confining pressures.

9. *Aging.* Newly deposited soils tend to be more susceptible to liquefaction than old deposits of soil. Older soil deposits may already have been subjected to seismic shaking or the soil particles may have deformed or been compressed into more stable arrangements.

Liquefaction Analysis. The most common type of analysis to determine the liquefaction potential is to use the standard penetration test (SPT) or the cone penetration test (CPT) (Seed et al., 1985; Stark and Olson, 1995). The analysis is based on the simplified method proposed by Seed and Idriss (1971). The method of analysis is as follows:

1. *Seismic shear stress ratio (SSR) caused by the earthquake.* The first step in the liquefaction analysis is to determine the seismic shear stress ratio (SSR). The seismic shear stress ratio induced by the earthquake at any point in the ground is estimated as follows (Seed and Idriss, 1971):

$$\text{SSR} = 0.65\, r_d \left(\frac{a_{max}}{g}\right)\left(\frac{\sigma_{v0}}{\sigma'_{v0}}\right) \qquad (11.1)$$

where SSR = seismic shear stress ratio (dimensionless parameter)

a_{max} = peak acceleration measured or estimated at the ground surface of the site (m/s^2)

g = acceleration of gravity (9.81 m/s^2)*

σ_{v0} = total vertical stress at a particular depth where the liquefaction analysis is being performed (kPa) (in order to calculate the total vertical stress, the total unit weight γ_t of the soil layers must be known)

σ'_{v0} = vertical effective stress at that same depth in the soil deposit where σ_{v0} was calculated (kPa) (in order to calculate the vertical effective stress, the location of the groundwater table must be known).

The term r_d = depth reduction factor, which can be estimated in the upper 10 m of soil as (Kayan et al., 1992):

$$r_d = 1 - (0.012)(z) \qquad (11.2)$$

where z = depth in meters below the ground surface where the liquefaction analysis is being performed (i.e., the same depth used to calculate σ_{v0} and σ'_{v0})

2. *Seismic shear stress ratio that will cause liquefaction of the soil.* The second step is to determine the seismic shear stress ratio (SSR) that will cause liquefaction of the *in situ* soil. Figure 11.8 presents a chart that can be used to determine the seismic shear stress ratio (SSR) that will cause liquefaction of the *in situ* soil. In order to use this chart, the results of the standard penetration test (SPT) must be expressed in terms of the SPT $(N_1)_{60}$ value. In liquefaction analysis, the SPT N_{60} value [Eq. (4.3)] is corrected for the overburden pressure. When a correction is applied to the SPT N_{60} value to account for the effect of overburden pressure, these values are referred to as SPT $(N_1)_{60}$ values. The procedure consists of multiplying the N_{60} value by a correction C_N in order to calculate the SPT $(N_1)_{60}$ value, or:

$$(N_1)_{60} = C_N N_{60} = (100/\sigma'_{v0})^{0.5} N_{60} \qquad (11.3)$$

where $(N_1)_{60}$ = standard penetration N-value corrected for both field testing procedures and overburden pressure

C_N = correction factor to account for the overburden pressure [as indicated in Eq. (11.3), C_N is approximately equal to $(100/\sigma'_{v0})^{0.5}$, where σ'_{v0} is the vertical effective stress in kPa]

N_{60} = standard penetration N-value corrected for testing procedures [note that N_{60} is calculated by using Eq. (4.3)]

Once the corrected SPT $(N_1)_{60}$ has been calculated, Fig. 11.8 can be used to determine the seismic shear stress ratio (SSR) that will cause liquefaction of the *in situ* soil. Note that Fig. 11.8 is for a projected earthquake of 7.5 magnitude. The figure also has different curves that are to be used according to the percent fines in the soil. For a given $(N_1)_{60}$ value,

*Usually the engineering geologist will determine the peak acceleration at the ground surface at the site from fault, seismicity, and attenuation studies. Typically the engineering geologist provides a peak ground acceleration in the form of a_{max}/g = a constant. For example, the engineering geologist may determine that the peak ground surface acceleration at a site is $a_{max}/g = 0.1$, in which case the value of 0.1 (dimensionless) is substituted into Eq. (11.1) in place of a_{max}/g.

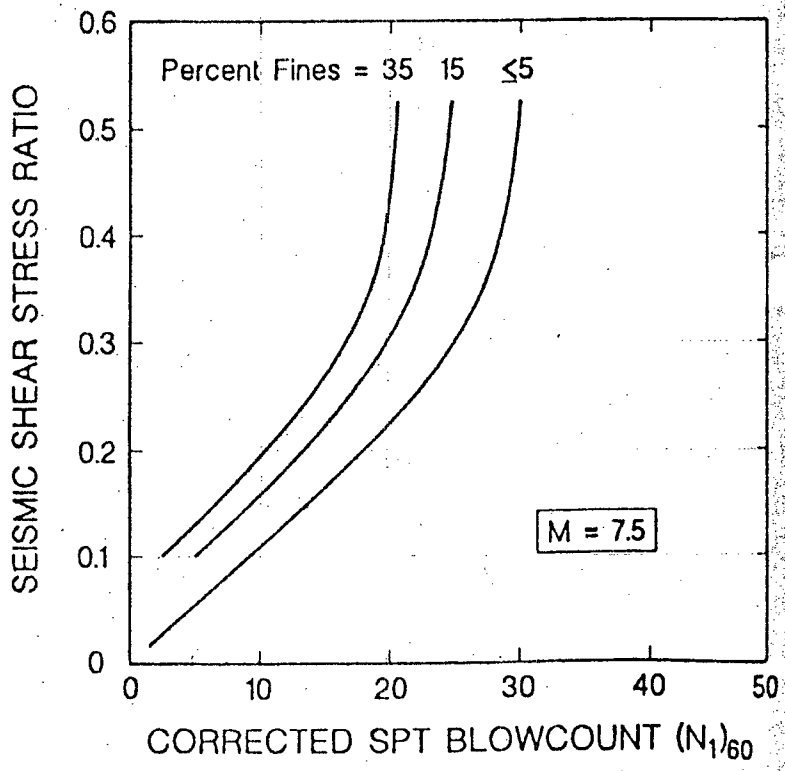

FIGURE 11.8 Relationship between seismic shear stress ratio (SSR) triggering liquefaction and $(N_1)_{60}$ values for clean and silty sands for $M = 7.5$ earthquakes. (*After Seed and DeAlba, 1986; reproduced from Stark and Olson, 1995; reprinted with permission of the American Society of Civil Engineers.*)

soils with more fines have a higher seismic shear stress ratio (SSR) that will cause liquefaction of the *in situ* soil.

Figure 11.9 presents a chart for clean sands (5 percent or less fines) and different magnitude earthquakes. The magnitude 7.5 curve in Fig. 11.9 is similar to the magnitude 7.5 curve for 5 percent or less fines in Fig. 11.8.

3. *Compare seismic shear stress ratios.* The final step in the liquefaction analysis is to compare the seismic shear stress ratio (SSR) values. If the SSR value from Eq. (11.1) is greater than the SSR value obtained from either Fig. 11.8 or Fig. 11.9, then liquefaction could occur during the earthquake, and vice versa.

Example. It is planned to construct a building on a cohesionless soil deposit (fines less than 5 percent). There is a nearby major active fault and the engineering geologist has determined that the peak ground acceleration $(a_{max}) = 0.4g$. Assume the site conditions are the same as stated in Prob. 18 (Chap. 6), i.e., a level ground surface with the groundwater table located 1.5 m below ground surface and the standard penetration test performed at a depth of 3 m. If the earthquake magnitude $(M) = 7.5$, will the saturated clean sand located at a depth of 3 m below ground surface liquefy during the anticipated earthquake?

Solution. From Prob. 18 (Chap. 6), $\sigma'_{v0} = 43$ kPa and $N_{60} = 5$. Using the total unit weights from Prob. 18 (Chap. 6), $\sigma_{v0} = 58$ kPa. Since $z = 3$ m, $r_d = 0.96$. Using the following values:

$$r_d = 0.96$$
$$a_{max}/g = 0.4$$
$$(\sigma_{v0}/\sigma'_{v0}) = (58/43) = 1.35$$

and inserting the above values into Eq. (11.1), we find the seismic shear stress ratio (SSR) caused by the earthquake is 0.34.

The next step is to determine the seismic shear stress ratio (SSR) that will cause liquefaction of the *in situ* soil. From Prob. 18 (Chap. 6), the N-value corrected for field testing procedures $(N_{60}) = 5$. Using Eq. (11.3) with $\sigma'_{v0} = 43$ kPa and $N_{60} = 5$, we find

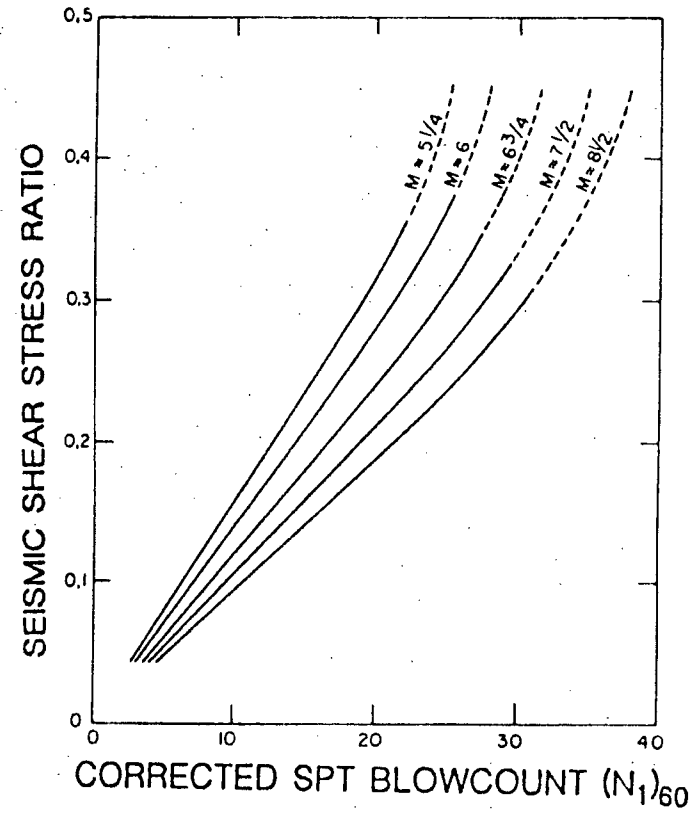

FIGURE 11.9 Relationship between seismic shear stress ratio (SSR) triggering liquefaction and $(N_1)_{60}$ values for clean sand for different magnitude earthquakes. (*After Seed et al., 1983; reprinted with permission of the American Society of Civil Engineers.*)

$_{60}$ = 8. Entering Fig. 11.8 with $(N_1)_{60}$ = 8 and intersecting the curve labeled ≤ fines, the seismic shear stress ratio (SSR) that will cause liquefaction of the *in situ* soil at a depth of 3 m = 0.08.

The final step is to compare the SSR caused by the earthquake (SSR = 0.34) with the SSR that will cause liquefaction of the *in situ* soil (SSR = 0.08). From a comparison of the SSR values, it is probable that during the earthquake the *in situ* sand located at a depth of 3 m below ground surface will liquefy.

In the above liquefaction analysis, there are many different equations and corrections that are applied to the seismic shear stress ratio (SSR). For example, there are four different corrections (E_m, C_b, C_r, and σ'_{v0}) that are applied to the SPT *N*-value in order to calculate the $(N_1)_{60}$ value. All of these different equations and various corrections may provide the engineer with a sense of high accuracy, when in fact, the entire analysis is only a gross approximation. The analysis should be treated as such and engineering experience and judgment are essential in the final determination of whether or not a site has liquefaction potential.

11.2.3 Slope Movement and Settlement

Besides liquefaction of loose saturated sands, other soil conditions can result in slope movement or settlement during an earthquake. For example, Grantz et al. (1964) describe an interesting case of ground vibrations from the 1964 Alaskan earthquake that caused 0.8 m (2.6 ft) of alluvium settlement. Other loose soils, such as cohesionless sand and gravel, will also be susceptible to settlement due to the ground vibrations from earthquakes.

Slopes having a low factor of safety can experience large horizontal movement during an earthquake. Types of slopes most susceptible to movement during earthquakes include those slopes composed of soil that loses shear strength with strain (such as sensitive soil) and ancient landslides that can become reactivated by seismic forces (Day and Poland, 1996).

11.2.4 Translation and Rotation

An unusual effect caused by earthquakes is translation and rotation of objects. For example, Fig. 11.10 shows a photograph of a brick mailbox that rotated and translated (moved laterally) during the Northridge earthquake. The initial position in Fig. 11.10 refers to the pre-earthquake position of the mailbox.

Earthquakes have caused the rotation of other movable objects, such as grave markers (Athanasopoulos, 1995; Yegian et al., 1994). According to Athanasopoulos (1995), such objects will rotate in such a manner as to be aligned with the strong component of the earthquake. Besides rotation, translation (lateral movement) can also occur during an earthquake. The objects will tend to move in the same direction as the propagation of energy waves, i.e., in a direction away from the epicenter of the earthquake.

11.3 ESTIMATING EARTHQUAKE GROUND MOVEMENT

Often the geotechnical engineer will be required to estimate the amount of foundation displacement caused by earthquake-induced soil movement. For example, the *Uniform*

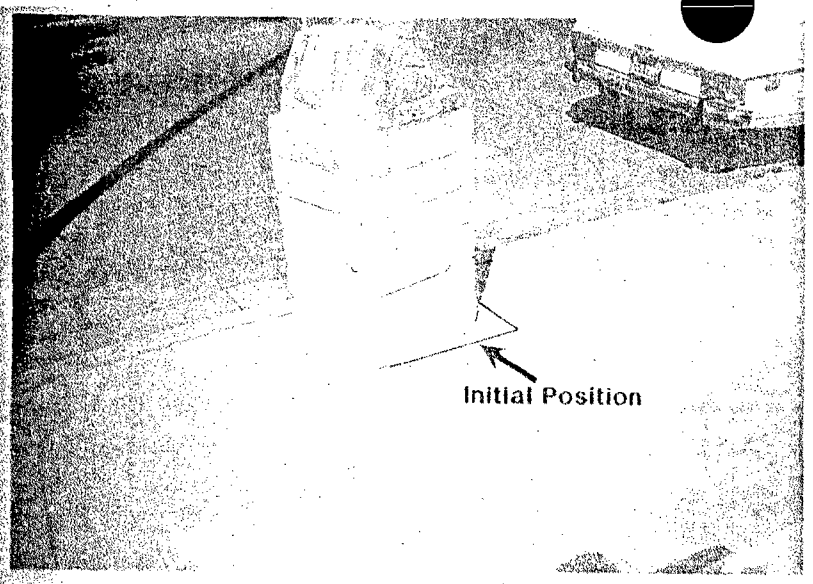

FIGURE 11.10 Rotation of brick mailbox, 1994 Northridge, California, earthquake.

Building Code (1997), which is the building code required for construction in California, states (code provision submitted by the author, adopted in May 1994):

> The potential for soil liquefaction and soil strength loss during earthquakes shall be evaluated during the geotechnical investigation. The geotechnical report shall assess potential consequences of any liquefaction and soil strength loss, including estimation of differential settlement, lateral movement or reduction in foundation soil-bearing capacity, and discuss mitigating measures. Such measures shall be given consideration in the design of the building and may include, but are not limited to, ground stabilization, selection of appropriate foundation type and depths, selection of appropriate structural systems to accommodate anticipated displacement or any combination of these measures.

The intent of this building code requirement is to obtain an approximate estimate of the foundation displacement caused by the earthquake induced soil movement. In terms of accuracy of the calculations used to determine the earthquake induced soil movement, Tokimatsu and Seed (1984) conclude:

> It should be recognized that, even under static loading conditions, the error associated with the estimation of settlement is on the order of ±25 to 50%. It is therefore reasonable to expect less accuracy in predicting settlements for the more complicated conditions associated with earthquake loadin.... In the application of the methods, it is essential to check that the final results are reasonable in light of available experience.

Pseudostatic Approach. A vast majority of foundation and earthwork designs are based on the pseudostatic approach (Coduto, 1994). This method ignores the cyclic nature of earthquakes and treats them as if they apply an additional static force upon the slope, retaining wall, or foundation element. For example, as will be discussed in Sec. 15.3, a common

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Appendix B

Settlement Analyses

MWH

By AS Date 6 May 07 Client Stoller / DOE Sheet 1 of 2

Chkd. By _____ Description _____ Job No. _____

ESTIMATING PRIMARY SETTLEMENT OF TAILINGS

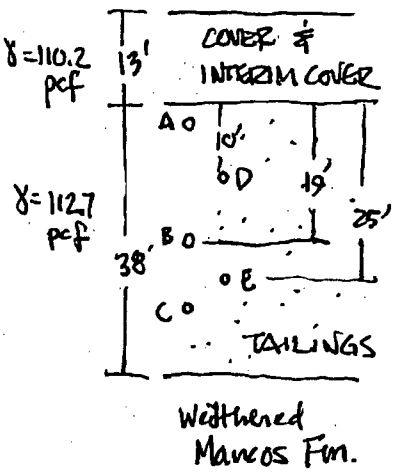
STRESSES AT A: $\sigma_1' = 113$ $\sigma_2' = 1433$ (in psf)

B: $\sigma_1' = 1578$ $\sigma_2' = 1433 + 1578 = 3011$

C: $\sigma_1' = 3156$ $\sigma_2' = 3156 + 1433 = 4589$

D: $\sigma_1' = 1127$ $\sigma_2' = 1127 + 1433 = 2560$

E: $\sigma_1' = 2818$ $\sigma_2' = 2818 + 1433 = 4251$



SETTLEMENT AT A: $\sigma_2'/\sigma_1' = 12.7$, $\log \sigma_2'/\sigma_1' = 1.10$

$$S = \frac{C_c}{1+e_0} H_0 \log \frac{\sigma_2'}{\sigma_1'} = \frac{0.2}{1+0.8} 1.0 \cdot 1.10 = 0.12 \text{ ft}$$

B: $\sigma_2'/\sigma_1' = 1.908$, $\log \sigma_2'/\sigma_1' = 0.28$

$$S = \frac{0.2}{1+0.8} \cdot 18 \cdot 0.28 = 0.56 \text{ ft}$$

C: $\sigma_2'/\sigma_1' = 1.454$, $\log \sigma_2'/\sigma_1' = 0.16$

$$S = \frac{0.2}{1+0.8} \cdot 19 \cdot 0.16 = 0.34 \text{ ft}$$

D: $\sigma_2'/\sigma_1' = 2.27$, $\log \sigma_2'/\sigma_1' = 0.356$

$$S = \frac{0.2}{1+0.8} \cdot 19 \cdot 0.356 = 0.75 \text{ ft}$$

E: $\sigma_2'/\sigma_1' = 1.509$, $\log \sigma_2'/\sigma_1' = 0.179$

$$S = \frac{0.2}{1+0.8} \cdot 19 \cdot 0.179 = 0.38 \text{ ft}$$

A+B+C = 1.02 ft, D+E = 1.13 ft

MWH

By CTS Date 6 May 07 Client Sheet 2 of 2

Chkd. By Description Job No.

ESTIMATING SECONDARY SETTLEMENT OF TAILINGS

From Keshian and Larson (1988) and Holtz and Kovacs (1981):

Secondary settlement, $S = C_\alpha H \log(t_2/t_1)$

H = tailings thickness = 38 ft

t_1 = 10 years (from tailings placement to cover construction)

t_2 = 1000 years (design life of disposal cell)

$\log(t_2/t_1) = 2.0$

C_α = secondary compression index

- From Keshian and Rager (1988), C_α for remolded sand/slime tailings ranged from 0.003 to 0.01
- From testing on Moab tailings (Shaw, 2006a and 2006b), C_α for remolded tailings ranged from 0.003 to 0.013
- From Holtz and Kovacs (1981), $C_\alpha/C_c = 0.05$ for inorganic soils. For $C_c = 0.20$, $C_\alpha = 0.01$

For $C_\alpha = 0.01$, $S = 0.01 \cdot 38 \cdot 2.0 = 0.76$ ft

0.003, $S = 0.003 \cdot 38 \cdot 2.0 = 0.23$ ft

Client:	**Stoller**	**Job No.:**	**181268**
Project:	**Crescent Junction Disposal Cell**	**Date:**	**5/8/2007**
Detail:	**Estimate Primary Settlement of Tailings**	**Computed By**	**CLS/RTS**

Tailings Property	Value	Source
Cc:	0.19	Shaw laboratory testing (2006b) mean value for transitional tailings
Specific Gravity:	2.8	Shaw laboratory testing (2006a) mean value for transitional tailings
Dry Unit Weight (pcf)	98	90% of Standard Proctor from average of transitional tailings (Golder 2006)
Moisture Content	19%	optimum mc of Standard Proctor from average of transitional tailings (Golder 2006)
eo	0.78	calculated

Layer	Moist Unit Weight (pcf)	H_o (ft)	Overburden Stress (soil) (psf)	Cover Soil Pressure (psf)	Total Stress (overburden + cover) (psf)	$C_c/1+e_o$	Incremental Settlement (ft)	Incremental Settlement (in)
0-2'	116.6	2.00	116.62	1433	1549.35	0.10	0.233	2.80
2-4'	116.6	2.00	349.86	1433	1782.59	0.10	0.147	1.76
4-6'	116.6	2.00	583.10	1433	2015.83	0.10	0.112	1.34
6-8'	116.6	2.00	816.34	1433	2249.07	0.10	0.091	1.10
8-10'	116.6	2.00	1049.58	1433	2482.31	0.10	0.078	0.93
10-12'	116.6	2.00	1282.82	1433	2715.55	0.10	0.068	0.81
12-14'	116.6	2.00	1516.06	1433	2948.79	0.10	0.060	0.72
14-16'	116.6	2.00	1749.30	1433	3182.03	0.10	0.054	0.65
16-18'	116.6	2.00	1982.54	1433	3415.27	0.10	0.049	0.59
18-20'	116.6	2.00	2215.78	1433	3648.51	0.10	0.045	0.54
20-22'	116.6	2.00	2449.02	1433	3881.75	0.10	0.042	0.50
22-24'	116.6	2.00	2682.26	1433	4114.99	0.10	0.039	0.46
24-26'	116.6	2.00	2915.50	1433	4348.23	0.10	0.036	0.43
26-28'	116.6	2.00	3148.74	1433	4581.47	0.10	0.034	0.41
28-30'	116.6	2.00	3381.98	1433	4814.71	0.10	0.032	0.38
30-32'	116.6	2.00	3615.22	1433	5047.95	0.10	0.030	0.36
32-34'	116.6	2.00	3848.46	1433	5281.19	0.10	0.029	0.34
34-36'	116.6	2.00	4081.70	1433	5514.43	0.10	0.027	0.33
36-38'	116.6	2.00	4314.94	1433	5747.67	0.10	0.026	0.31
						Total:	**1.23**	**14.8**

Appendix C

Cover Cracking Analyses

MWH

By CLS Date 6 May 2007 Client DOE / Stoller Sheet 1 of 1

Chkd. By RTS 5/10/07 Description Job No.

EVALUATION OF COVER CRACKING

From Caldwell and Reith (1993): allowable cover strain at failure = e_f (%)

$$e_f = 0.05 + 0.003\ PI$$

where PI = plasticity index of cover soil

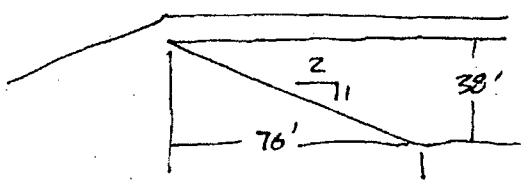
for alluvial material / weathered Mancos cover soil PI is 5 to 10

for PI = 5, $e_f = 0.05 + 0.003(5) = 0.065$ %

10, $e_f = 0.05 + 0.003(10) = 0.080$ %

The location of maximum differential settlement is along the inside slope of the embankment, from 0 to ~~1.8~~ 2.0 ft of settlement in 76 ft (for both primary and secondary settlement)

$\Delta = \cancel{1.8}\ 2.0$, $L = 76$ } $\Delta/L = \cancel{0.024}\ 0.0026$



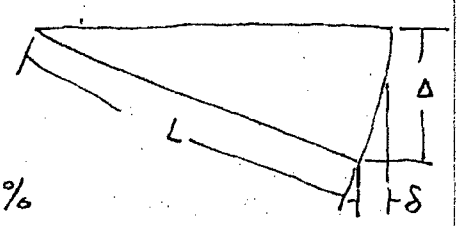
Checking Figure Z-16 in EPA (1991):

for distortion (Δ/L) of ~~0.024~~ 0.0026, tensile strain < 0.1 %

checking by geometry and linear distortion:

$$\delta = (L^2 + \Delta^2)^{1/2} - L = (76^2 + \cancel{1.8}^{2.0\,2})^{\frac{1}{2}} - 76$$

$$= \cancel{0.0213}\ 0.0263 \text{ ft}$$



tensile strain $= \epsilon = \dfrac{\delta}{L} = \dfrac{\cancel{0.0213}\ 0.0263}{76} = 0.03$ %

$\epsilon < e_f$ – therefore cover settlement is acceptable

U.S. Department of Energy—Grand Junction, Colorado

Calculation Cover Sheet

Calc. No.: MOA-02-09-2005-2-08-01 **Discipline:** Hydrology **No. of Sheets:** 4
Doc. No.: X0113000

Location: RAP Attachment 1, Appendix E

Project: Moab Project

Site: Crescent Junction Site Characterization

Feature: Site Drainage—Hydrology Parameters

Sources of Data:

Sources of Formulae and References:

DOE (U.S. Department of Energy), 1989. *Technical Approach Document, Revision II*, UMTRA-DOE/AL 050424.0002, U.S. Department of Energy Uranium Mill Tailings Remedial Action Project, December.

Preliminary Calc. ☐ **Final Calc.** ☒ **Supersedes Calc. No.** MOA-02-08-2005-2-08-00

Author:	[illegible]	5-31-07	**Checked by:**	S. Gray Stoll	6-7-07
	Name	Date		Name	Date
Approved by:	John E Elmer	5/31/07			
	Name	Date		Name	Date
				Name	Date
				D. Duffer	May 31, 07
				Name	Date

No text for this page

Problem Statement:

To determine the hydrometeorological characteristics of the Crescent Junction site, Utah, at 38.96° North, 109.80° West, elevation 4,950 feet (ft) above mean sea level (amsl) for the following designs during and after remedial action:

A. During remedial action at the disposal site:

1. 10-year, 60-minute storm to size ditches and erosion protection.
2. 10-year, 24-hour storm to size wastewater retention basins.
3. 25-year, 60-minute storm to size emergency spillway of the basins.

B. After remedial action at the disposal site:

1. Probable Maximum Precipitation (PMP) storm intensity and duration to size ditches and design erosion protection for ditches and embankment.

Method of Solution:

For remedial action at the disposal site, look up point-precipitation frequency estimates on the National Oceanic and Atmospheric Administration (NOAA) website and download the results.

For post-remedial action at the disposal site, use Hydrometeorological Report (HMR) No. 49 to calculate PMP storm intensity for general-storm PMP and the local-storm PMP. Select most intense storm for design purposes.

Assumptions:

Standard procedures used to calculate design storms and PMP will be protective of human life, infrastructure, and environment.

Calculation:

During remedial action, rainfall will be determined from the NOAA precipitation-frequency atlas for Utah (Appendix A).

The design storm information was downloaded from the NOAA website: http://hdsc.nws.noaa.gov/hdsc/pfds/sa/ut_pfds.html.

Point precipitation frequency estimates were drawn directly from http://hdsc.nws.noaa.gov/cgi-bin/hdsc/buildout.perl?type=pf&series=pd&units=us&statename=UTAH&stateabv=ut&study=sa&season=All&intype=3&plat=&plon=&liststation=THOMPSON+++++++++++++++++UT+%2C+42-8705&slat=38.96&slon=-109.8&mlat=40.051&mlon=-108.490&elev=0&xy0=lat&xy1=-lon&xy2=lat&xy3=-lon&xy4=lat&xy5=-lon&xy6=lat&xy7=-lon&xy8=lat&xy9=-lon&xy10=lat&xy11=-lon&xy12=lat&xy13=-lon&xy14=lat&xy15=-lon&xy16=lat&xy17=-lon&xy18=lat&xy19=-lon&xy20=lat&xy21=-lon&xy22=lat&xy23=-lon. The data from this website are presented in Appendix A. The design-storm data are presented in Table 1.

After remediation, rainfall will be determined for the Crescent Junction Disposal Site from the general storm PMP or the local-storm PMP; whichever is more severe, according to HMR No. 49 (Appendix B). The watershed areas of the proposed diversion ditch (if required), and the proposed tailings site are each less than 10 square miles (mi^2); therefore, no depth-area correction is required for the PMP. The basin area of the Crescent Wash drainage is 22 mi^2; therefore a depth-area correction of 98 percent is required to compute the general storm PMP. The minimum site elevation for the project is approximately 4,950 ft amsl. The wet season of the site is from July to October. The general-storm PMP and the local-storm PMP are calculated as shown in Appendix B. The maximum general-storm PMP, which occurs during the month of August, has an estimated maximum intensity of 4.7 inches in 6 hours. A comparison of the

general-storm and the local-storm PMPs indicates that the intensity of the local-storm PMP, which carries an estimated depth of 7.4 inches in 6 hours, exceeds the intensity of the general-storm PMP; consequently, the local-storm PMP should be used for engineering design purposes in accordance with Section 4.1.3 of the Technical Approach Document (DOE 1989). The estimated precipitation depths for the local-storm PMP are presented in Table 2.

Discussion:

Not applicable.

Conclusions and Recommendations:

Table 1. Summary of Design Storm Data for the Crescent Junction, Utah, Site

Recurrence Interval (years)	Rainfall Inches for Duration Hours	
	60 minute	24 hour
10	0.8 inches	1.63 inches
25	1.07 inches	

Table 2. Estimated Precipitation Depths for Local-Storm PMP, Crescent Junction, Utah, Site

Hourly Increments	First Hour	Second Hour	Third Hour				Fourth Hour	Fifth Hour	Sixth Hour
PMP Depths (inches)	0.1	0.3	6.0				0.7	0.2	0.1
Third-Hour Component Depths (inches)			4.3	0.8	0.6	0.3			

Computer Source:

Not applicable

Appendix A

Point Precipitation Frequency Estimates From NOAA Atlas 14

POINT PRECIPITATION FREQUENCY ESTIMATES FROM NOAA ATLAS 14

Utah 38.96 N 109.8 W 4954 feet

from "Precipitation-Frequency Atlas of the United States" NOAA Atlas 14, Volume 1, Version 3
G.M. Bonnin, D. Todd, B. Lin, T. Parzybok, M.Yekta, and D. Riley
NOAA, National Weather Service, Silver Spring, Maryland, 2003

Extracted: Thu Jul 7 2005

Confidence Limits | Seasonality | Location Maps | Other Info. | Grids | Maps | Help | Docs

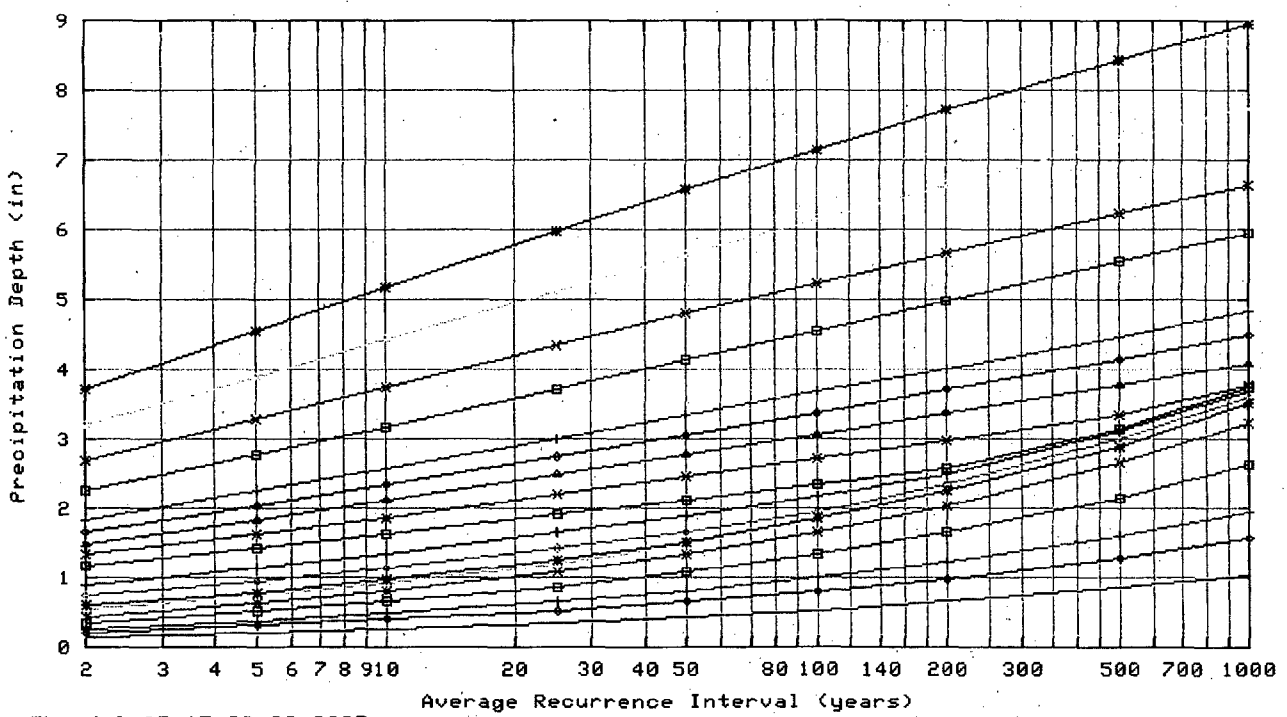
Precipitation Frequency Estimates (inches)

ARI* (years)	5 min	10 min	15 min	30 min	60 min	120 min	3 hr	6 hr	12 hr	24 hr	48 hr	4 day	7 day	10 day	20 day	30 day	45 day	60 day
2	0.14	0.21	0.26	0.35	0.44	0.53	0.59	0.73	0.89	1.16	1.34	1.49	1.66	1.83	2.25	2.70	3.19	3.71
5	0.20	0.30	0.38	0.51	0.62	0.73	0.79	0.94	1.15	1.42	1.64	1.83	2.03	2.24	2.77	3.29	3.89	4.54
10	0.25	0.39	0.48	0.65	0.80	0.91	0.97	1.13	1.36	1.63	1.87	2.10	2.33	2.57	3.18	3.75	4.42	5.16
25	0.34	0.52	0.64	0.87	1.07	1.21	1.26	1.42	1.65	1.91	2.20	2.47	2.75	3.01	3.73	4.34	5.12	5.97
50	0.42	0.65	0.80	1.08	1.34	1.49	1.52	1.66	1.90	2.12	2.45	2.76	3.05	3.34	4.14	4.79	5.64	6.56
100	0.53	0.80	0.99	1.33	1.65	1.82	1.84	1.95	2.16	2.35	2.71	3.05	3.38	3.68	4.56	5.23	6.15	7.14
200	0.65	0.98	1.22	1.64	2.03	2.23	2.25	2.35	2.47	2.58	2.98	3.36	3.71	4.01	4.97	5.66	6.64	7.71
500	0.84	1.28	1.59	2.15	2.65	2.88	2.89	3.00	3.11	3.15	3.34	3.77	4.15	4.47	5.54	6.22	7.28	8.43
1000	1.03	1.57	1.94	2.62	3.24	3.49	3.50	3.60	3.69	3.73	3.77	4.09	4.50	4.82	5.95	6.63	7.75	8.95

Text version of table

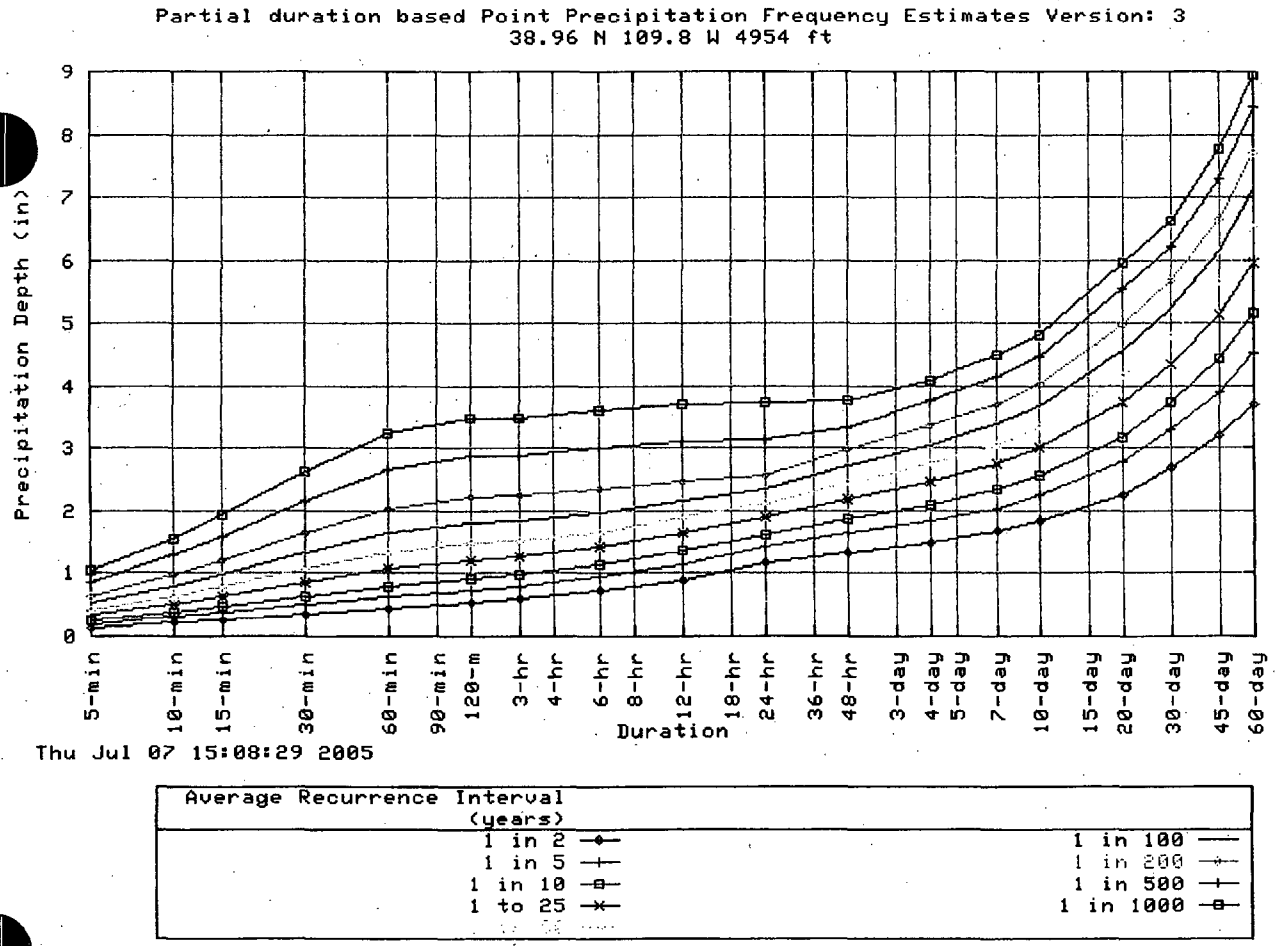
* These precipitation frequency estimates are based on a partial duration series. ARI is the Average Recurrence Interval. Please refer to the documentation for more information. NOTE: Formatting forces estimates near zero to appear as zero.

Partial duration based Point Precipitation Frequency Estimates Version: 3
38.96 N 109.8 W 4954 ft



Thu Jul 07 15:08:29 2005

Duration			
5-min		48-hr	30-day
10-min	3-hr	4-day	
15-min	6-hr	7-day	60-day
30-min	12-hr	10-day	
60-min	24-hr	20-day	



Confidence Limits -

* Upper bound of the 90% confidence interval Precipitation Frequency Estimates (inches)																		
ARI** (years)	5 min	10 min	15 min	30 min	60 min	120 min	3 hr	6 hr	12 hr	24 hr	48 hr	4 day	7 day	10 day	20 day	30 day	45 day	60 day
2	0.16	0.25	0.30	0.41	0.51	0.60	0.66	0.82	1.00	1.25	1.43	1.61	1.80	1.99	2.46	2.92	3.45	4.02
5	0.23	0.35	0.43	0.58	0.72	0.83	0.88	1.06	1.27	1.52	1.74	1.96	2.19	2.42	3.02	3.56	4.19	4.89
10	0.29	0.44	0.55	0.74	0.92	1.03	1.09	1.28	1.50	1.75	1.99	2.24	2.51	2.77	3.45	4.06	4.76	5.55
25	0.40	0.60	0.75	1.00	1.24	1.38	1.43	1.60	1.85	2.06	2.35	2.65	2.96	3.25	4.04	4.71	5.51	6.41
50	0.50	0.76	0.94	1.26	1.56	1.71	1.73	1.90	2.12	2.32	2.63	2.95	3.29	3.62	4.50	5.20	6.08	7.08
100	0.62	0.94	1.16	1.56	1.94	2.11	2.13	2.25	2.46	2.59	2.94	3.28	3.66	4.01	4.99	5.71	6.65	7.74
200	0.77	1.17	1.45	1.95	2.41	2.61	2.63	2.75	2.86	2.87	3.26	3.65	4.05	4.41	5.47	6.22	7.21	8.41
500	1.02	1.55	1.93	2.60	3.21	3.47	3.49	3.58	3.67	3.70	3.71	4.15	4.62	4.96	6.15	6.91	7.97	9.27
1000	1.27	1.94	2.40	3.24	4.01	4.28	4.30	4.37	4.42	4.47	4.51	4.58	5.08	5.43	6.69	7.42	8.55	9.96

* The upper bound of the confidence interval at 90% confidence level is the value which 5% of the simulated quantile values for a given frequency are greater than.
** These precipitation frequency estimates are based on a partial duration series. ARI is the Average Recurrence Interval.
Please refer to the documentation for more information. NOTE: Formatting prevents estimates near zero to appear as zero.

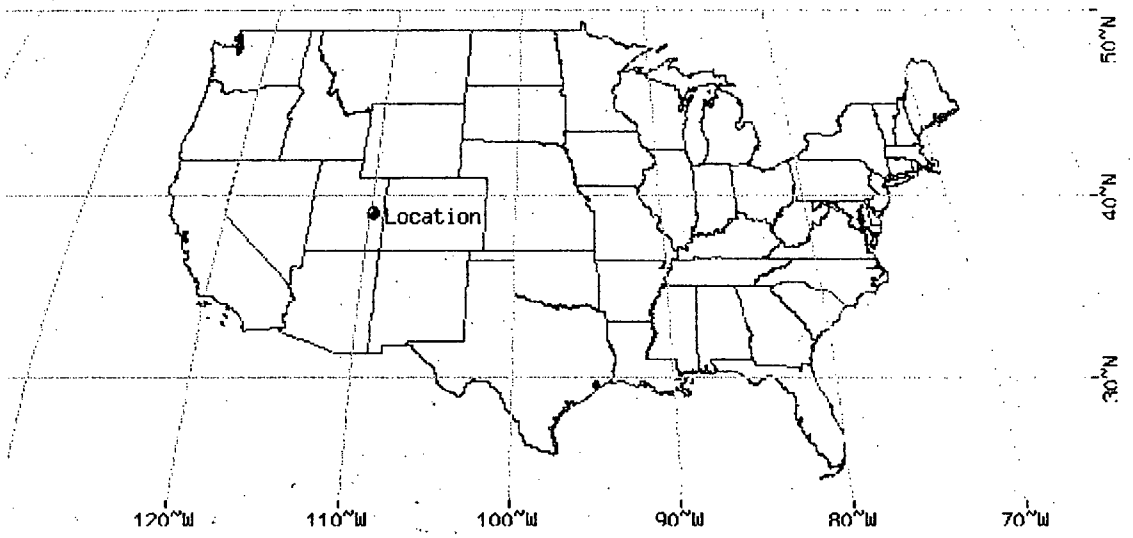
*** Lower bound of the 90% confidence interval Precipitation Frequency Estimates (inches)**

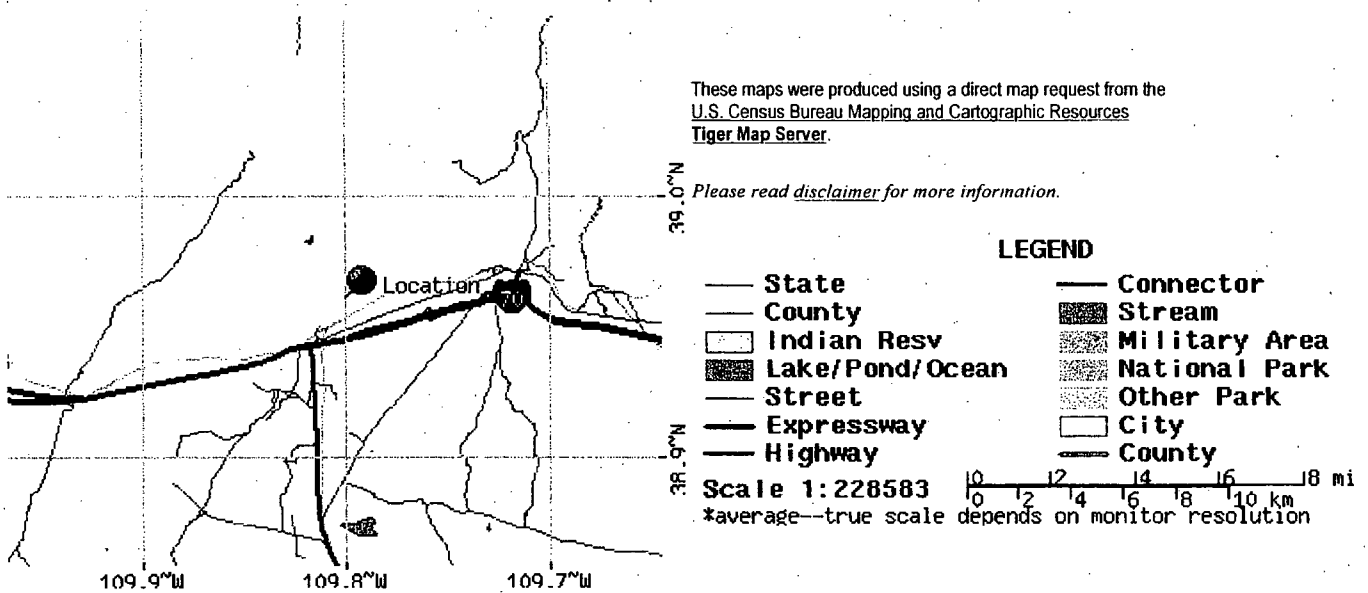
ARI** (years)	5 min	10 min	15 min	30 min	60 min	120 min	3 hr	6 hr	12 hr	24 hr	48 hr	4 day	7 day	10 day	20 day	30 day	45 day	60 day
2	0.12	0.19	0.23	0.31	0.39	0.47	0.53	0.66	0.81	1.09	1.26	1.40	1.56	1.71	2.08	2.50	2.94	3.44
5	0.17	0.26	0.33	0.44	0.54	0.65	0.70	0.85	1.03	1.33	1.53	1.70	1.89	2.08	2.56	3.03	3.58	4.19
10	0.22	0.33	0.41	0.55	0.69	0.79	0.86	1.01	1.21	1.52	1.75	1.95	2.16	2.38	2.91	3.44	4.07	4.76
25	0.29	0.44	0.54	0.73	0.91	1.03	1.09	1.25	1.47	1.78	2.04	2.27	2.52	2.76	3.40	3.98	4.67	5.47
50	0.35	0.53	0.66	0.89	1.10	1.24	1.29	1.44	1.67	1.97	2.25	2.51	2.77	3.04	3.75	4.36	5.12	5.98
100	0.42	0.64	0.80	1.07	1.33	1.48	1.54	1.66	1.88	2.17	2.46	2.74	3.02	3.30	4.09	4.71	5.53	6.45
200	0.50	0.76	0.94	1.27	1.57	1.75	1.82	1.96	2.12	2.35	2.66	2.98	3.27	3.55	4.41	5.05	5.91	6.88
500	0.62	0.94	1.17	1.58	1.95	2.16	2.25	2.43	2.61	2.64	2.92	3.27	3.59	3.87	4.83	5.46	6.39	7.42
1000	0.73	1.11	1.37	1.85	2.29	2.51	2.63	2.85	3.06	3.09	3.12	3.49	3.81	4.10	5.12	5.74	6.73	7.80

* The lower bound of the confidence interval at 90% confidence level is the value which 5% of the simulated quantile values for a given frequency are less than.
** These precipitation frequency estimates are based on a partial duration maxima series. ARI is the Average Recurrence Interval.

Please refer to the documentation for more information. NOTE: Formatting prevents estimates near zero to appear as zero.

Maps -





Other Maps/Photographs -

w USGS digital orthophoto quadrangle (DOQ) covering this location from TerraServer; **USGS Aerial Photograph** also be available
n this site. A DOQ is a computer-generated image of an aerial photograph in which image displacement caused by terrain ef and camera tilts has been removed. It combines the image characteristics of a photograph with the geometric qualities of a map. Visit the USGS for more information.

Watershed/Stream Flow Information -

Find the Watershed for this location using the U.S. Environmental Protection Agency's site.

Climate Data Sources -

Precipitation frequency results are based on data from a variety of sources, but largely NCDC. The following links provide general information
about observing sites in the area, regardless of if their data was used in this study. For detailed information about the stations used in this study,
please refer to our documentation.

Using the **National Climatic Data Center's (NCDC)** station search engine, locate other climate stations within:

+/-30 minutes ...OR... +/-1 degree of this location (38.96/-109.8). Digital ASCII data can be obtained directly from **NCDC**.

Find Natural Resources Conservation Service (NRCS) SNOTEL (SNOwpack TELemetry) stations by visiting the **Western Regional Climate Center's state-specific SNOTEL station maps**.

---

drometeorological Design Studies Center
DOC/NOAA/National Weather Service
1325 East-West Highway
Silver Spring, MD 20910
(301) 713-1669
Questions?: HDSC.Questions@noaa.gov

Disclaimer

Appendix B

General-Storm and Local-Storm PMP Estimates

General Storm PMP Computation
July

Table 6.1.--General-storm PMP computations for the Colorado River and Great basin

Drainage Crescent Junction Disposal Site Elev 5000 Area less than 1 mi^2 (km^2)

Latitude 38°57'50"N (38.96°N) Longitude ___ of basin center 109° 48' 00" W (109.80°W)

Month July

Step		Duration (hrs) 6	12	18	24	48	72
A. Convergence PMP							
1. Drainage average value from one of figures 2.5 to 2.16	11.5 in. (~~mm~~)						
2. Reduction for barrier-elevation [fig. 2.18]	50 %						
3. Barrier-elevation reduced PMP [step 1 X step 2]	5.8 in. (~~mm~~)						
4. Durational variation [figs. 2.25 to 2.27 and table 2.7].		69	86	94	100	115	121 %
5. Convergence PMP for indicated durations [steps 3 X 4]		4.0	5.0	5.4	5.8	6.7	7.0 in. (~~mm~~)
6. Incremental 10 mi^2 (26 km^2) PMP [successive subtraction in step 5]		4.0	1.0	0.4	0.4	0.9	0.3 in. (~~mm~~)
7. Areal reduction [select from figs. 2.28 and 2.29]		95	98	98	100	100	100 %
8. Areally reduced PMP [step 6 X step 7]		3.8	1.0	0.4	0.4	0.9	0.3 in. (~~mm~~)
9. Drainage average PMP [accumulated values of step 8]		3.8	4.8	5.2	5.6	6.5	6.8 in. (~~mm~~)
B. Orographic PMP							
1. Drainage average orographic index from figure 3.11a to d.	2.0 in. (~~mm~~)						
2. Areal reduction [figure 3.20]	98 %						
3. Adjustment for month [one of figs. 3.12 to 3.17]	99 %						
4. Areally and seasonally adjusted PMP [steps 1 X 2 X 3]	1.94 in. (~~mm~~)						
5. Durational variation [table 3.9]		30	57	80	100	157	185 %
6. Orographic PMP for given durations [steps 4 X 5]		0.6	1.1	1.6	2.0	3.1	3.7 in. (~~mm~~)
C. Total PMP							
1. Add steps A9 and B6		4.4	5.9	6.8	7.6	9.6	10.5 in. (~~mm~~)

2. PMP for other durations from smooth curve fitted to plot of computed data.

3. Comparison with local-storm PMP (see sec. 6.3).

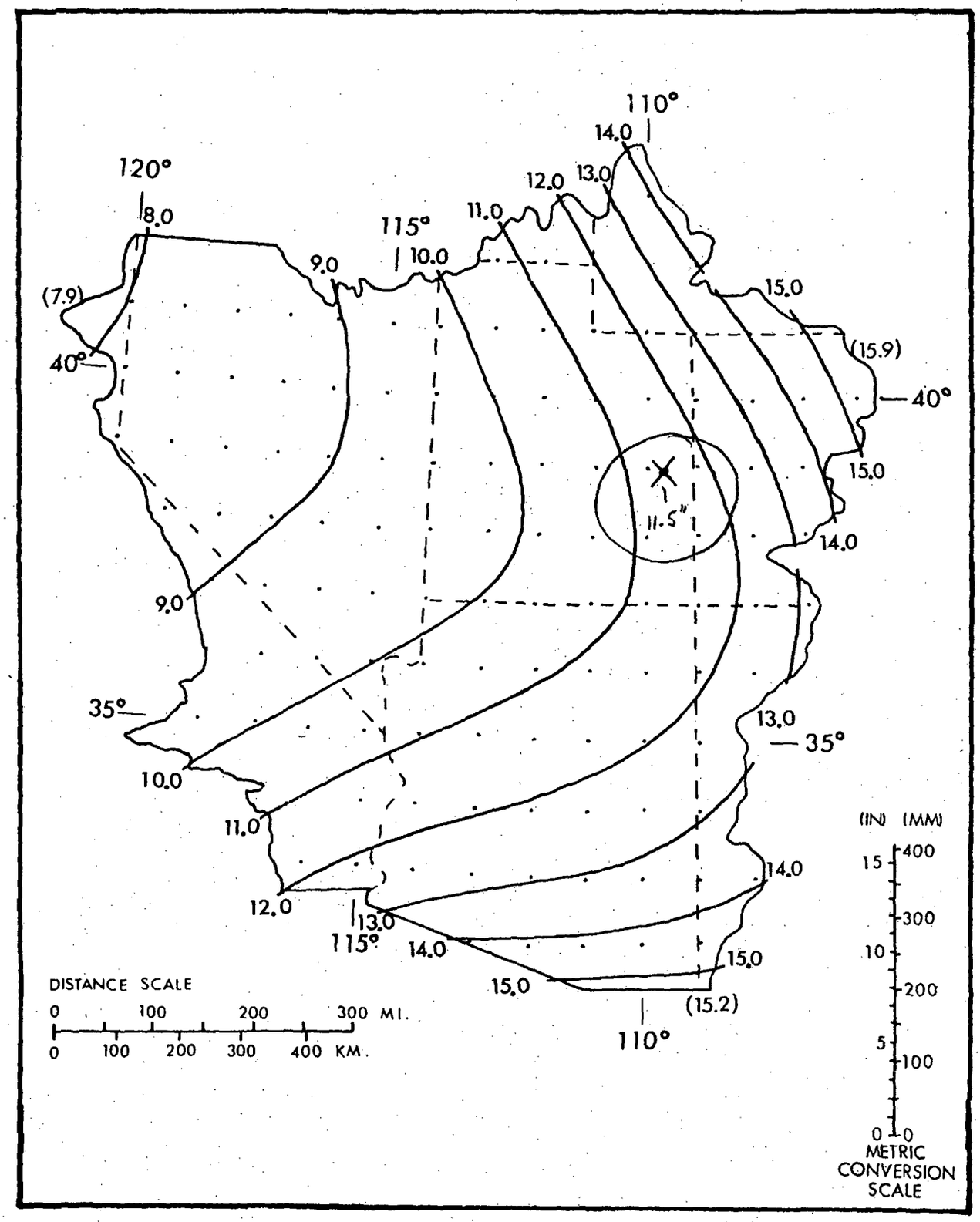


Figure 2.11.--1000-mb (100-kPa) 24-hr convergence PMP (inches) for 10 mi² (26 km²) for July. Values in parentheses are limiting values and are to facilitate extrapolation beyond the indicated gradient.

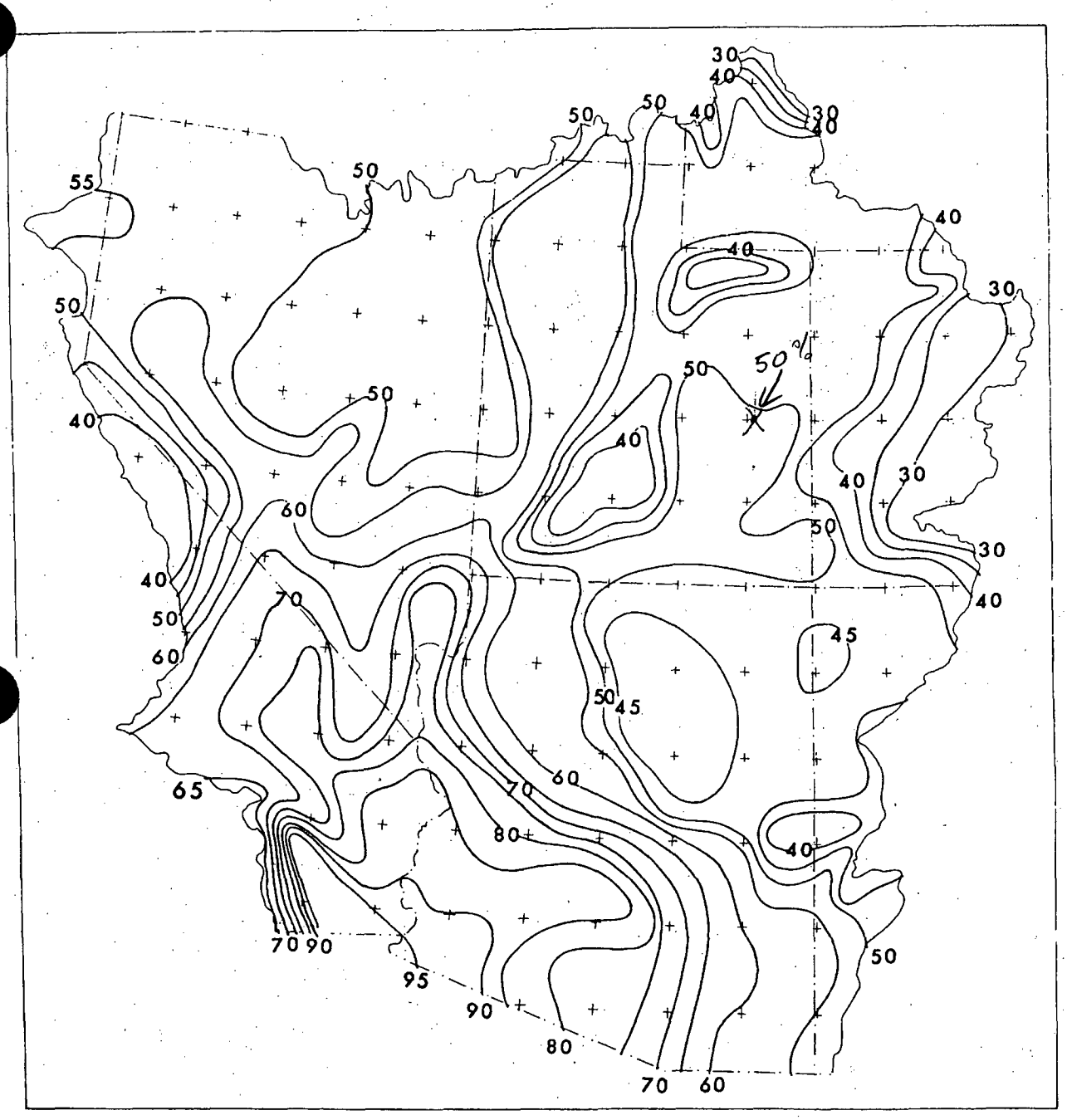
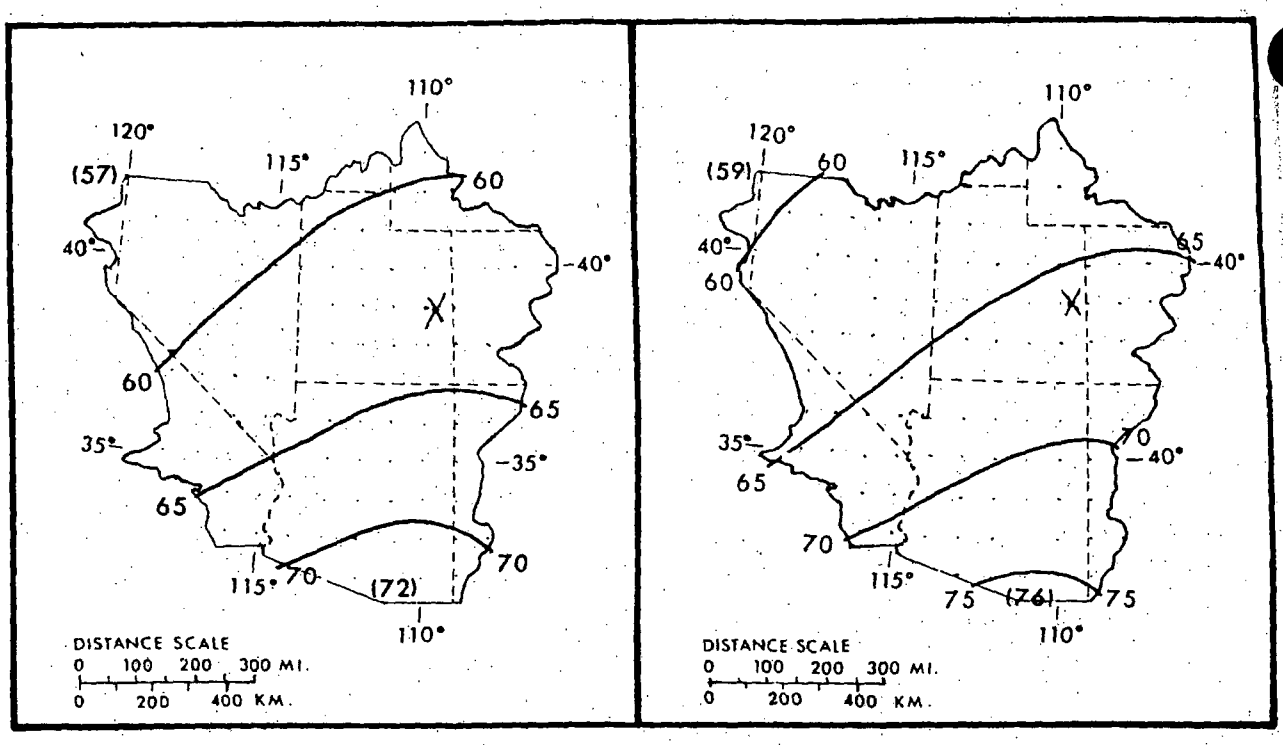
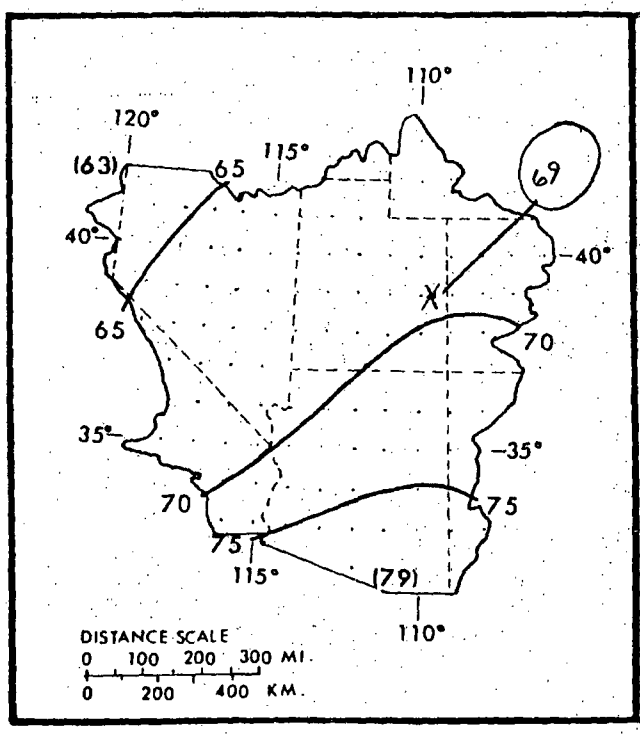


Figure 2.18.--Percent of 1000-mb (100-kPa) convergence PMP resulting from effective elevation and barrier considerations. Isolines drawn for every five percent.

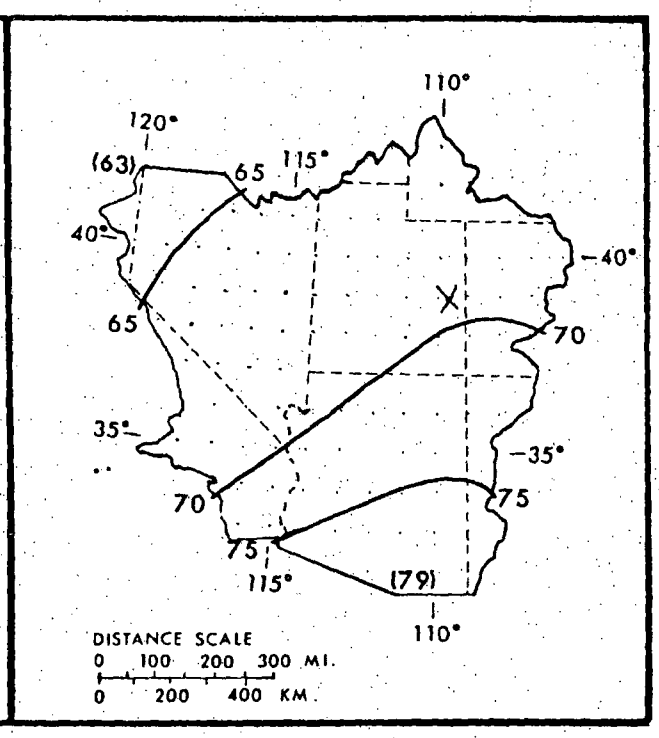


May

June



July



August

Figure 2.26.--Regional variation of 6/24-hr ratios by month (percent). Values in parentheses are limiting values and are to facilitate extrapolation beyond the indicated gradient.

July PMP

For the range of 6/24-hr ratios included in figures 2.25 to 2.27, depth-duration values in percent of 24-hr amounts are found in table 2.7. The regional ratio maps, and the depth-duration curves presented in figure 2.20 were used in adjusting the major storm data to 24-hr amounts listed in table 2.1.

Table 2.7.--Durational variation of convergence PMP (in percent of 24-hr amount).

Duration (Hrs)						Duration (Hrs)					
6	12	18	24	48	72	6	12	18	24	48	72
50	76	90	100	129	150	66	84	93	100	116	124
51	77	90	100	128	148	67	85	94	100	116	123
52	77	90	100	127	146	68	85	94	100	115	122
53	77	91	100	127	144	69	86	94	100	115	121
54	78	91	100	126	142						
55	78	91	100	125	140	70	87	94	100	114	120
56	79	91	100	124	138	71	87	95	100	114	119
57	79	92	100	123	137	72	88	95	100	113	118
58	80	92	100	122	135	73	88	95	100	113	118
59	80	92	100	121	134	74	89	95	100	112	117
						75	89	96	100	112	116
60	81	92	100	120	132	76	90	96	100	111	115
61	81	92	100	120	131	77	90	96	100	110	114
62	82	93	100	119	129	78	91	96	100	110	114
63	82	93	100	118	128	79	92	97	100	109	113
64	83	93	100	117	126						
65	84	93	100	117	125	80	92	97	100	109	113

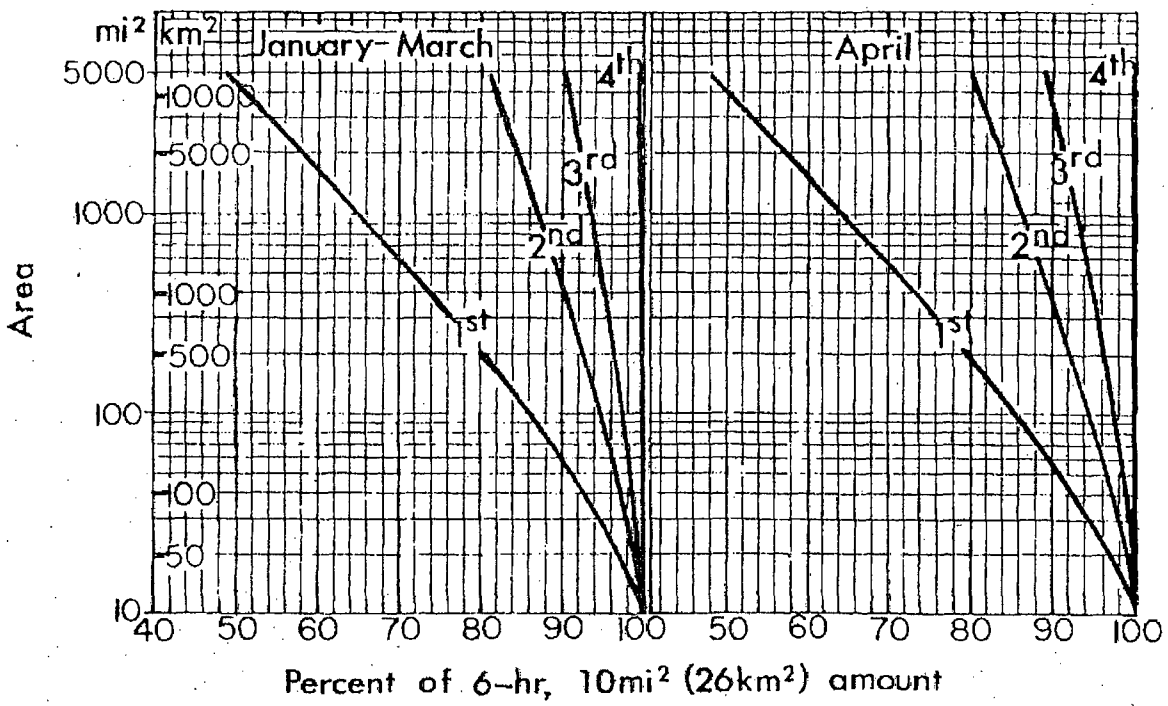
Note: For use, enter first column (6 hr) with 6/24-hr ratio from figures 2.25 to 2.27.

2.5 Areal Reduction for Basin Size

For operational use, basin average values of convergence PMP are needed rather than 10-mi^2 (26-km^2) values. Preferably, the method for reducing 10-mi^2 (26-km^2) values to basin average rainfalls should be derived from depth-area relations of storms in the region. However, all general storms in the region include large proportions of orographic precipitation.

Our solution was to use generalized depth-area relations developed for PMP estimates within bordering zones in the Central and Eastern United States (Riedel et al. 1956). The smoothed areal variations adopted for the Southwestern States are shown in figures 2.28 and 2.29 for each month or a combination of months where differences are insignificant.

Figures 2.28 and 2.29 give depth-area relations that reduce 10-mi^2 (26-km^2) convergence PMP for basin sizes up to 5,000 mi^2 (12,950 km^2) for each month. Areal variations are given for the 4 greatest (1st to 4th) 6-hr PMP increments. After the 4th increment no reduction for basin size is required. Application of these figures will become clear through consideration of an example of PMP computation in chapter 6.



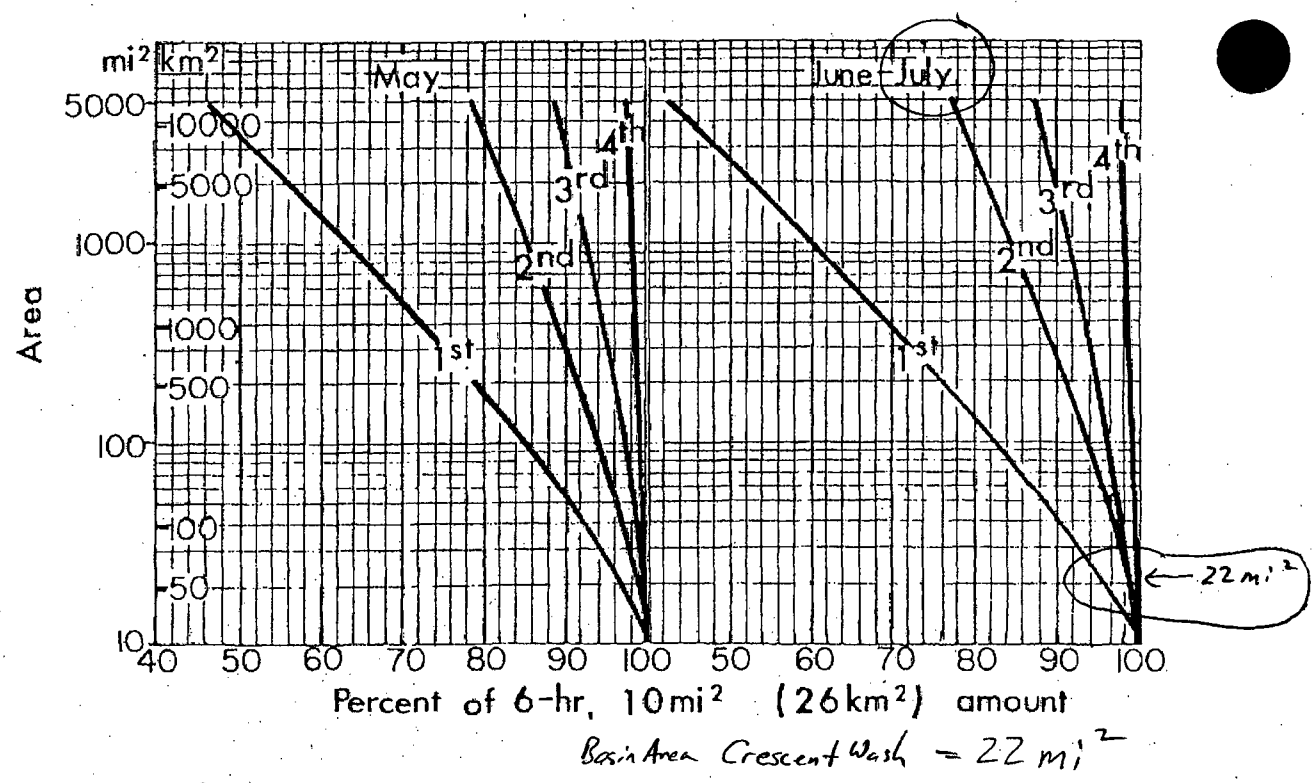
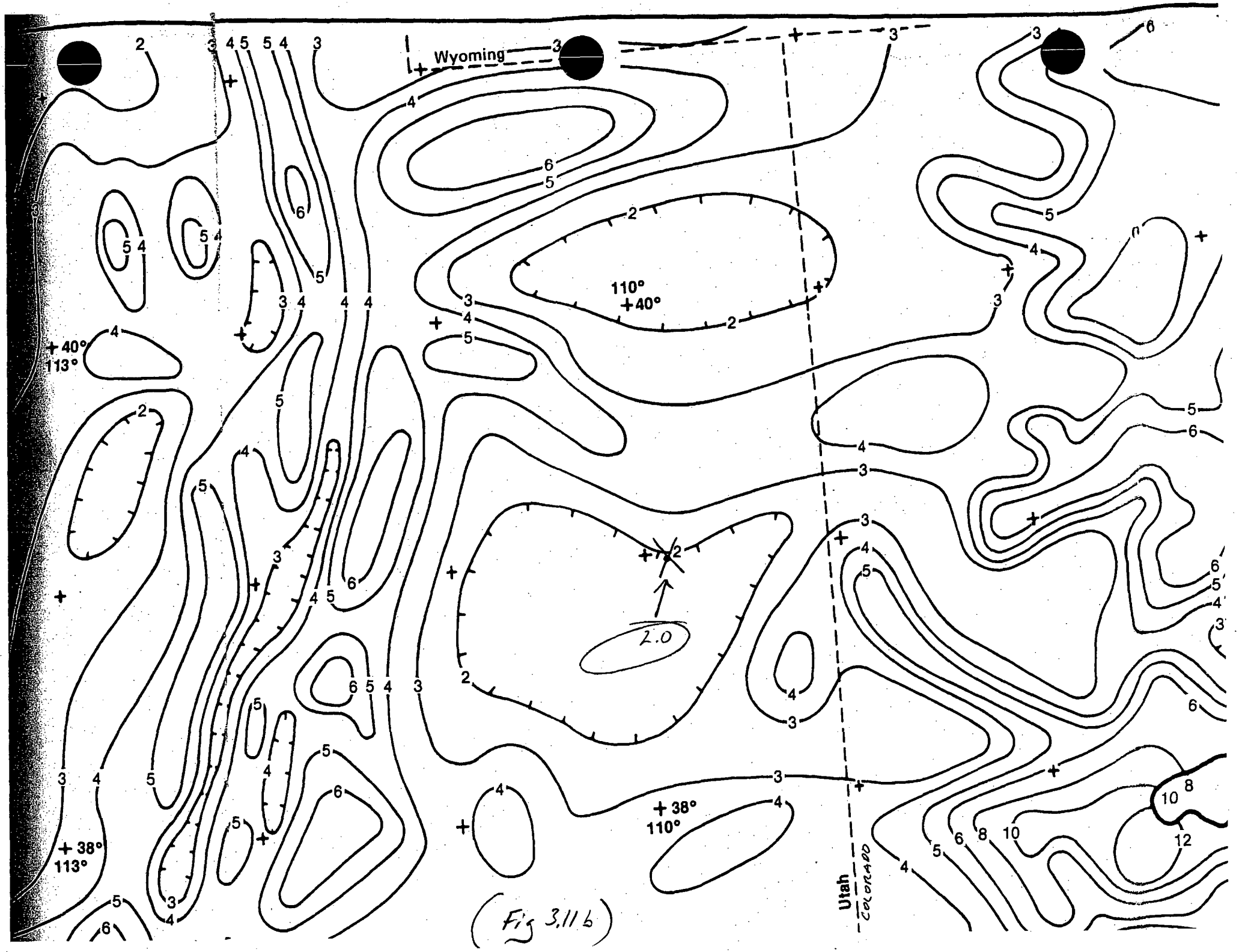


Figure 2.28.--Depth-area variation for convergence PMP for first to fourth 6-hr increments.



(Fig 3.11 b)

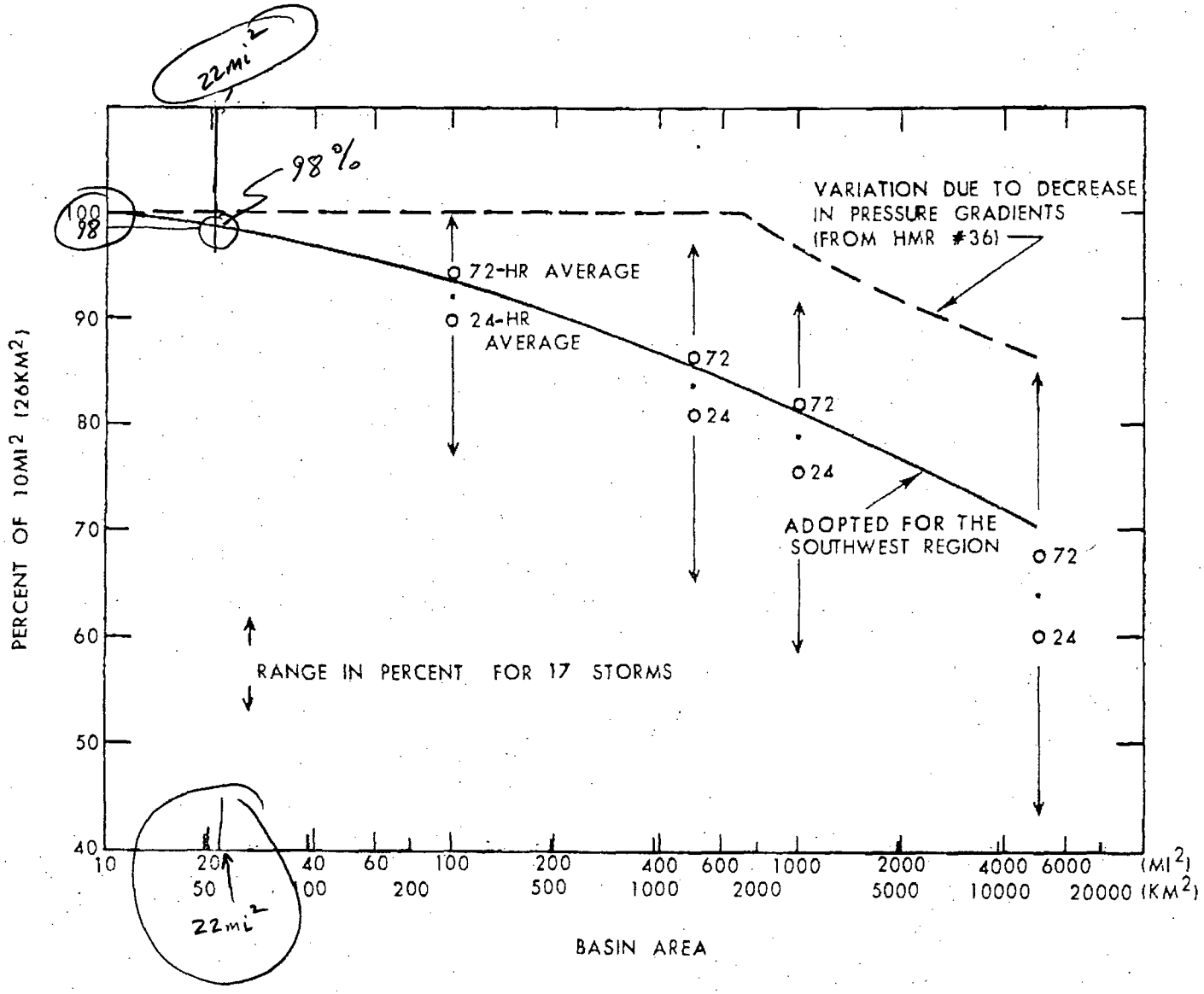
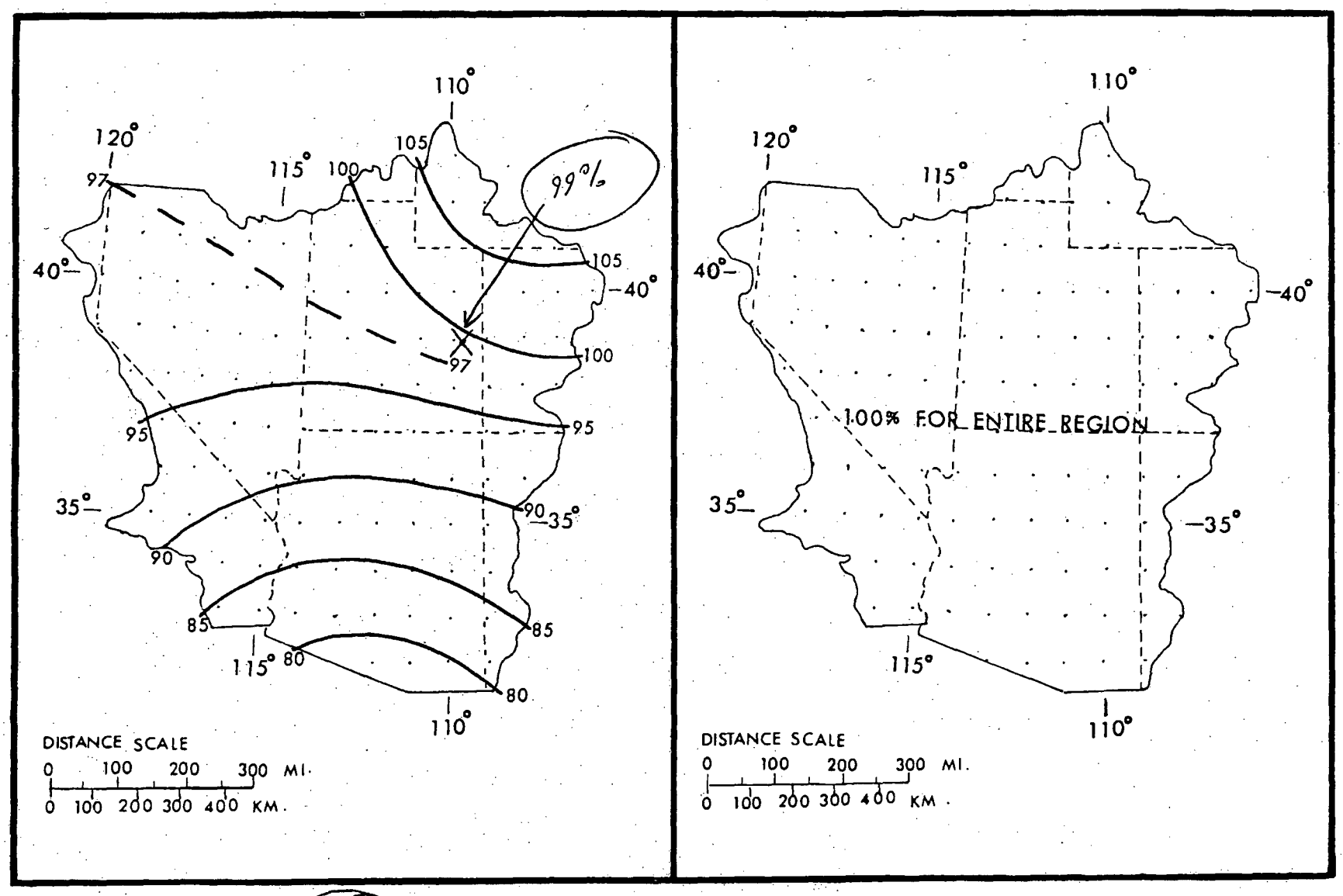


Figure 3.20.--Variation of orographic PMP with basin size.



July

August

Figure 3.15.--Seasonal variation in 10-mi^2 (26-km^2) 24-hr orographic PMP for the study region (in percent of values in figure 3.11).

Table 3.9.--Durational variation of orographic PMP

Latitude °N	Percent of 24-hr value					
	6 hr	12	18	24	48	72
42	28	55	79	100	161	190
41	29	56	79	100	160	189
40	30	57	80	100	159	187
39	30	57	80	100	157	185
38	31	58	81	100	155	182
37	32	59	81	100	152	177
36	33	60	82	100	149	172
35	34	61	82	100	146	167
34	35	62	83	100	143	162
33	36	63	84	100	139	157
32	37	64	84	100	135	152
31	39	66	85	100	132	146

4. LOCAL-STORM PMP FOR THE SOUTHWESTERN REGION AND CALIFORNIA

4.1 Introduction

This chapter provides generalized estimates of local or thunderstorm probable maximum precipitation. By "generalized" is meant that mapped values are given from which estimates of PMP may be determined for any selected drainage.

4.1.1 Region of Interest

Local-storm PMP was not included in the "Interim Report, Probable Maximum Precipitation in California" (HMR No. 36). During the formulation of the present study, we decided that the local-storm part of the study should include California west of the Sierra Nevada. It was also noted that PMP for summer thunderstorms was not considered west of the Cascade Divide in the Northwestern Region (HMR No. 43). As stated in the latter report, "No summer thunderstorms have been reported there (west of the Divide) of an intensity of those to the east, for which the moisture source is often the Gulf of Mexico or Gulf of California. The Cascade Divide offers an additional barrier to such moisture inflows to coastal areas where, in addition, the Pacific Ocean to the west has a stabilizing influence on the air to hinder the occurrence of intense summer local storms." Therefore, it was necessary to establish some continuation of the Cascade Divide into California so that the local-storm PMP definition would have continuity between the two regions.

The stabilizing influence of the Pacific air is at times interrupted by the warm moist tropical air from the south pushing into California, although it is difficult to determine where the limit of southerly flow occurs. General storms having the tropical characteristic of excessive thunderstorm rains are observed as far north as the northern end of the Sacramento Valley. Thus, a northern boundary has been selected for this study, excluding that portion of

General Storm PMP Computation
August

Table 6.1.--General-storm PMP computations for the Colorado River and Great basin

Drainage Crescent Junction Disposal Site (Elev 5000) Area less than 1 mi^2 (km^2)

Latitude 38°57'50" N (38.96°N), Longitude ___ of basin center 109°48'00" W (109.80°W)

Month August

Step	Duration (hrs) 6	12	18	24	48	72
A. Convergence PMP						
1. Drainage average value from one of figures 2.5 to 2.16 12.6 in. (~~mm~~)						
2. Reduction for barrier-elevation [fig. 2.18] 50 %						
3. Barrier-elevation reduced PMP [step 1 X step 2] 6.3 in. (~~mm~~)						
4. Durational variation [figs. 2.25 to 2.27 and table 2.7].	69	86	94	100	115	121 %
5. Convergence PMP for indicated durations [steps 3 X 4]	4.3	5.4	5.9	6.3	7.2	7.6 in. (~~mm~~)
6. Incremental 10 mi^2 (26 km^2) PMP [successive subtraction in step 5]	4.3	1.1	0.5	0.4	0.9	0.4 in. (~~mm~~)
7. Areal reduction [select from figs. 2.28 and 2.29]	95	100	100	100	100	100 %
8. Areally reduced PMP [step 6 X step 7]	4.1	1.1	0.5	0.4	0.9	0.4 in. (~~mm~~)
9. Drainage average PMP [accumulated values of step 8]	4.1	5.2	5.7	6.1	7.0	7.4 in. (~~mm~~)
B. Orographic PMP						
1. Drainage average orographic index from figure 3.11a to d. 2.0 in. (~~mm~~)						
2. Areal reduction [figure 3.20] 98 %						
3. Adjustment for month [one of figs. 3.12 to 3.17] 100%						
4. Areally and seasonally adjusted PMP [steps 1 X 2 X 3] 1.96 in. (~~mm~~)						
5. Durational variation [table 3.9]	30	57	80	100	157	185%
6. Orographic PMP for given durations [steps 4 X 5]	0.6	1.1	1.6	2.0	3.1	3.7 in. (~~mm~~)
C. Total PMP						
1. Add steps A9 and B6	4.7	6.3	7.3	8.1	10.1	11.1 in. (~~mm~~)

2. PMP for other durations from smooth curve fitted to plot of computed data.

3. Comparison with local-storm PMP (see sec. 6.3).

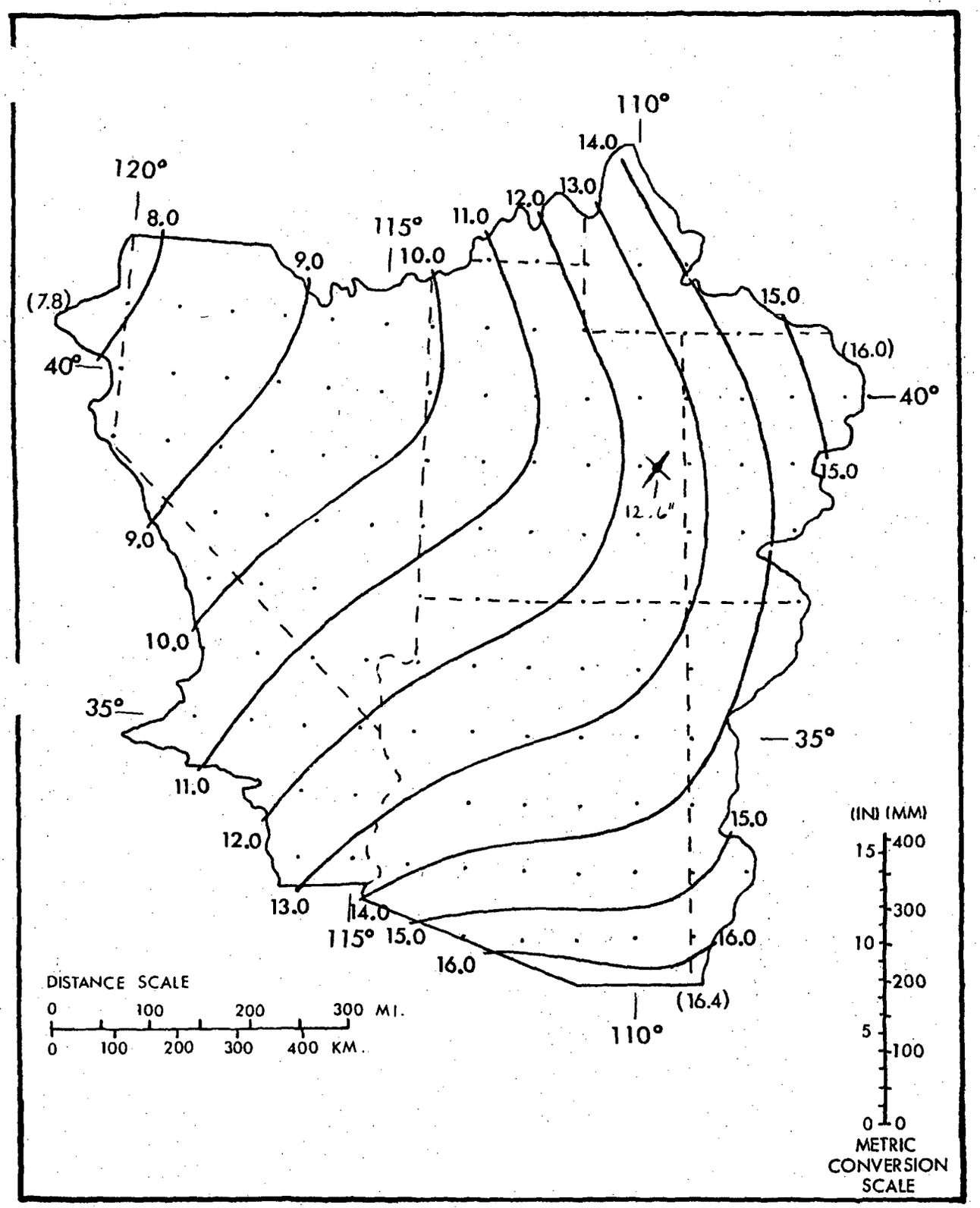


Figure 2.12.--1000-mb (100-kPa) 24-hr convergence PMP (inches) for 10 mi^2 (26 km^2) for August. Values in parentheses are limiting values and are to facilitate extrapolation beyond the indicated gradient.

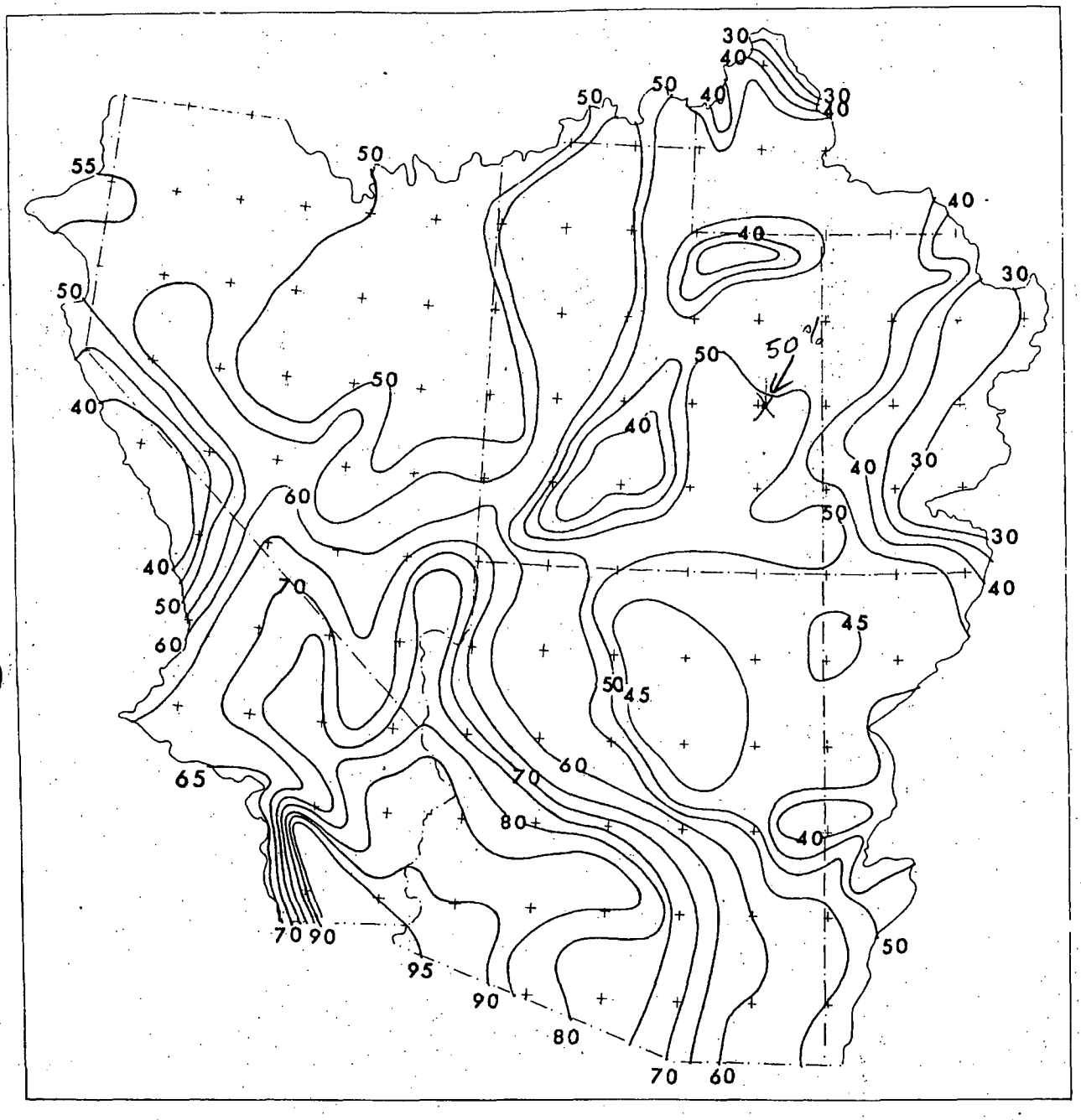
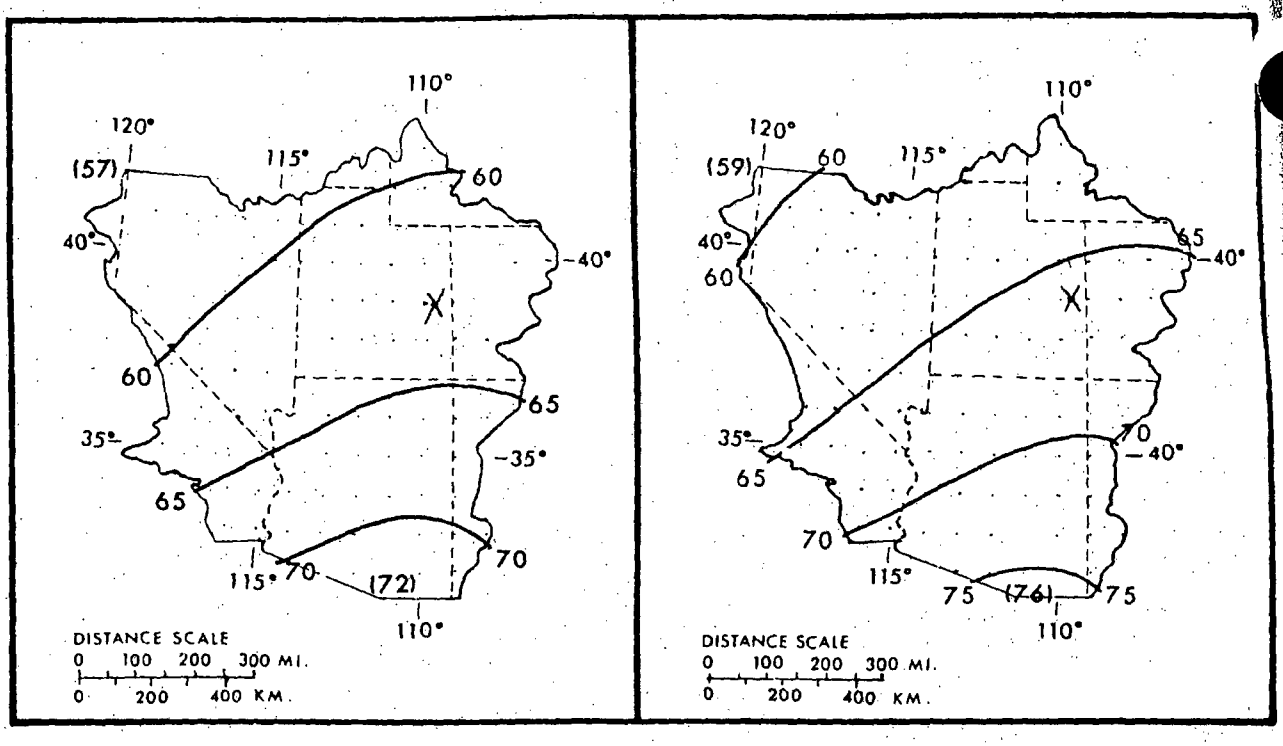
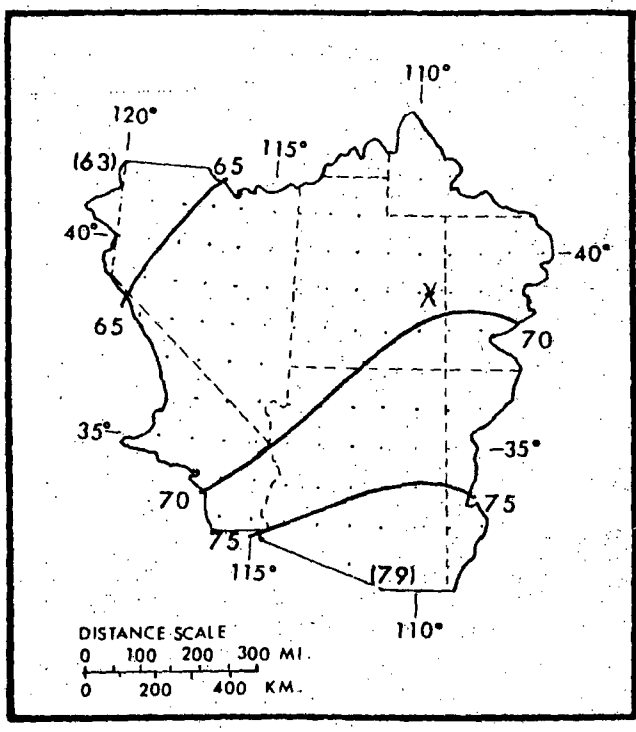


Figure 2.18.--Percent of 1000-mb (100-kPa) convergence PMP resulting from effective elevation and barrier considerations. Isolines drawn for every five percent.

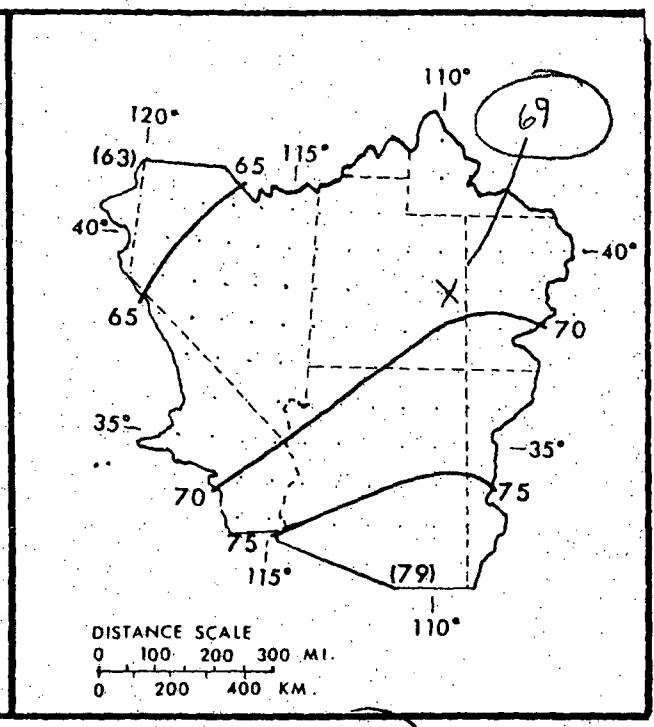


May

June



July



August

Figure 2.26.--Regional variation of 6/24-hr ratios by month (percent). Values in parentheses are limiting values and are to facilitate extrapolation beyond the indicated gradient.

For the range of 6/24-hr ratios included in figures 2.25 to 2.27, depth-duration values in percent of 24-hr amounts are found in table 2.7. The regional ratio maps, and the depth-duration curves presented in figure 2.20 were used in adjusting the major storm data to 24-hr amounts listed in table 2.1.

Table 2.7.--Durational variation of convergence PMP (in percent of 24-hr amount).

Duration (Hrs)						Duration (Hrs)					
6	12	18	24	48	72	6	12	18	24	48	72
50	76	90	100	129	150	66	84	93	100	116	124
51	77	90	100	128	148	67	85	94	100	116	123
52	77	90	100	127	146	68	85	94	100	115	122
53	77	91	100	127	144	69	86	94	100	115	121
54	78	91	100	126	142						
55	78	91	100	125	140	70	87	94	100	114	120
56	79	91	100	124	138	71	87	95	100	114	119
57	79	92	100	123	137	72	88	95	100	113	118
58	80	92	100	122	135	73	88	95	100	113	118
59	80	92	100	121	134	74	89	95	100	112	117
						75	89	96	100	112	116
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64	83	93	100	117	126						
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Note: For use, enter first column (6 hr) with 6/24-hr ratio from figures 2.25 to 2.27.

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For operational use, basin average values of convergence PMP are needed rather than 10-mi^2 (26-km^2) values. Preferably, the method for reducing 10-mi^2 (26-km^2) values to basin average rainfalls should be derived from depth-area relations of storms in the region. However, all general storms in the region include large proportions of orographic precipitation.

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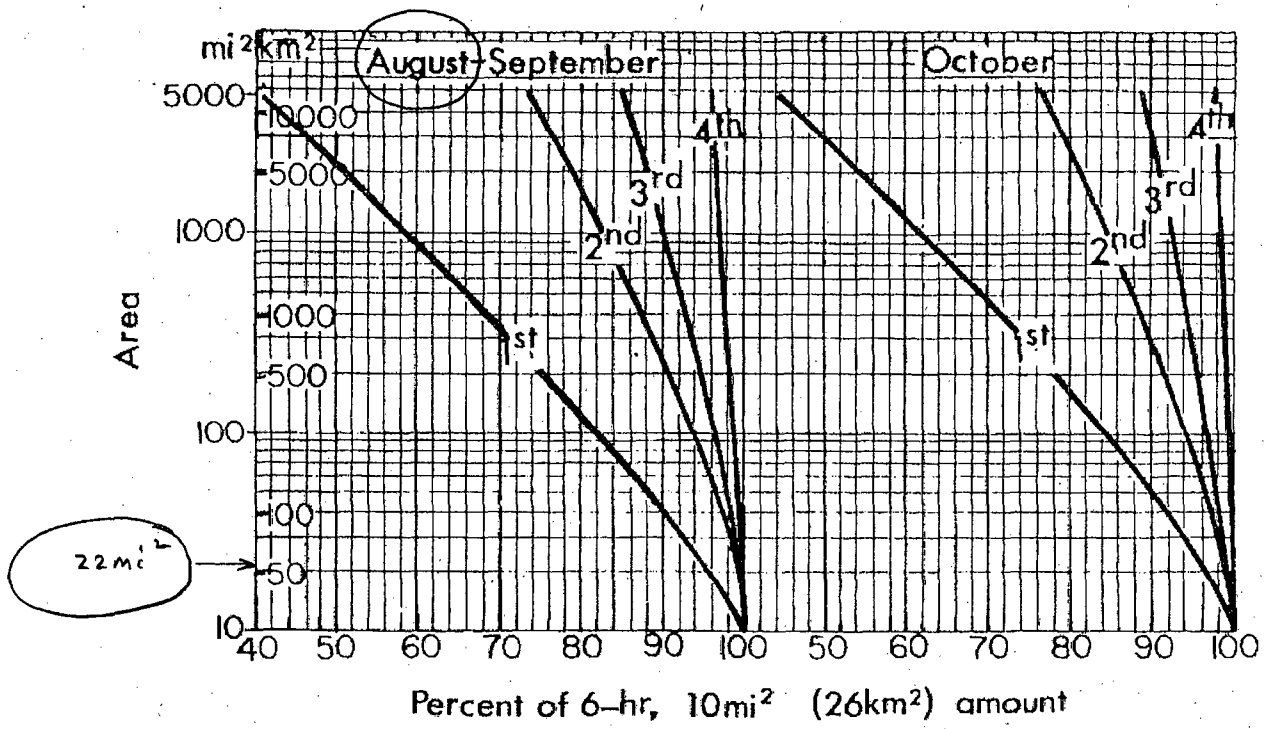


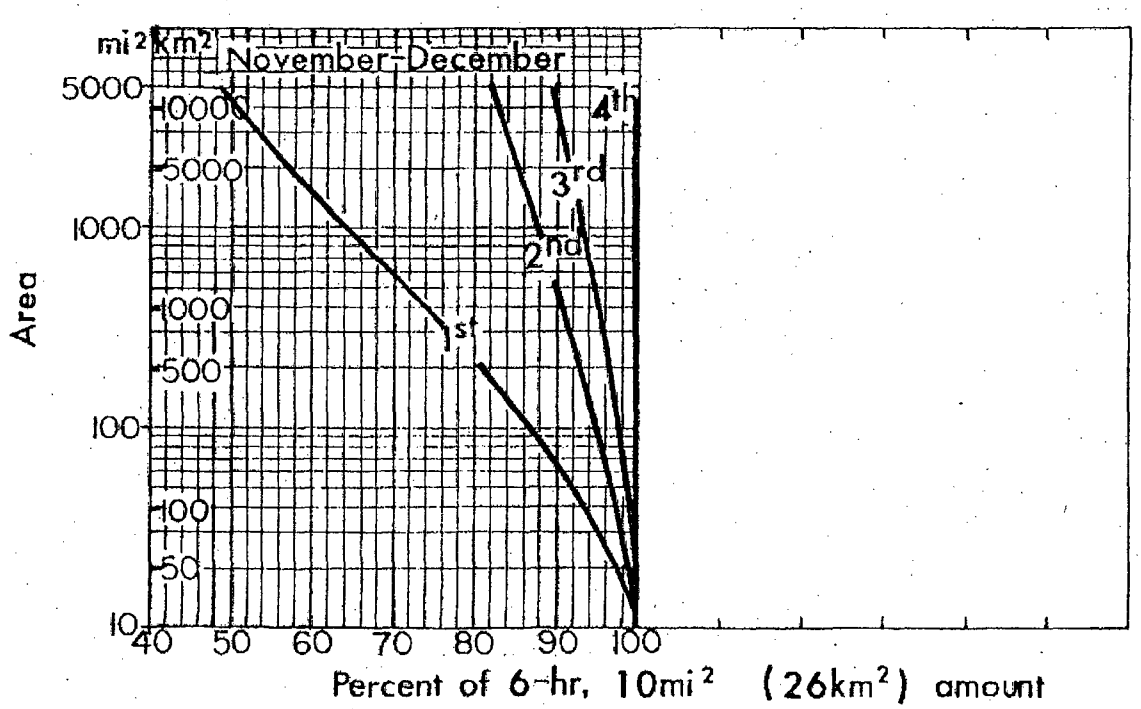
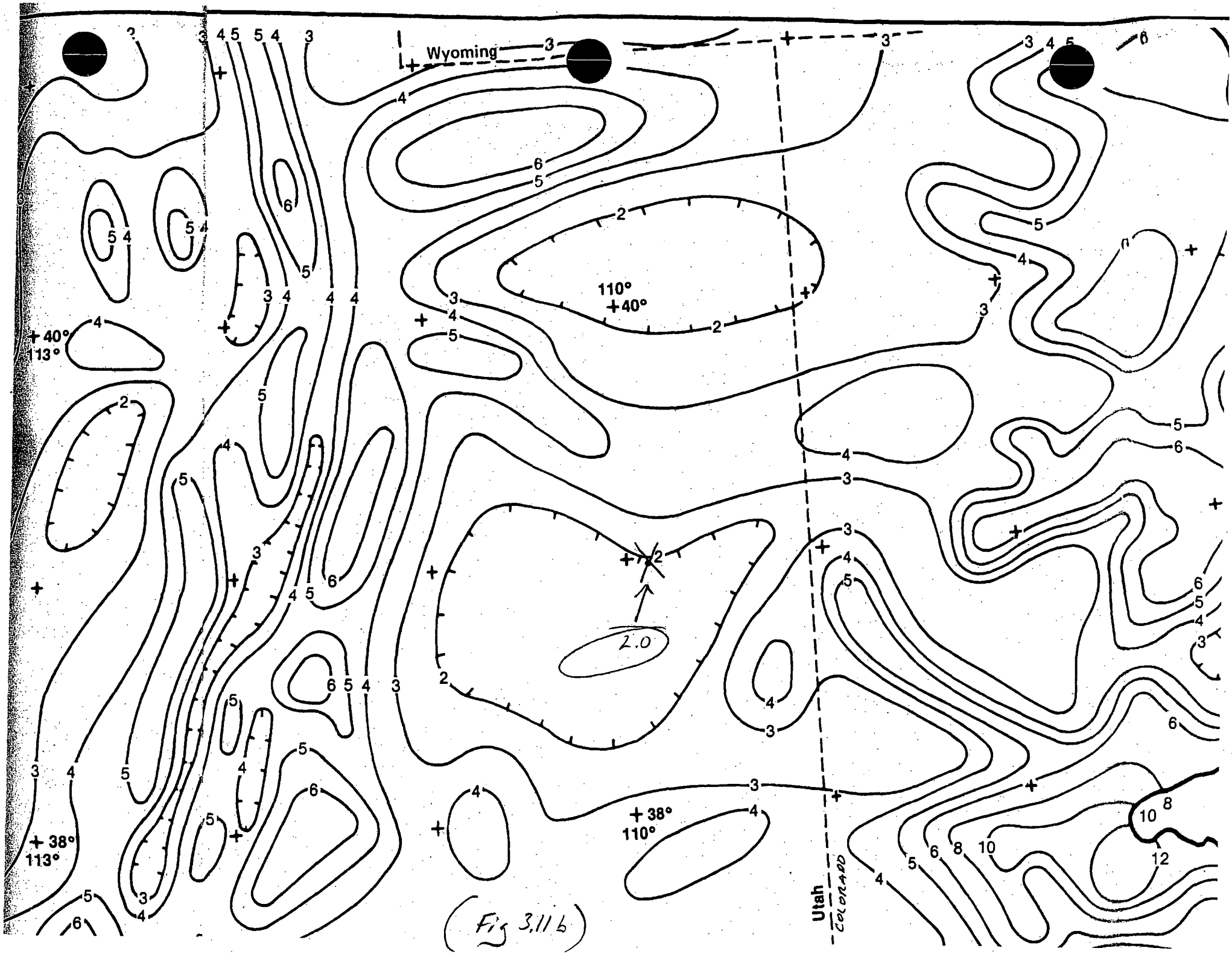


Figure 2.29.--Depth-area variation for convergence PMP for first to fourth 6-hr increments.



(Fig 3.11b)

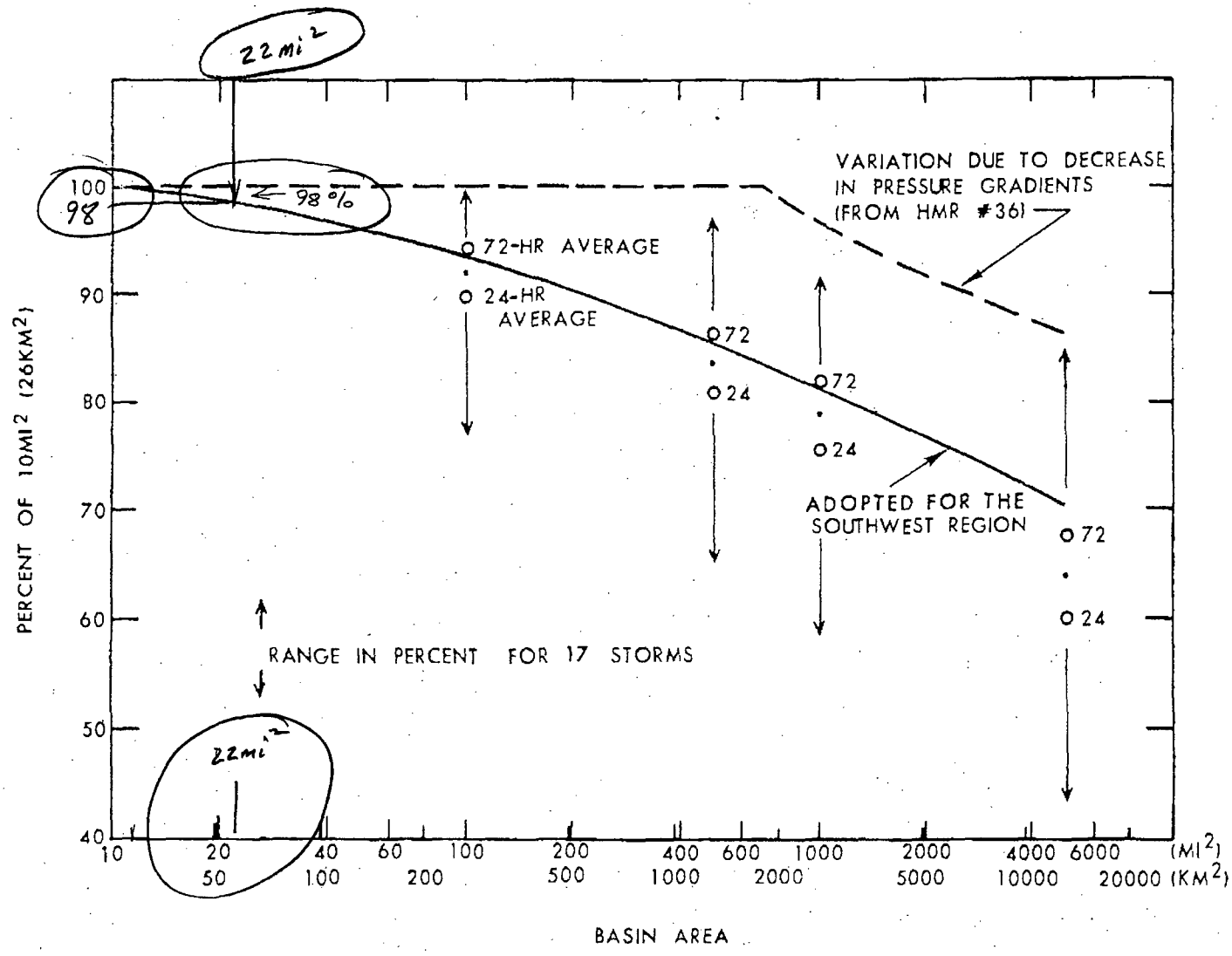
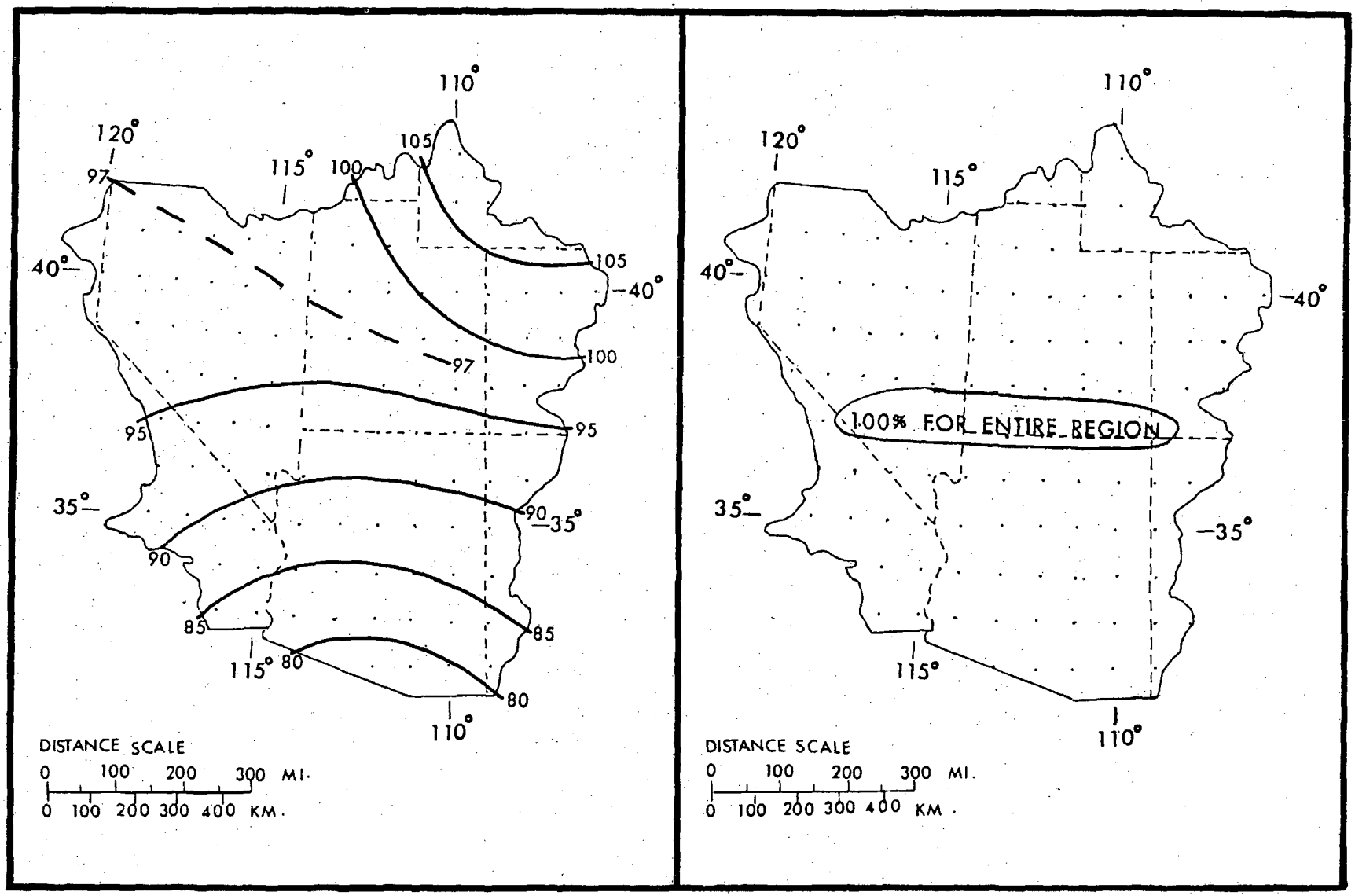


Figure 3.20.--Variation of orographic PMP with basin size.



July *August*

Figure 3.15.--Seasonal variation in 10-mi^2 (26-km^2) 24-hr orographic PMP for the study region (in percent of values in figure 3.11).

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September

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Latitude 38° 57' 50" N (38.96° N), Longitude ___ of basin center 109° 48' 00" W (109.80° W)

Month September

Step	Duration (hrs) 6	12	18	24	48	72	
A. Convergence PMP							
1. Drainage average value from one of figures 2.5 to 2.16	12.4 in. (~~mm~~)						
2. Reduction for barrier-elevation [fig. 2.18]	50 %						
3. Barrier-elevation reduced PMP [step 1 X step 2]	6.2 in. (~~mm~~)						
4. Durational variation [figs. 2.25 to 2.27 and table 2.7].	69	86	94	100	115	121	%
5. Convergence PMP for indicated durations [steps 3 X 4]	4.3	5.3	5.8	6.2	7.1	7.5	in. (~~mm~~)
6. Incremental 10 mi^2 (26 km^2) PMP [successive subtraction in step 5]	4.3	1.0	0.5	0.4	0.9	0.4	in. (~~mm~~)
7. Areal reduction [select from figs. 2.28 and 2.29]	95	100	100	100	100	100	%
8. Areally reduced PMP [step 6 X step 7]	4.1	1.0	0.5	0.4	0.9	0.4	in. (~~mm~~)
9. Drainage average PMP [accumulated values of step 8]	4.1	5.1	5.6	6.0	6.9	7.3	in. (~~mm~~)
B. Orographic PMP							
1. Drainage average orographic index from figure 3.11a to d.	2.0 in. (~~mm~~)						
2. Areal reduction [figure 3.20]	98 %						
3. Adjustment for month [one of figs. 3.12 to 3.17]	100 %						
4. Areally and seasonally adjusted PMP [steps 1 X 2 X 3]	1.96 in. (~~mm~~)						
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C. Total PMP							
1. Add steps A9 and B6	4.7	6.2	7.2	8.0	10.0	11.0	in. (~~mm~~)

2. PMP for other durations from smooth curve fitted to plot of computed data.

3. Comparison with local-storm PMP (see sec. 6.3).

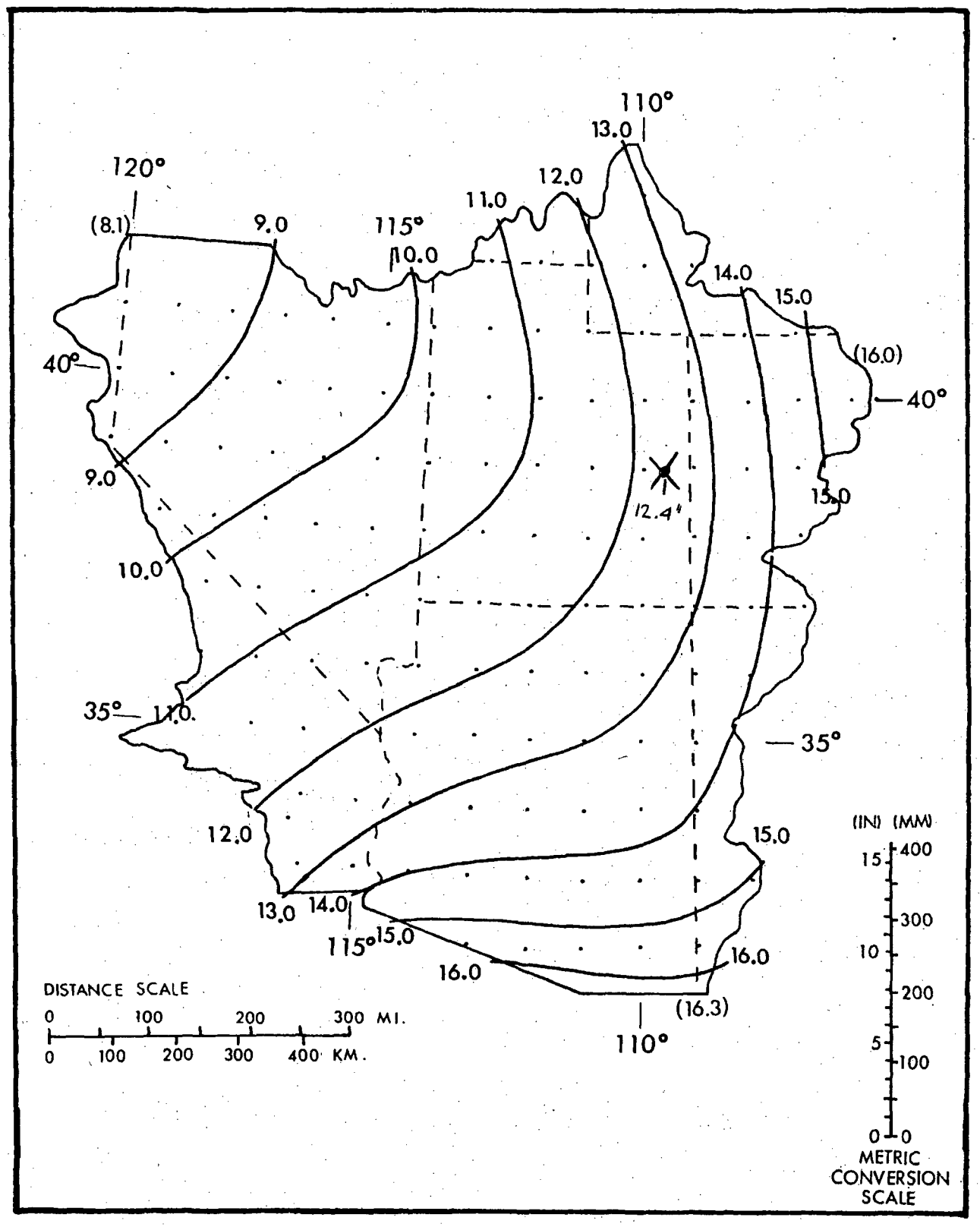


Figure 2.13.--1000-mb (100-kPa) 24-hr convergence PMP (inches) for 10 mi^2 (26 km^2) for September. Values in parentheses are limiting values and are to facilitate extrapolation beyond the indicated gradient.

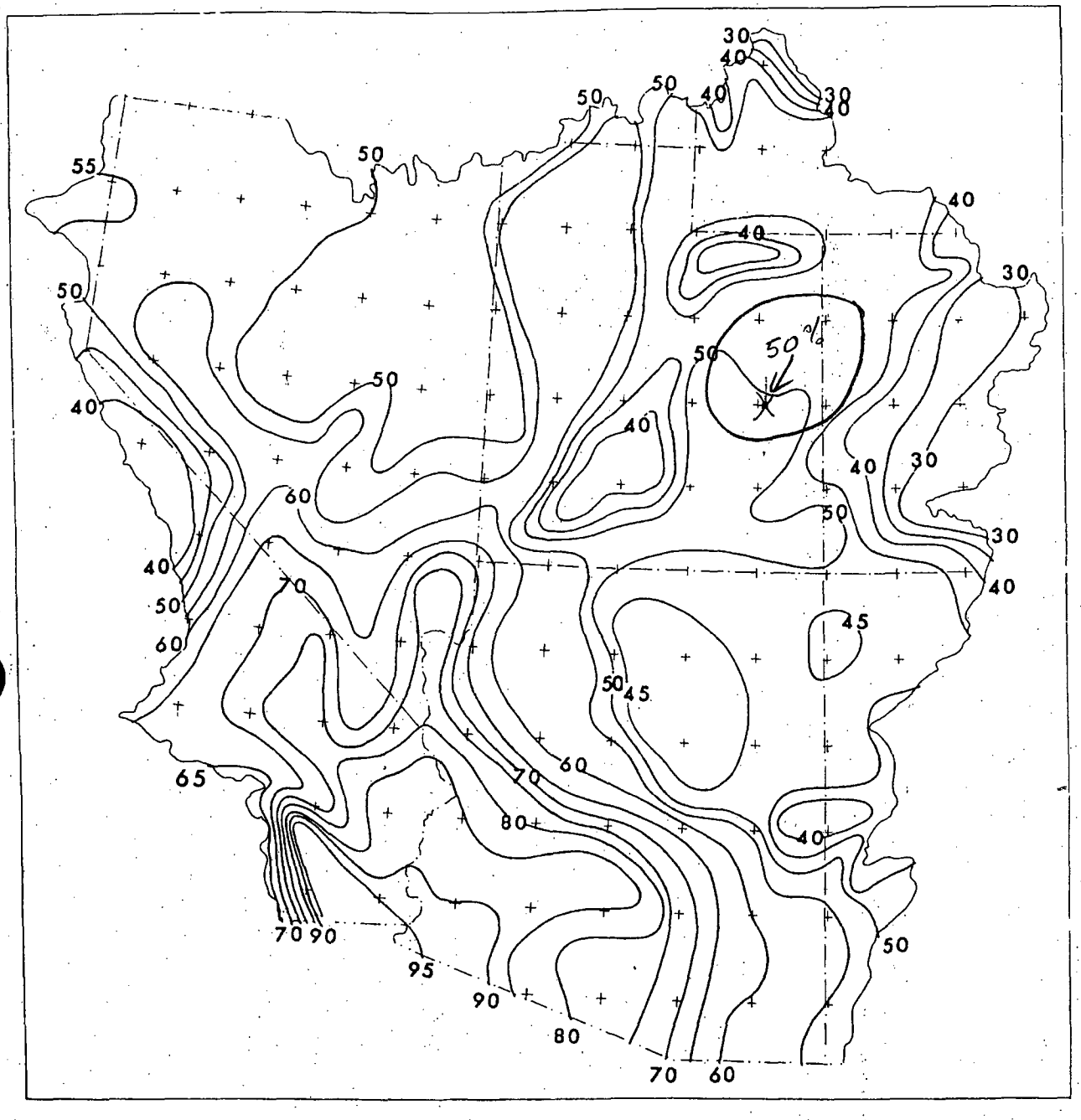
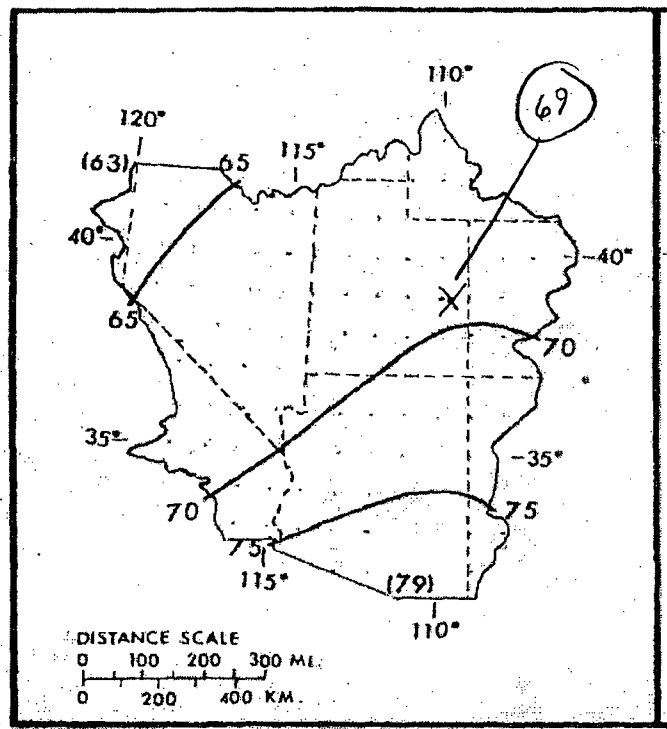
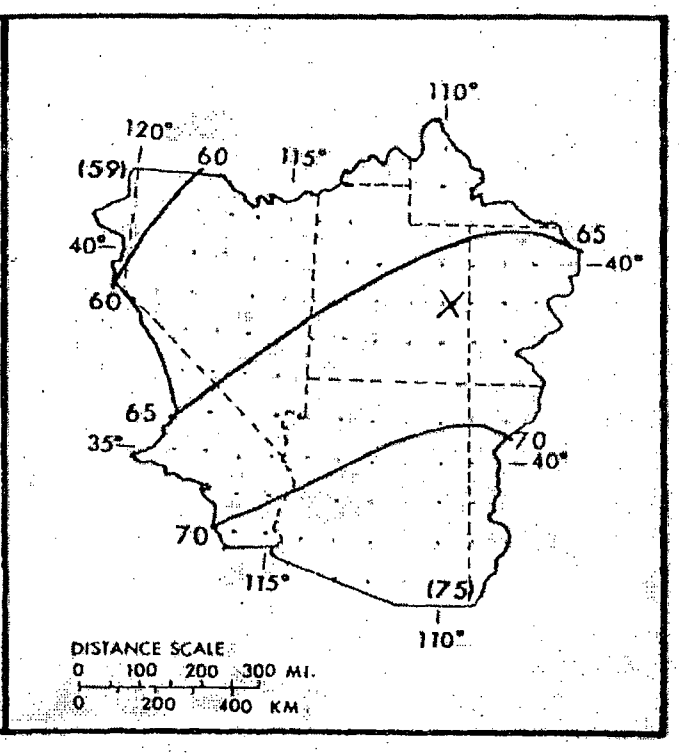


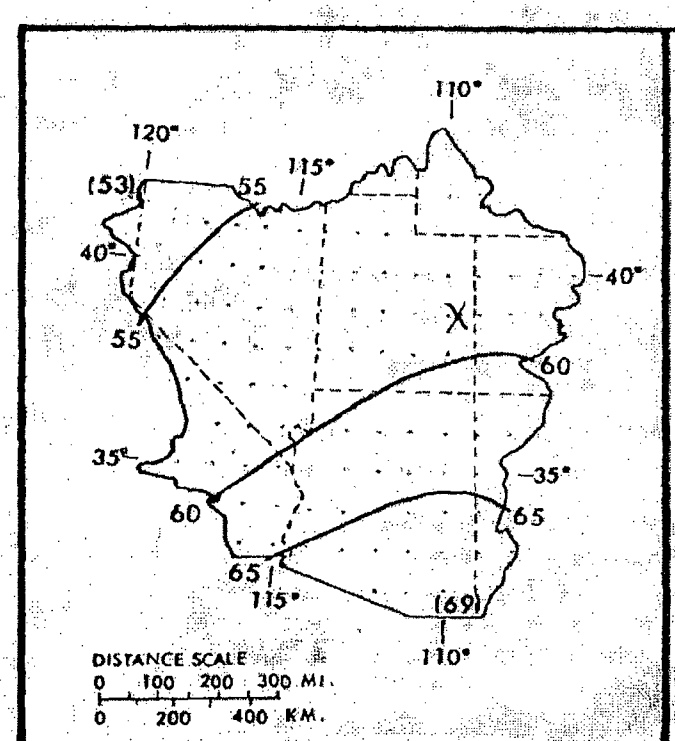
Figure 2.18.--Percent of 1000-mb (100-kPa) convergence PMP resulting from effective elevation and barrier considerations. Isolines drawn for every five percent.



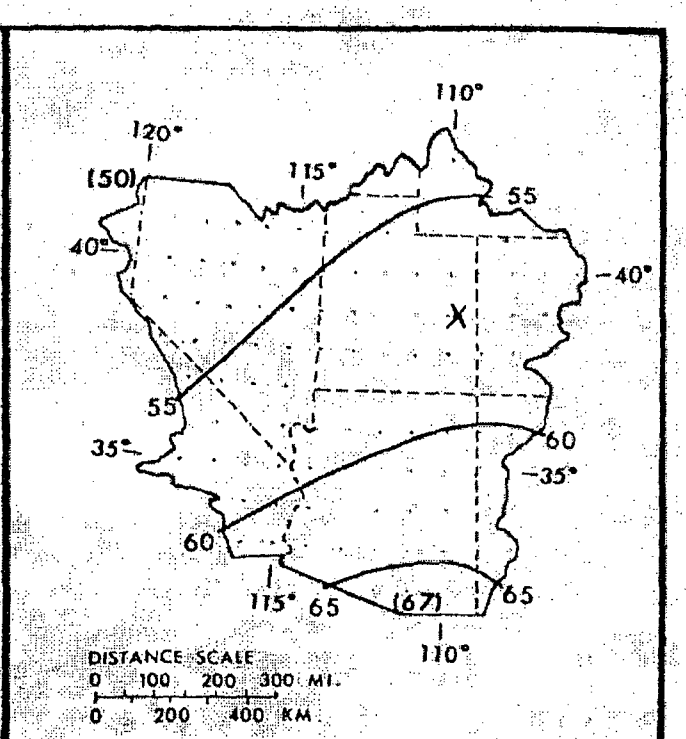
September



October



November



December

Figure 2.27.--Regional variation of 6/24-hr ratios by month (percent). Values in parentheses are limiting values and are to facilitate extrapolation beyond the indicated gradient.

For the range of 6/24-hr ratios included in figures 2.25 to 2.27, depth-duration values in percent of 24-hr amounts are found in table 2.7. The regional ratio maps, and the depth-duration curves presented in figure 2.20 were used in adjusting the major storm data to 24-hr amounts listed in table 2.1.

Table 2.7.--Durational variation of convergence PMP (in percent of 24-hr amount).

Duration (Hrs)						Duration (Hrs)					
6	12	18	24	48	72	6	12	18	24	48	72
50	76	90	100	129	150	66	84	93	100	116	124
51	77	90	100	128	148	67	85	94	100	116	123
52	77	90	100	127	146	68	85	94	100	115	122
53	77	91	100	127	144	69	86	94	100	115	121
54	78	91	100	126	142						
55	78	91	100	125	140	70	87	94	100	114	120
56	79	91	100	124	138	71	87	95	100	114	119
57	79	92	100	123	137	72	88	95	100	113	118
58	80	92	100	122	135	73	88	95	100	113	118
59	80	92	100	121	134	74	89	95	100	112	117
						75	89	96	100	112	116
60	81	92	100	120	132	76	90	96	100	111	115
61	81	92	100	120	131	77	90	96	100	110	114
62	82	93	100	119	129	78	91	96	100	110	114
63	82	93	100	118	128	79	92	97	100	109	113
64	83	93	100	117	126						
65	84	93	100	117	125	80	92	97	100	109	113

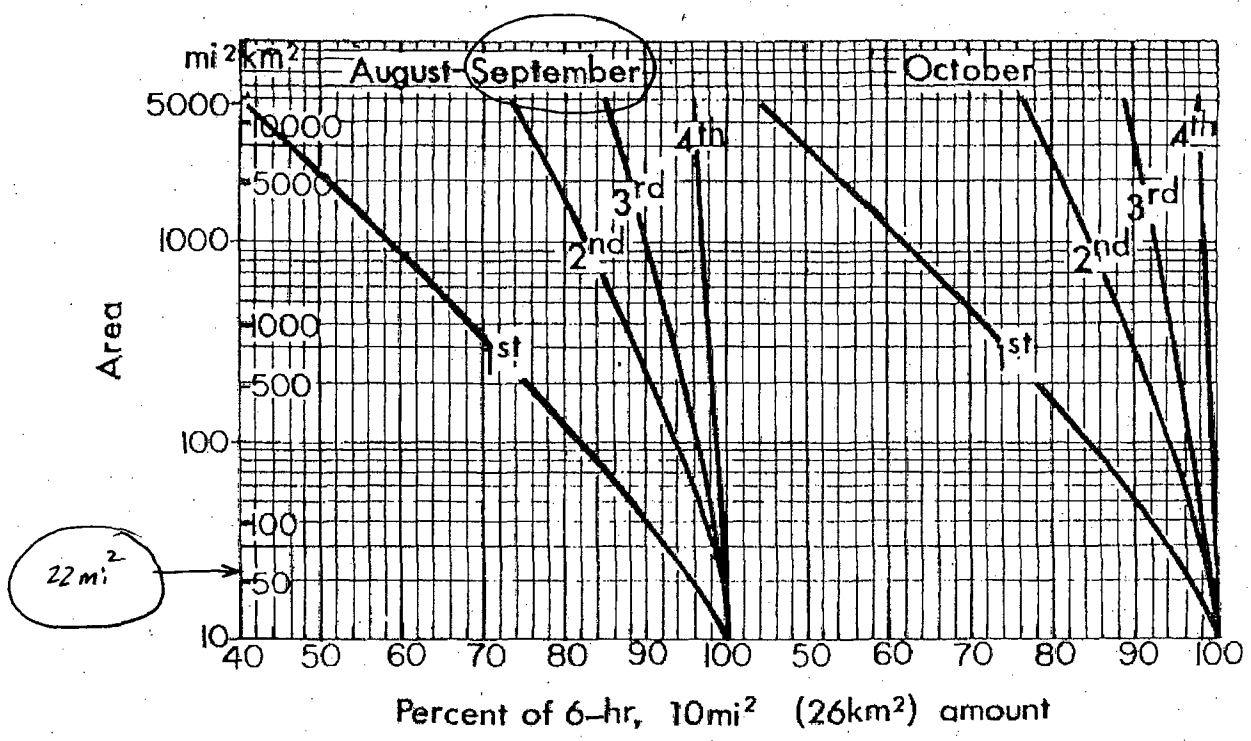
Note: For use, enter first column (6 hr) with 6/24-hr ratio from figures 2.25 to 2.27.

2.5 Areal Reduction for Basin Size

For operational use, basin average values of convergence PMP are needed rather than 10-mi^2 (26-km^2) values. Preferably, the method for reducing 10-mi^2 (26-km^2) values to basin average rainfalls should be derived from depth-area relations of storms in the region. However, all general storms in the region include large proportions of orographic precipitation.

Our solution was to use generalized depth-area relations developed for PMP estimates within bordering zones in the Central and Eastern United States (Riedel et al. 1956). The smoothed areal variations adopted for the Southwestern States are shown in figures 2.28 and 2.29 for each month or a combination of months where differences are insignificant.

Figures 2.28 and 2.29 give depth-area relations that reduce 10-mi^2 (26-km^2) convergence PMP for basin sizes up to 5,000 mi^2 (12,950 km^2) for each month. Areal variations are given for the 4 greatest (1st to 4th) 6-hr PMP increments. After the 4th increment no reduction for basin size is required. Application of these figures will become clear through consideration of an example of PMP computation in chapter 6.



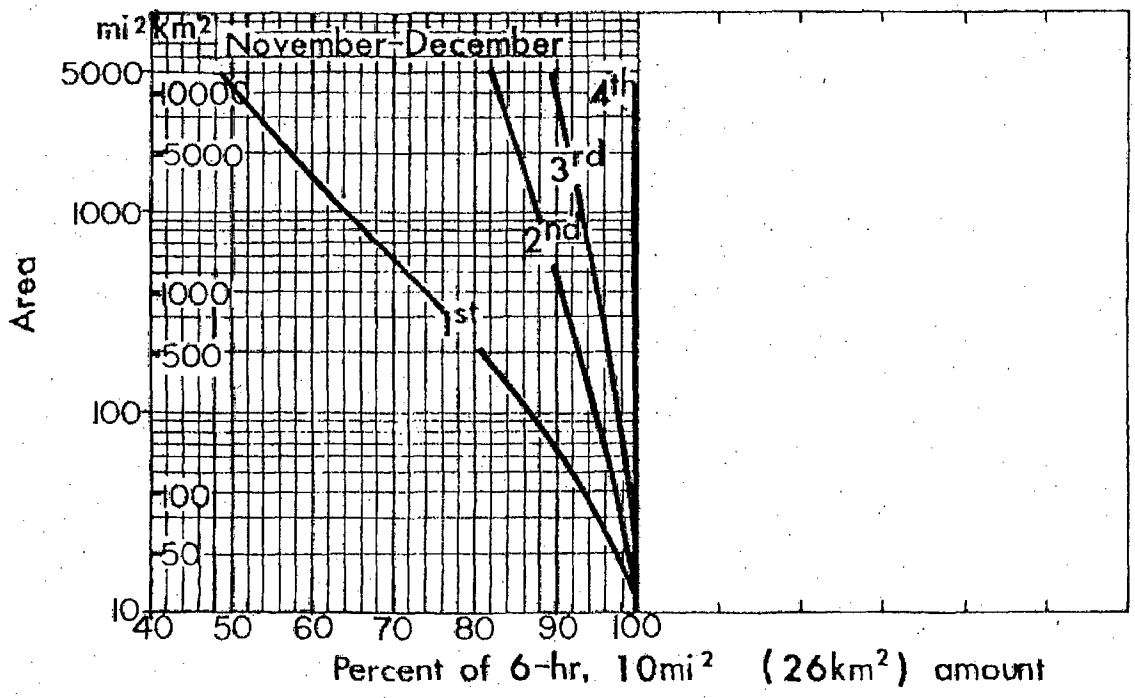
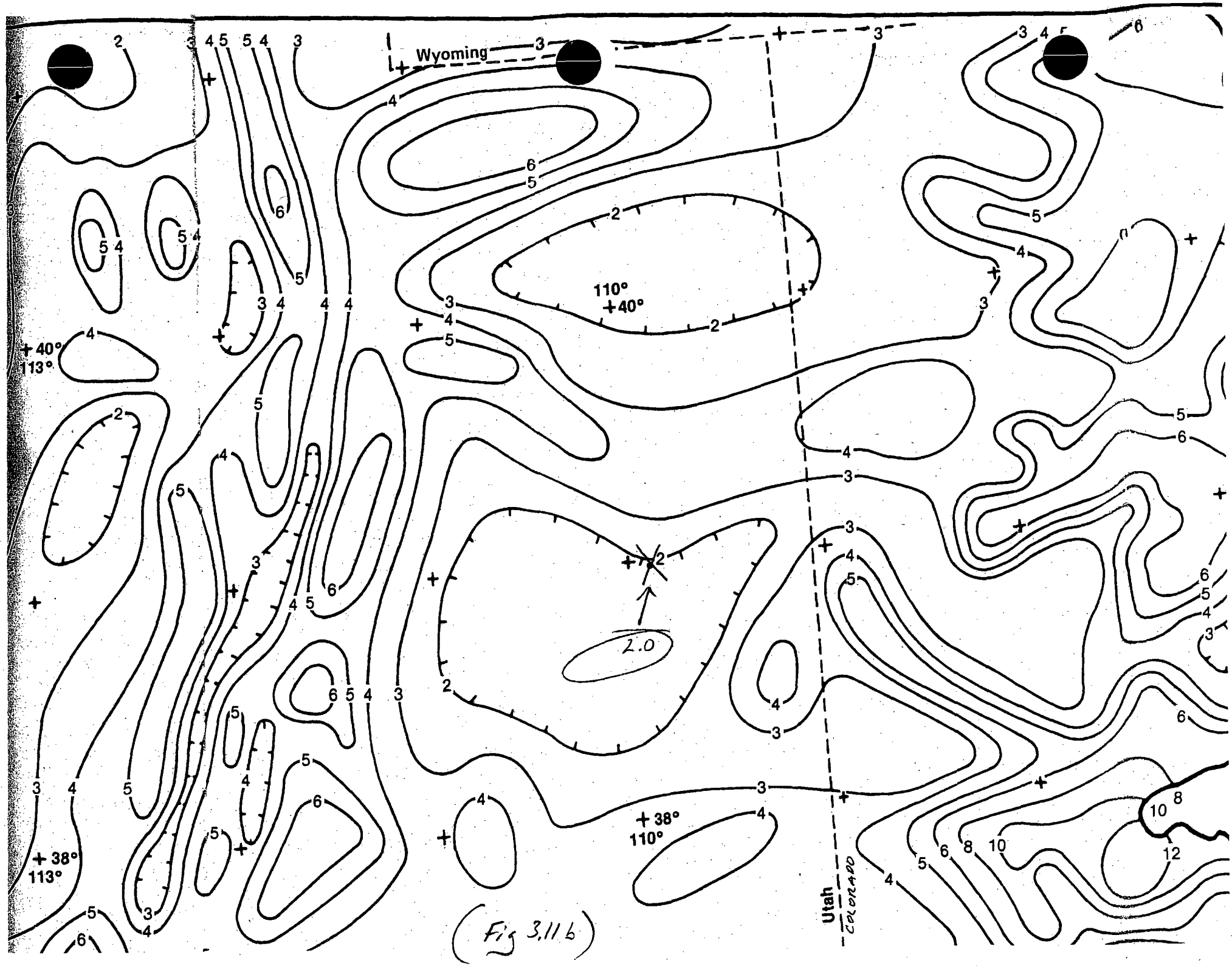
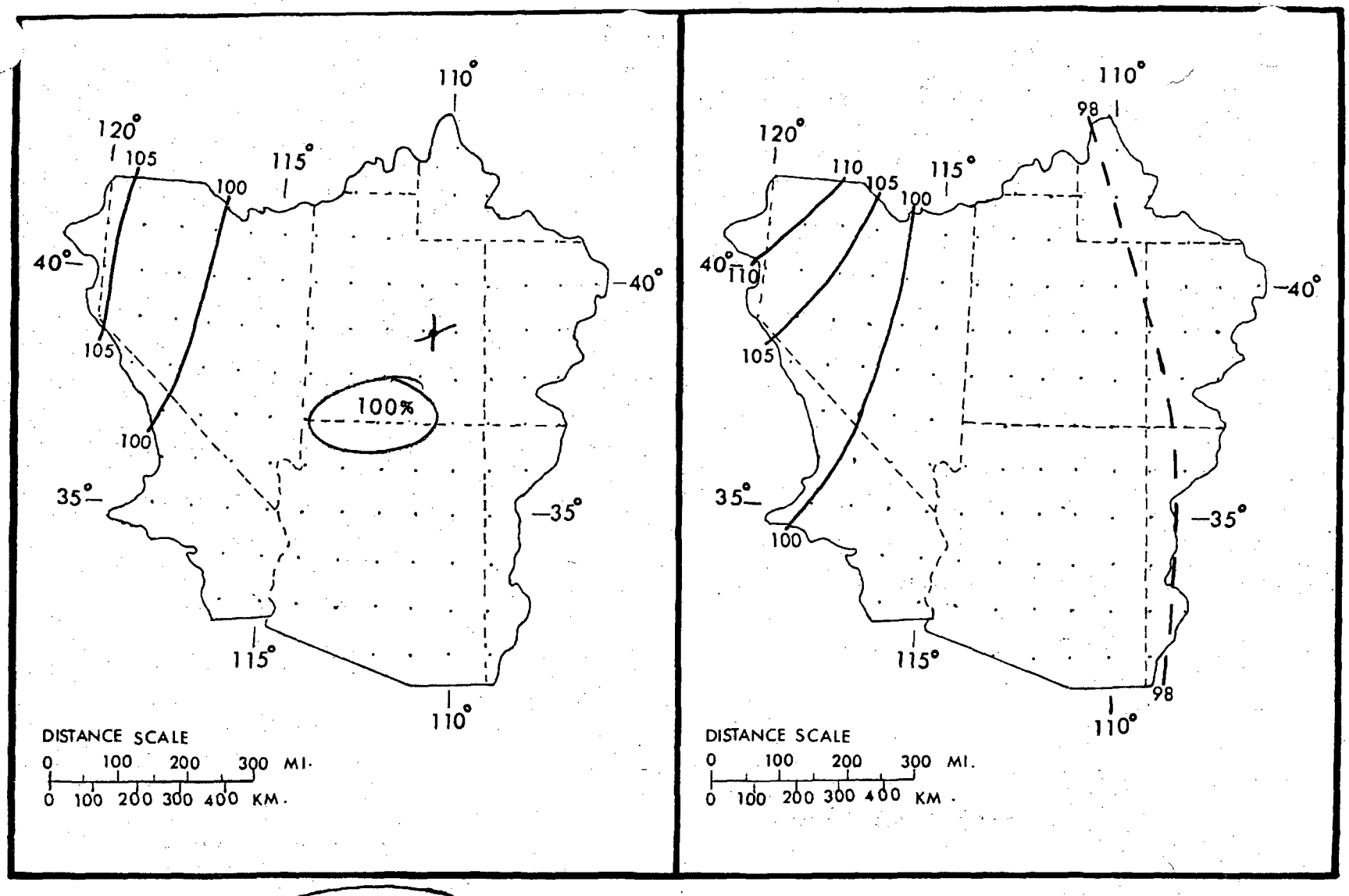


Figure 2.29.--Depth-area variation for convergence PMP for first to fourth 6-hr increments.



(Fig 3.11 b)



September *October*

Figure 3.16.--Seasonal variation in 10-mi^2 (26-km^2) 24-hr orographic PMP for the study region (in percent of values in figure 3.11).

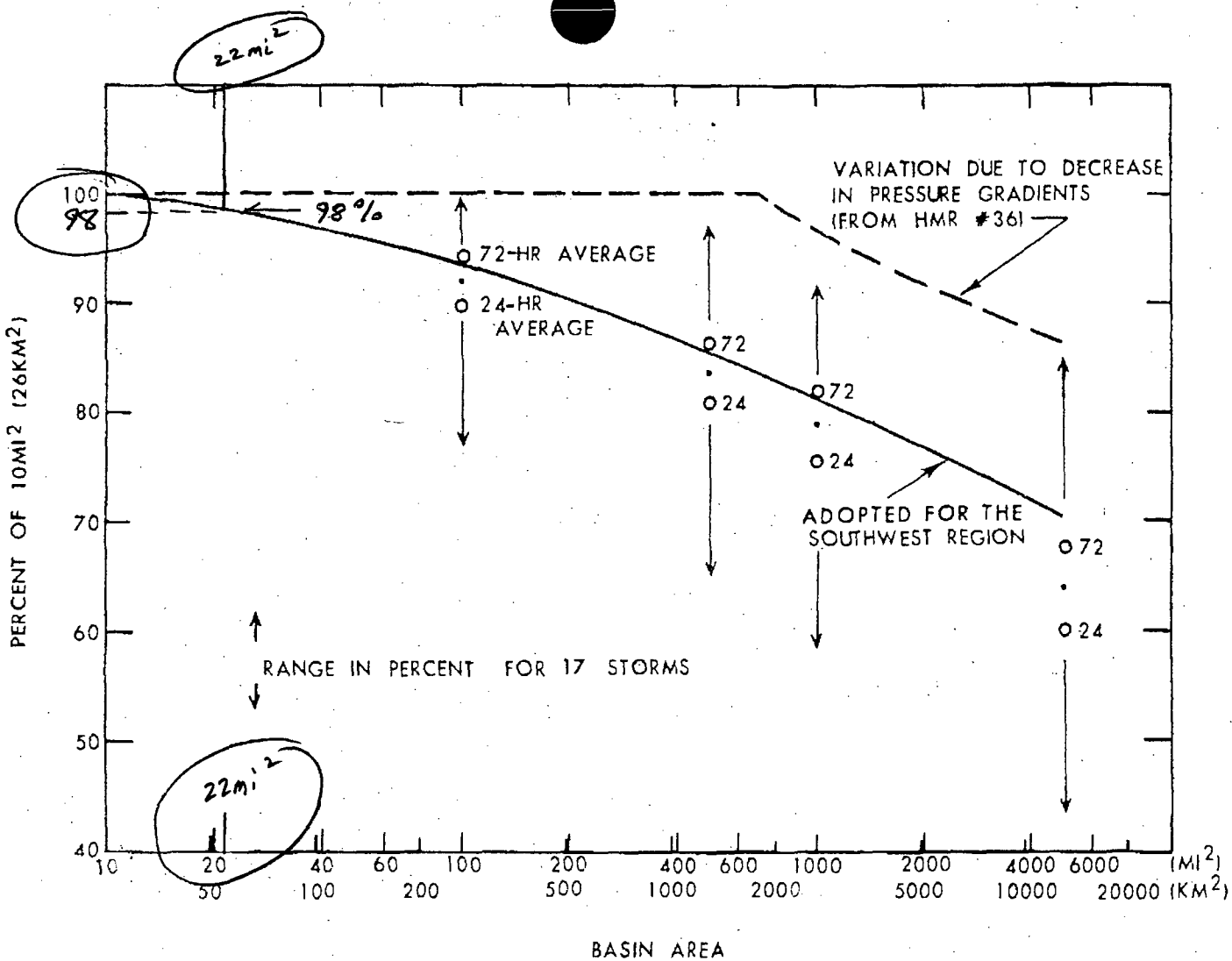


Figure 3.20.—Variation of orographic PMP with basin size.

Table 3.9.--Durational variation of orographic PMP

Latitude °N	Percent of 24-hr value					
	6 hr	12	18	24	48	72
42	28	55	79	100	161	190
41	29	56	79	100	160	189
40	30	57	80	100	159	187
39	30	57	80	100	157	185
38	31	58	81	100	155	182
37	32	59	81	100	152	177
36	33	60	82	100	149	172
35	34	61	82	100	146	167
34	35	62	83	100	143	162
33	36	63	84	100	139	157
32	37	64	84	100	135	152
31	39	66	85	100	132	146

4. LOCAL-STORM PMP FOR THE SOUTHWESTERN REGION AND CALIFORNIA

4.1 Introduction

This chapter provides generalized estimates of local or thunderstorm probable maximum precipitation. By "generalized" is meant that mapped values are given from which estimates of PMP may be determined for any selected drainage.

4.1.1 Region of Interest

Local-storm PMP was not included in the "Interim Report, Probable Maximum Precipitation in California" (HMR No. 36). During the formulation of the present study, we decided that the local-storm part of the study should include California west of the Sierra Nevada. It was also noted that PMP for summer thunderstorms was not considered west of the Cascade Divide in the Northwestern Region (HMR No. 43). As stated in the latter report, "No summer thunderstorms have been reported there (west of the Divide) of an intensity of those to the east, for which the moisture source is often the Gulf of Mexico or Gulf of California. The Cascade Divide offers an additional barrier to such moisture inflows to coastal areas where, in addition, the Pacific Ocean to the west has a stabilizing influence on the air to hinder the occurrence of intense summer local storms." Therefore, it was necessary to establish some continuation of the Cascade Divide into California so that the local-storm PMP definition would have continuity between the two regions.

The stabilizing influence of the Pacific air is at times interrupted by the warm moist tropical air from the south pushing into California, although it is difficult to determine where the limit of southerly flow occurs. General storms having the tropical characteristic of excessive thunderstorm rains are observed as far north as the northern end of the Sacramento Valley. Thus, a northern boundary has been selected for this study, excluding that portion of

General Storm PMP Computation
October

Table 6.1.--General-storm PMP computations for the Colorado River and Great basin

Drainage Crescent Junction Disposal Site Area less than 1 mi^2 (~~km^2~~)

Latitude 38°57'50"N (38.96°N), Longitude ___ of basin center 109°48'00" W (109.80°W)

Month October

Step	Duration (hrs) 6	12	18	24	48	72
A. Convergence PMP						
1. Drainage average value from one of figures 2.5 to 2.16 11.6 in. (~~mm~~)						
2. Reduction for barrier-elevation [fig. 2.18] 50 %						
3. Barrier-elevation reduced PMP [step 1 X step 2] 5.8 in. (~~mm~~)						
4. Durational variation [figs. 2.25 to 2.27 and table 2.7].	67	85	94	100	116	123 %
5. Convergence PMP for indicated durations [steps 3 X 4]	3.9	4.9	5.5	5.8	6.7	7.1 in. (~~mm~~)
6. Incremental 10 mi^2 (26 km^2) PMP [successive subtraction in step 5]	3.9	1.0	0.6	0.3	0.9	0.4 in. (~~mm~~)
7. Areal reduction [select from figs. 2.28 and 2.29]	96	99	99	100	100	100 %
8. Areally reduced PMP [step 6 X step 7]	3.7	1.0	0.6	0.3	0.9	0.4 in. (~~mm~~)
9. Drainage average PMP [accumulated values of step 8]	3.7	4.7	5.3	5.6	6.5	6.9 in. (~~mm~~)
B. Orographic PMP						
1. Drainage average orographic index from figure 3.11a to d. 2.0 in. (~~mm~~)						
2. Areal reduction [figure 3.20] 98 %						
3. Adjustment for month [one of figs. 3.12 to 3.17] 98 %						
4. Areally and seasonally adjusted PMP [steps 1 X 2 X 3] 1.92 in. (~~mm~~)						
5. Durational variation [table 3.9]	30	57	80	100	157	185%
6. Orographic PMP for given durations [steps 4 X 5]	0.6	1.1	1.5	1.9	3.0	3.6 in. (~~mm~~)
C. Total PMP						
1. Add steps A9 and B6	4.3	5.8	6.8	7.5	9.5	10.5 in. (~~mm~~)

2. PMP for other durations from smooth curve fitted to plot of computed data.

3. Comparison with local-storm PMP (see sec. 6.3).

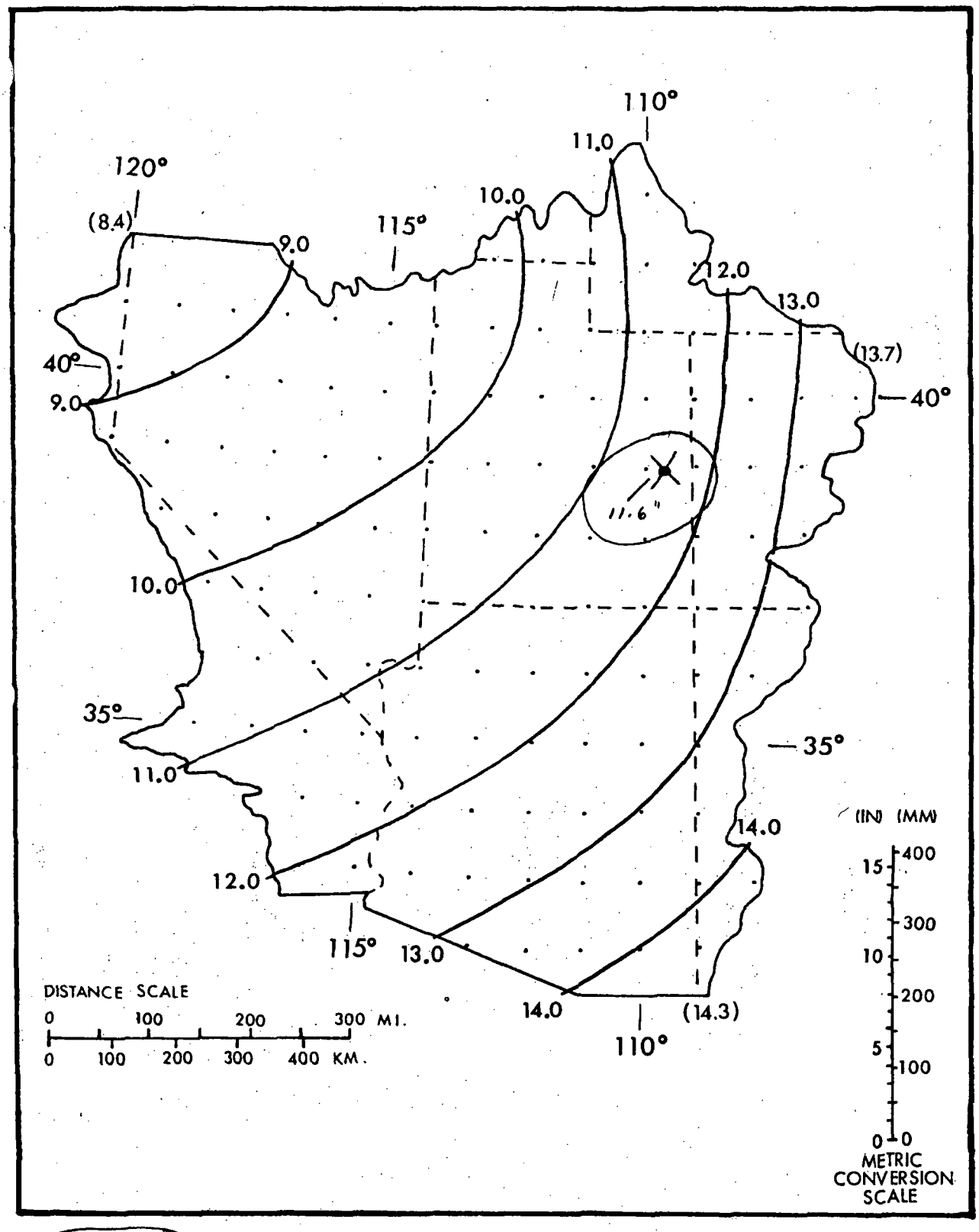


Figure 2.14.--1000-mb (100-kPa) 24-hr convergence PMP (inches) for 10 mi^2 (26 km^2) for October. Values in parentheses are limiting values and are to facilitate extrapolation beyond the indicated gradient.

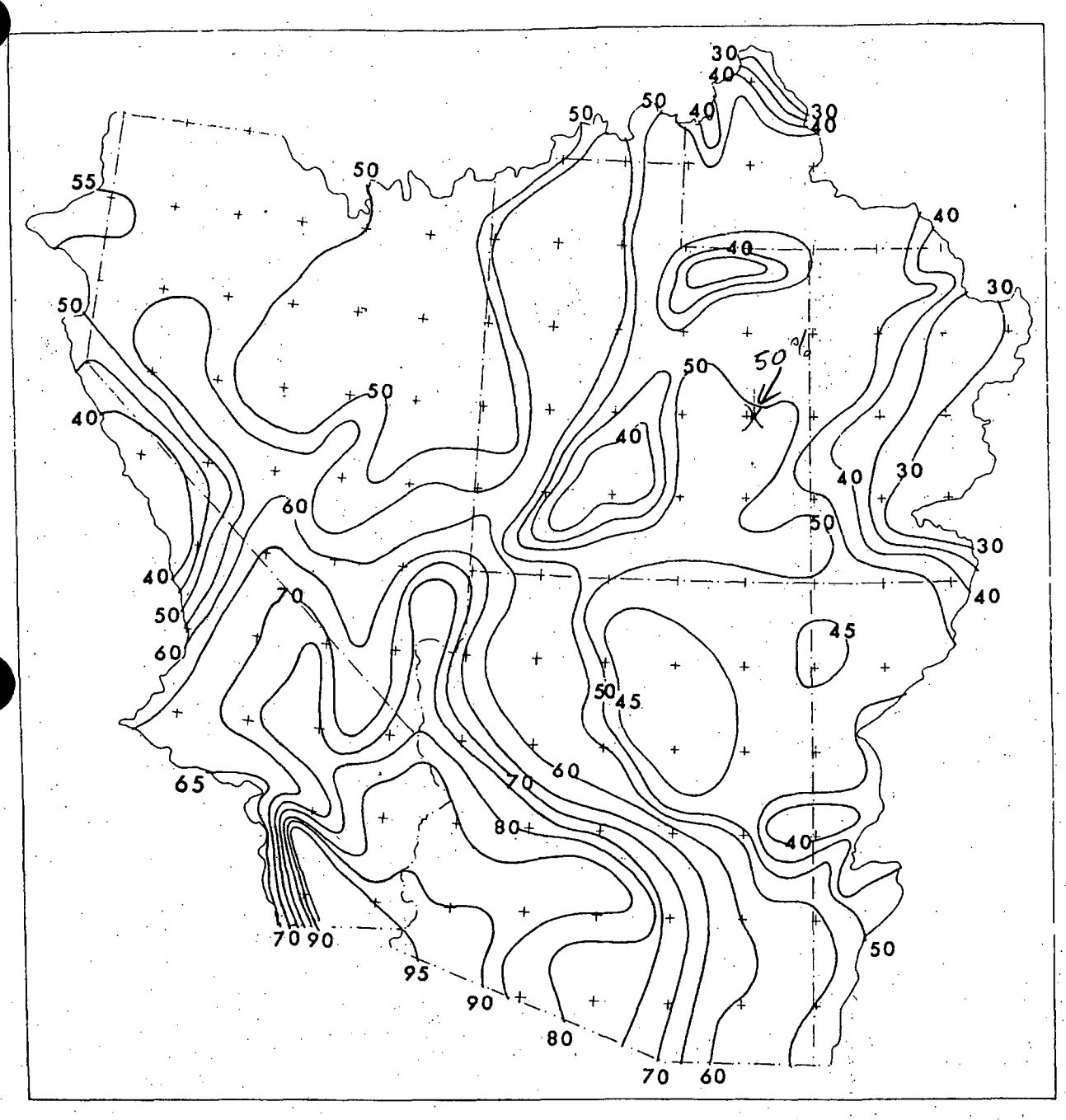
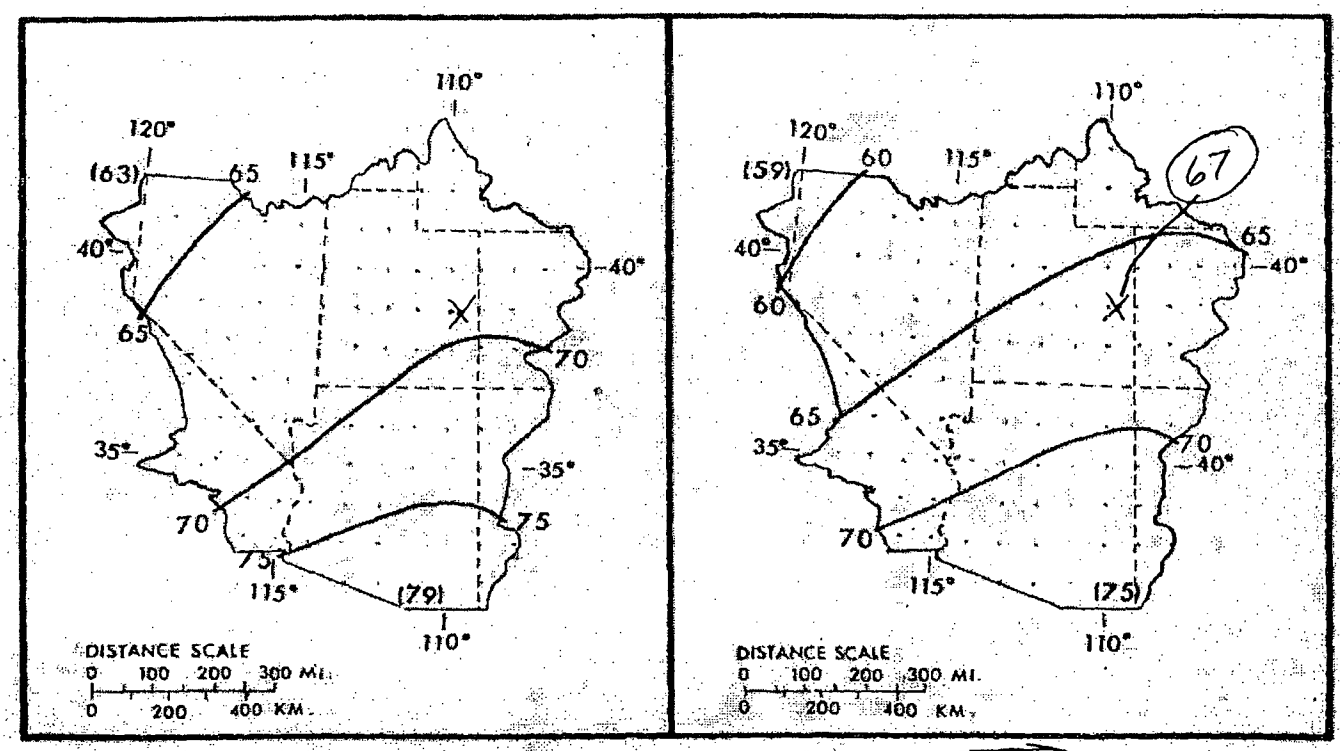
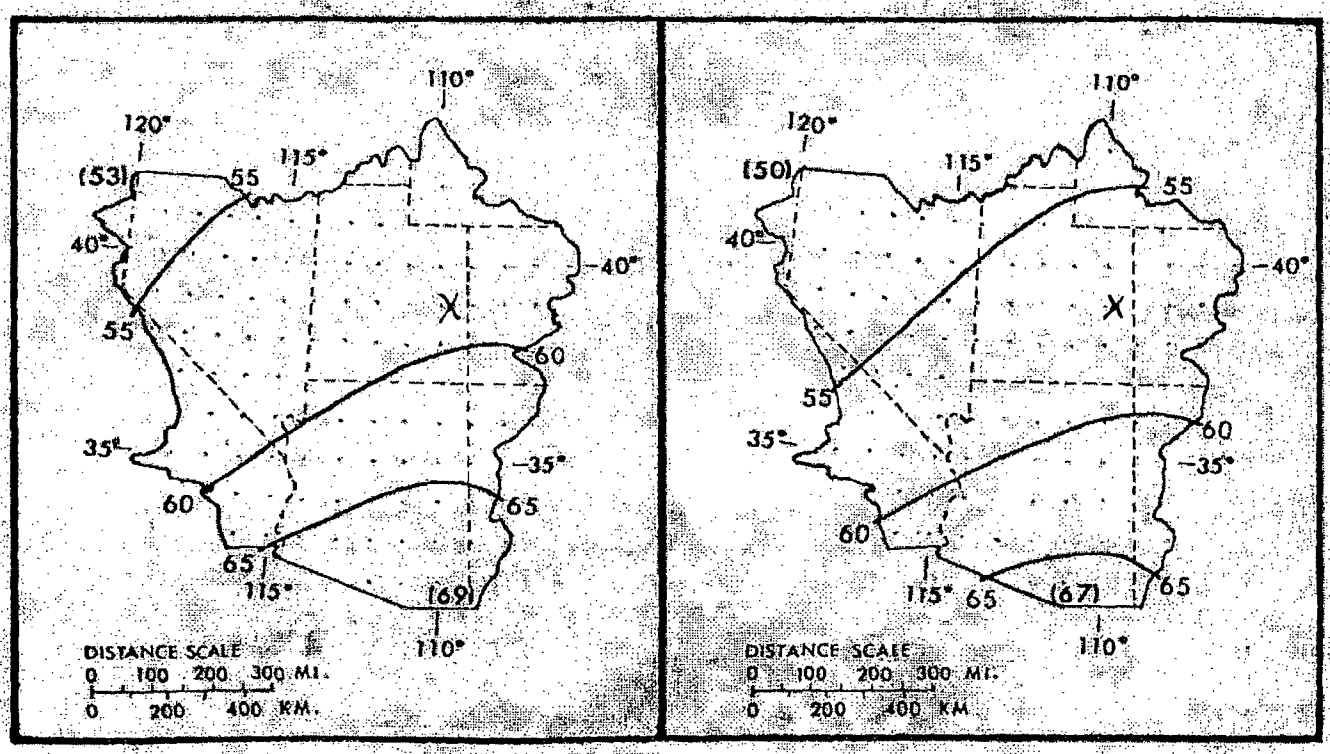


Figure 2.18.--Percent of 1000-mb (100-kPa) convergence PMP resulting from effective elevation and barrier considerations. Isolines drawn for every five percent.



September

October



November *December*

Figure 2.27.--Regional variation of 6/24-hr ratios by month (percent). Values in parentheses are limiting values and are to facilitate extrapolation beyond the indicated gradient.

For the range of 6/24-hr ratios included in figures 2.25 to 2.27, depth-duration values in percent of 24-hr amounts are found in table 2.7. The regional ratio maps, and the depth-duration curves presented in figure 2.20 were used in adjusting the major storm data to 24-hr amounts listed in table 2.1.

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Note: For use, enter first column (6 hr) with 6/24-hr ratio from figures 2.25 to 2.27.

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For operational use, basin average values of convergence PMP are needed rather than 10-mi^2 (26-km^2) values. Preferably, the method for reducing 10-mi^2 (26-km^2) values to basin average rainfalls should be derived from depth-area relations of storms in the region. However, all general storms in the region include large proportions of orographic precipitation.

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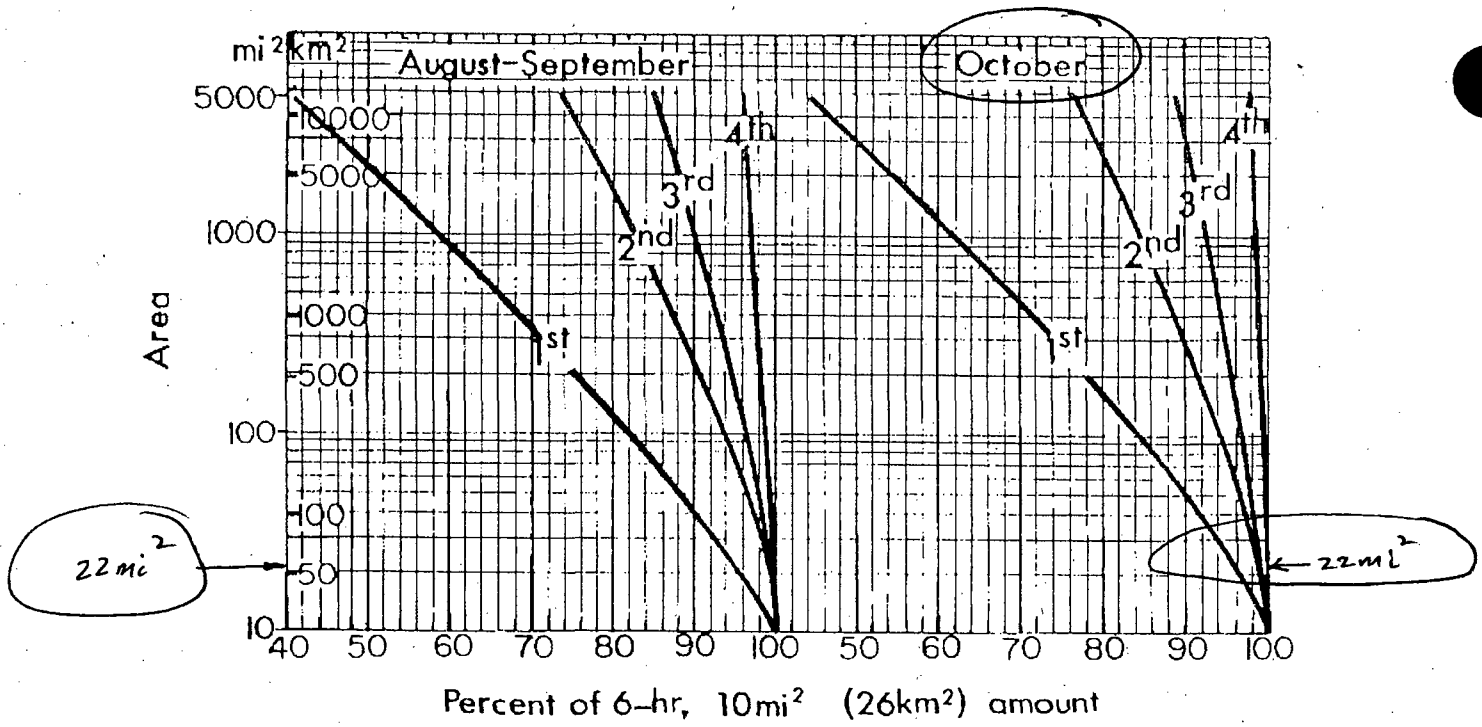


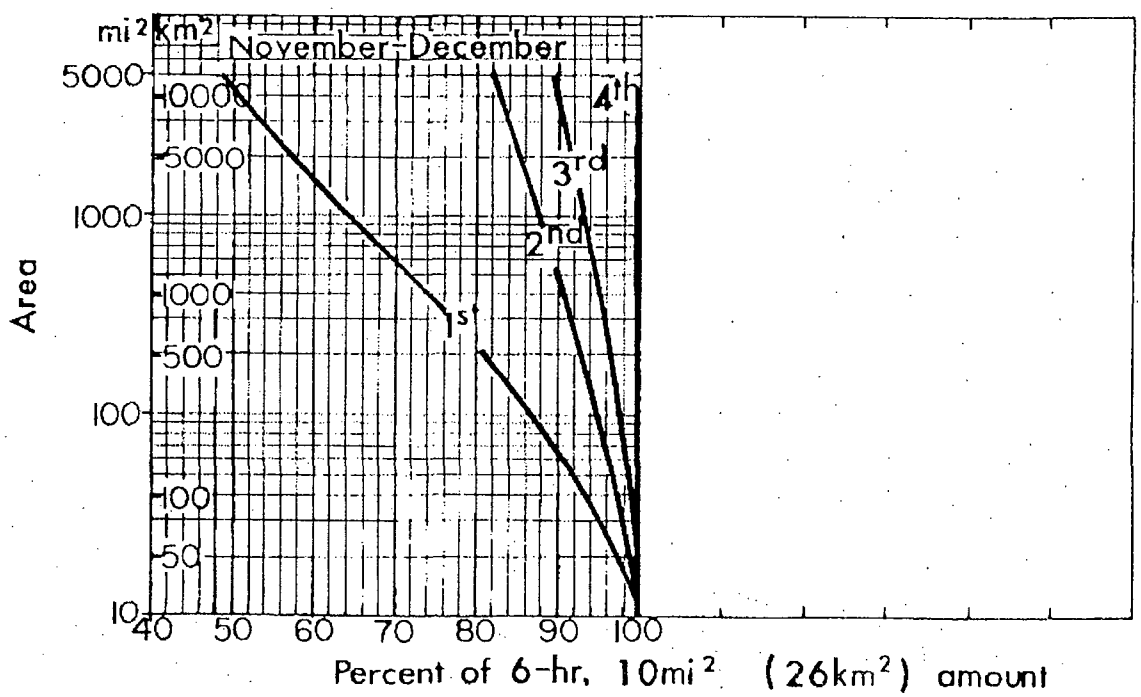
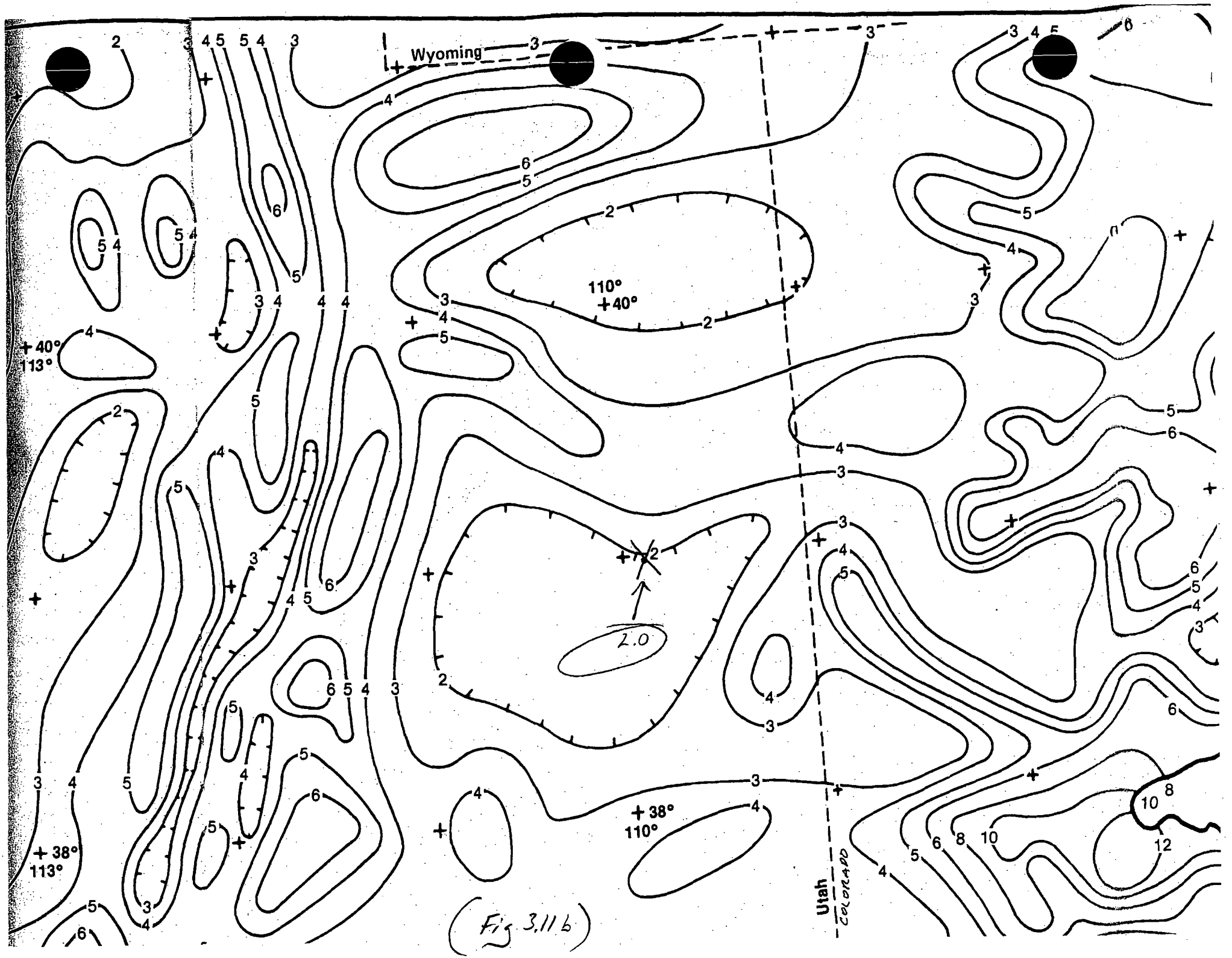


Figure 2.29.--Depth-area variation for convergence PMP for first to fourth 6-hr increments.



(Fig 3.11 b)

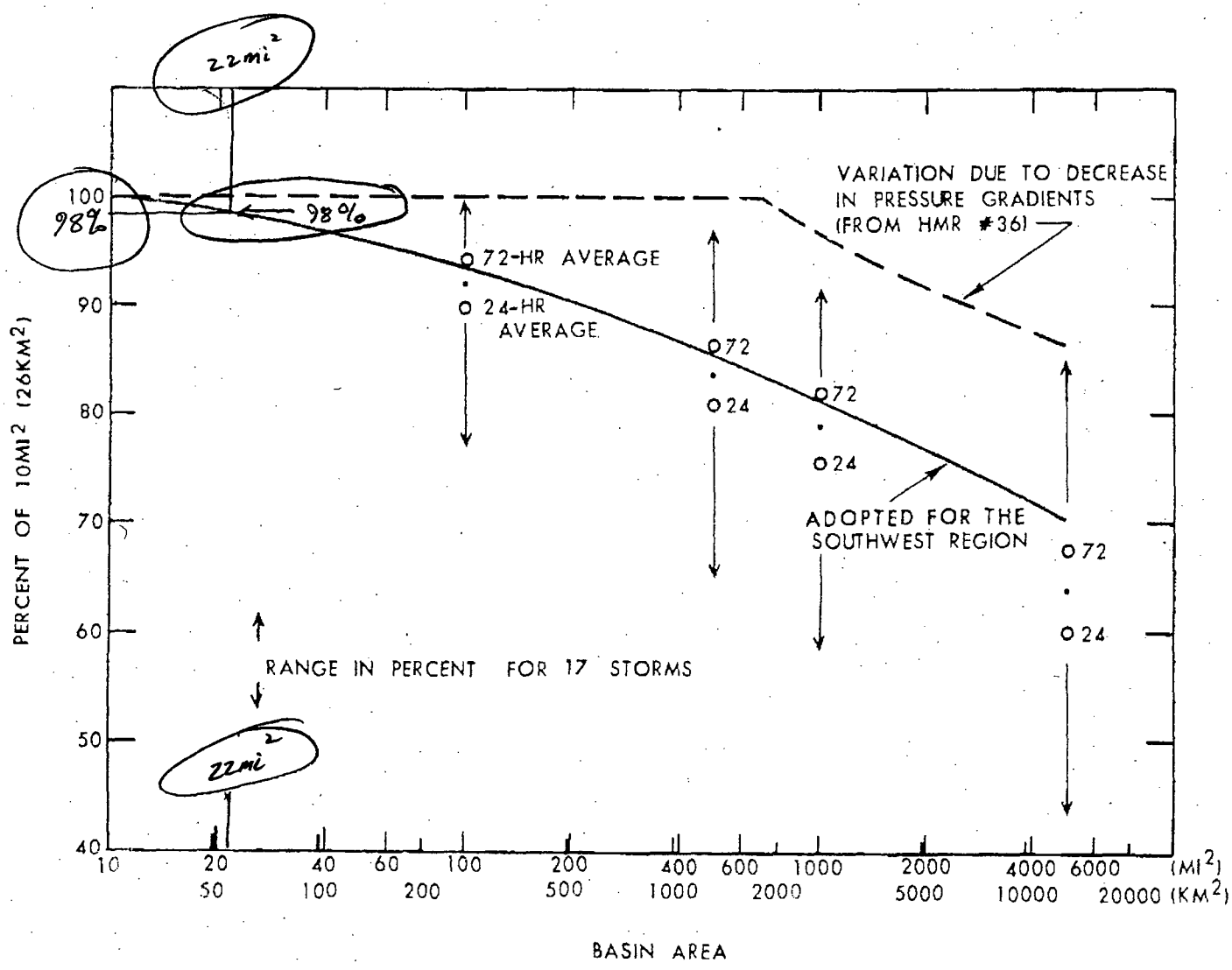
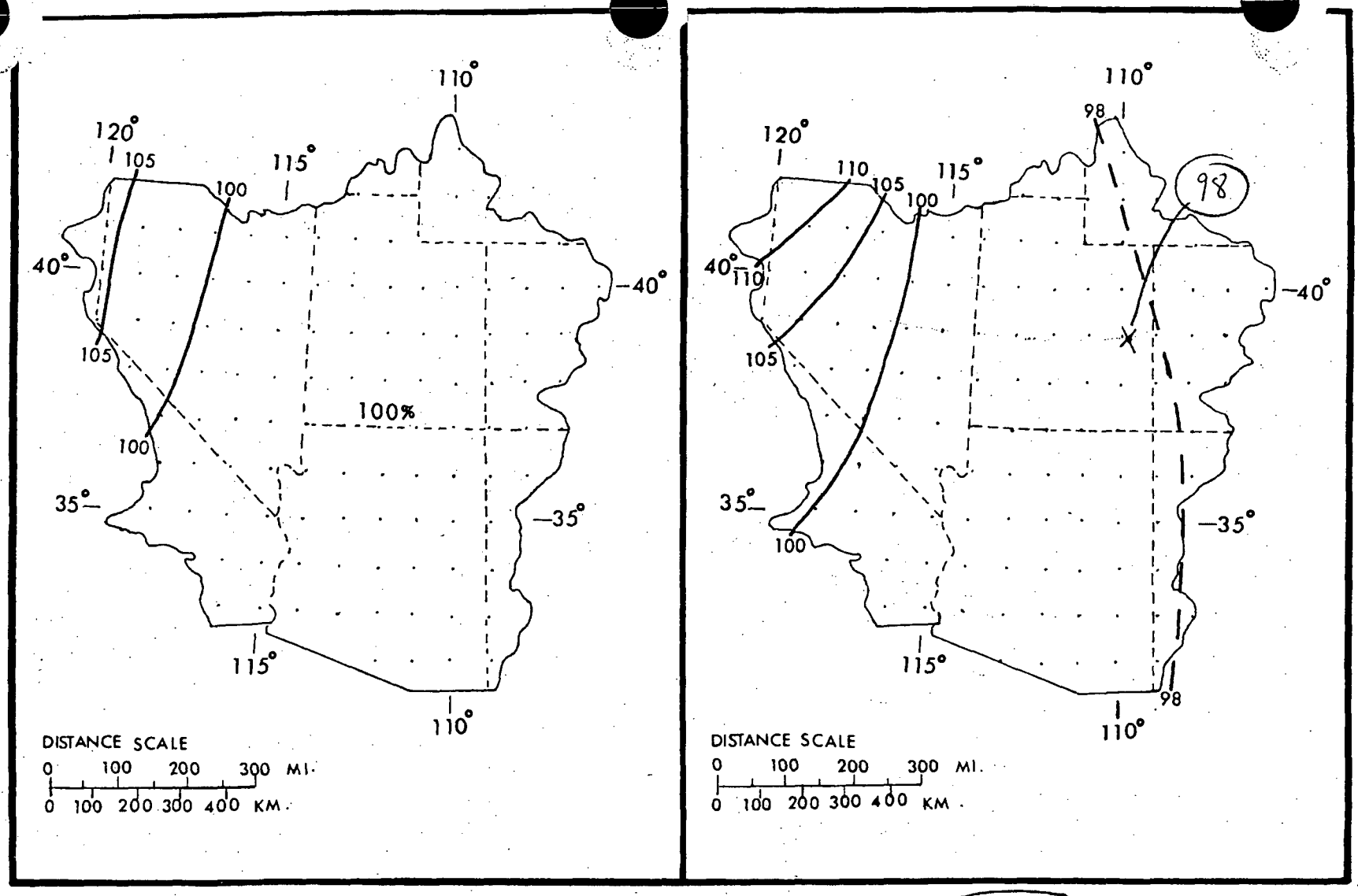


Figure 3.20.--Variation of orographic PMP with basin size.



September *October*

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Local Storm PMP Computation

Table 6.3A.--Local-storm PMP computation, Colorado River, Great Basin and California drainages. For drainage average depth PMP. Go to table 6.3B if areal variation is required.

HMR No. 49

Drainage Crescent Junction Disposal Site Area less than 1 mi^2 ~~(km^2)~~
Latitude 38°57'50" (38.96°) Longitude 109°48'00"W (109.80°) Minimum Elevation 4940 ft ~~(m)~~
Steps correspond to those in sec. 6.3A.

1. Average 1-hr 1-mi^2 (2.6-km^2) PMP for drainage [fig. 4.5]. 8.2 in. ~~(mm)~~

2. a. Reduction for elevation. [No adjustment for elevations up to 5,000 feet (1,524 m): 5% decrease per 1,000 feet (305 m) above 5,000 feet (1,524 m)]. (None req'd) 100 %

   b. Multiply step 1 by step 2a. 8.2 in. ~~(mm)~~

3. Average 6/1-hr ratio for drainage [fig. 4.7]. 1.1

	Duration (hr)									
	1/4	1/2	3/4	1	2	3	4	5	6	
4. Durational variation for 6/1-hr ratio of step 3 [table 4.4].	86	93	97	100	107	109	110	110	110	%
5. 1-mi^2 (2.6-km^2) PMP for indicated durations [step 2b X step 4].	7.1	7.6	8.0	8.2	8.8	8.9	9.0	9.0	9.0	in. ~~(mm)~~
6. Areal reduction [fig. 4.9].	61	67	71	73	76	78	80	81	82	%
7. Areal reduced PMP [steps 5 X 6].	4.3	5.1	5.7	6.0	6.7	6.9	7.2	7.3	7.4	in. ~~(mm)~~
8. Incremental PMP [successive subtraction in step 7].				6.0	0.7	0.2	0.3	0.1	0.1	in. ~~(mm)~~
	4.3	0.8	0.6	0.3	} 15-min. increments					

9. Time sequence of incremental PMP according to: HMR No. 5

   Hourly increments [table 4.7]. 0.1 0.3 6.0 0.7 0.2 0.1 in. ~~(mm)~~

   Four largest 15-min. increments [table 4.8]. 4.3 0.8 0.6 0.3 in. ~~(mm)~~

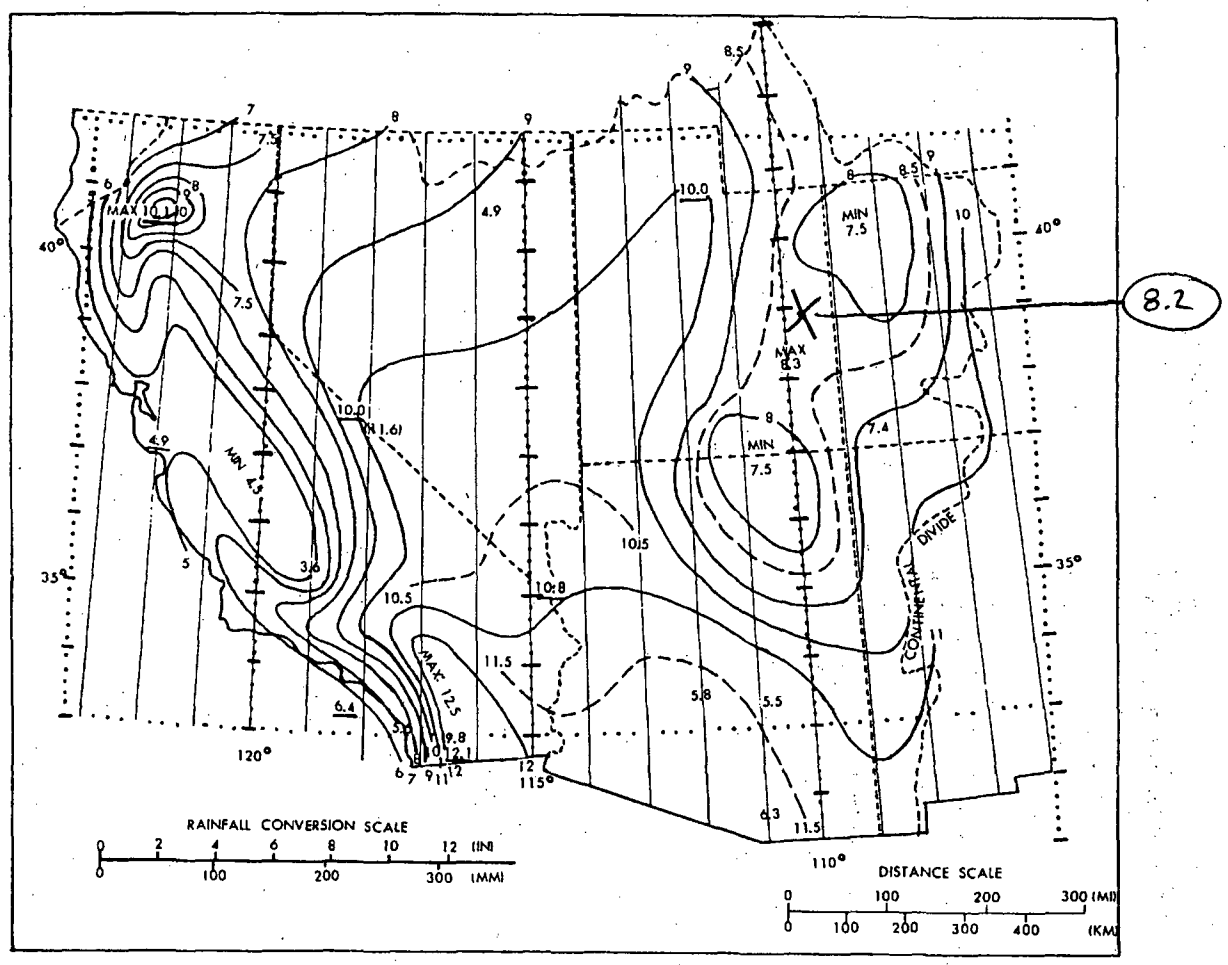

Figure 4.5--Local-storm PMP for 1 mi^2 (2.6 km^2) 1 hr. Directly applicable for locations between sea level and 5000 ft (1524 m). Elevation adjustment must be applied for locations above 5000 ft.

events. In contrast to figure 4.4, figure 4.5 maintains a maximum between these two locations. There is no known meteorological basis for a different solution. The analysis suggests that in the northern portion of the region maximum PMP occurs between the Sierra Nevada on the west and the Wasatch range on the east.

A discrete maximum (> 10 inches, 254 mm) occurs at the north end of the Sacramento Valley in northern California because the northward-flowing moist air is increasingly channeled and forced upslope. Support for this PMP center comes from the Newton, Kennett, and Red Bluff storms (fig. 4.1). Although the analysis in this region appears to be an extension of the broad maximum through the center of the Southwestern Region, it does not indicate the direction of moist inflow. The pattern has evolved primarily as a result of attempts to tie plotted maxima into a reasonable picture while considering inflow directions, terrain effects, and moisture potential.

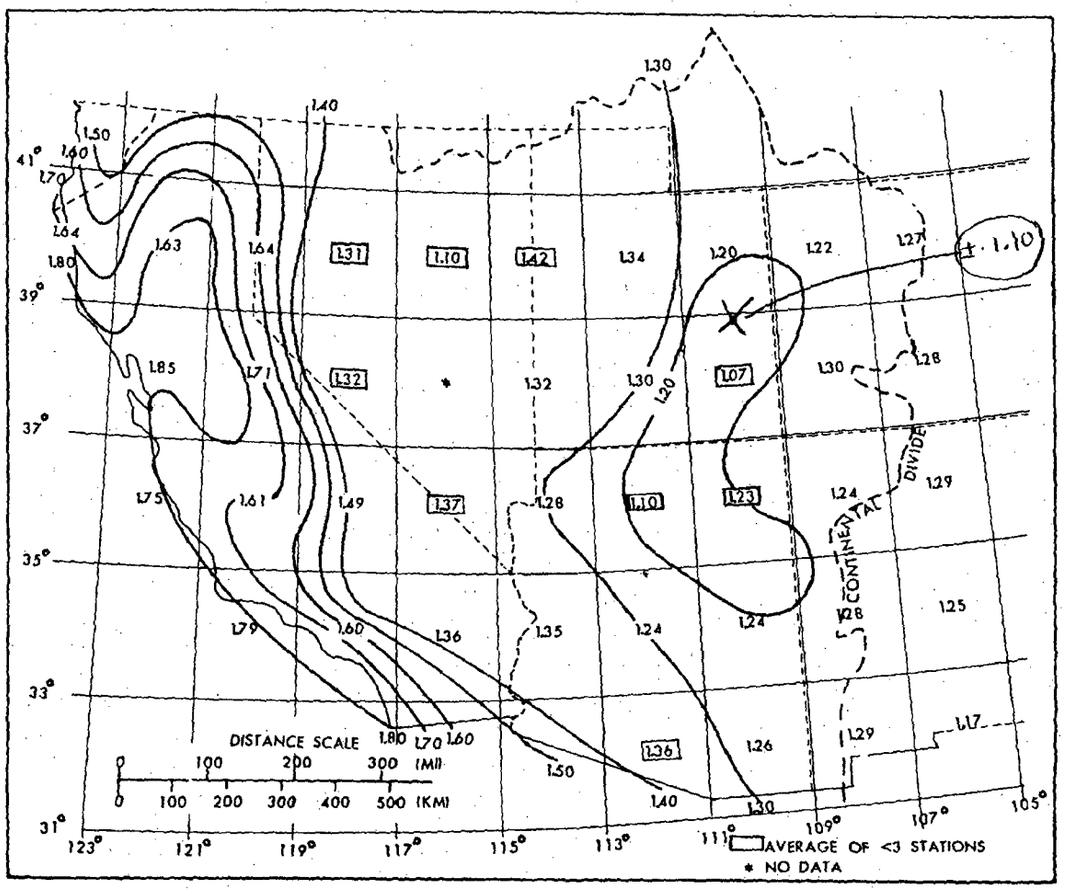

Figure 4.7.--Analysis of 6/1-hr ratios of averaged maximum station data (plotted at midpoints of a 2° latitude-longitude grid).

establish the basic depth-duration curve, then structure a variable set of depth-duration curves to cover the range of 6/1-hr ratios that are needed.

Three sets of data were considered for obtaining a base relation (see table 4.3 for depth-duration data).

a. An average of depth-duration relations from each of 17 greatest 3-hr rains from summer storms (1940-49) in Utah (U. S. Weather Bureau 1951b) and in unpublished tabulations for Nevada and Arizona (1940-63). The 3-hr amounts ranged from 1 to 3 inches (25 to 76 mm) in these events.

b. An average depth-duration relation from 14 of the most extreme short-duration storms listed in Storm Rainfall (U. S. Army, Corps of Engineers 1945-). These storms come from Eastern and Central States and have 3-hr amounts of 5 to 22 inches (127 to 559 mm).

ratios than storms with high 3/1-hr ratios. The geographical distribution of 15-min to 1-hr ratios also were inversely correlated with magnitudes of the 6/1-hr ratios of figure 4.7. For example, Los Angeles and San Diego (high 6/1-hr ratios) have low 15-min to 1-hr ratios (approximately 0.60) whereas the 15-min to 1-hr ratios in Arizona and Utah (low 6/1-hr ratios) were generally higher (approximately 0.75).

Depth-duration relations for durations less than 1 hour were then smoothed to provide a family of curves consistent with the relations determined for 1 to 6 hours, as shown in figure 4.3. Adjustment was necessary to some of the curves to provide smoother relations through the common point at 1 hour.

We believe we were justified in reducing the number of the curves shown in figure 4.3 for durations less than 1 hour, letting one curve apply to a range of 6/1-hr ratios. The corresponding curves have been indicated by letter designators, A-D, on figure 4.3. As an example, for any 6-hr amount between 115% and 135% of 1-hr, 1-mi^2 (2.6-km^2) PMP, the associated values for durations less than 1 hour are obtained from the curve designated as "B".

Table 4.4 lists durational variations in percent of 1-hr PMP for selected 6/1-hr rain ratios. These values were interpolated from figure 4.3.

To determine 6-hr PMP for a basin, use figure 4.3 (or table 4.4) and the geographical distribution of 6/1-hr ratios given in figure 4.7.

Table 4.4.--Durational variation of 1-mi^2 (2.6-km^2) local-storm PMP in percent of 1-hr PMP (see figure 4.3)

6/1-hr ratio	Duration (hr) 1/4	1/2	3/4	1	2	3	4	5	6
1.1	86	93	97	100	107	109	110	110	110
1.2	74	89	95	100	110	115	118	119	120
1.3	74	89	95	100	114	121	125	128	130
1.4	63	83	93	100	118	126	132	137	140
1.5	63	83	93	100	121	132	140	145	150
1.6	43	70	87	100	124	138	147	154	160
1.8	43	70	87	100	130	149	161	171	180
2.0	43	70	87	100	137	161	175	188	200

4.5 Depth-Area Relation

We have thus far developed local-storm PMP for an area of 1 mi^2 (2.6 km^2). To apply PMP to a basin, we need to determine how 1-mi^2 (2.6-km^2) PMP should decrease with increasing area. We have adopted depth-area relations based on rainfalls in the Southwest and from consideration of a model thunderstorm.

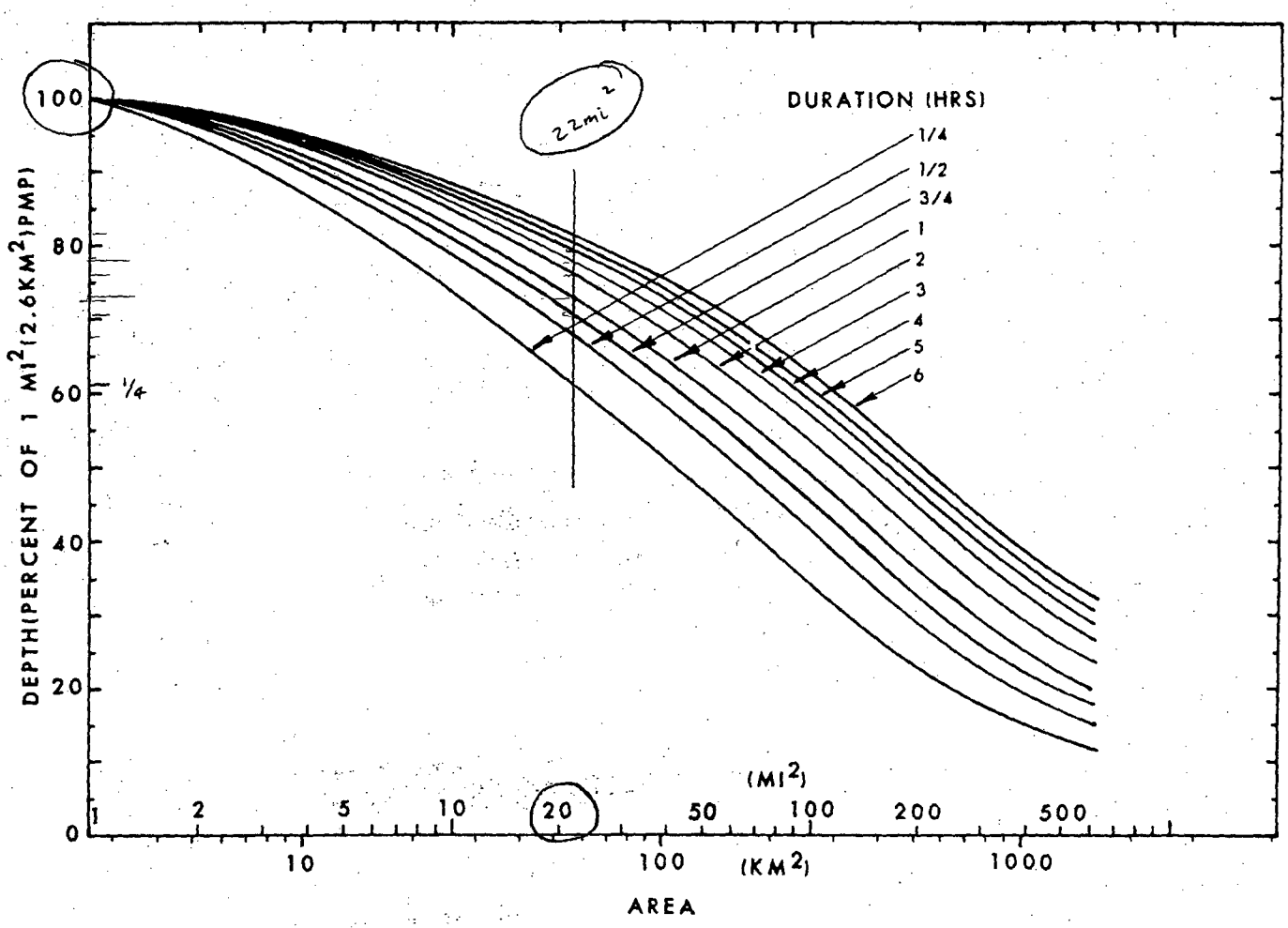

Figure 4.9.--Adopted depth-area relations for local-storm PMP.

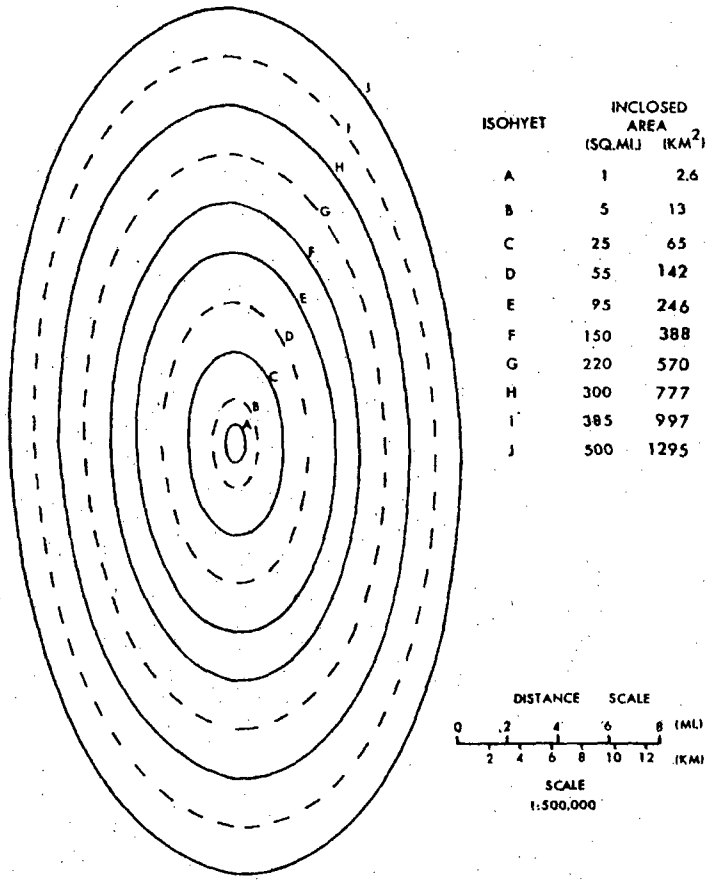

Figure 4.10.--Idealized local-storm isohyetal pattern.

storm period. The sequence of hourly incremental PMP for the Southwest 6-hr thunderstorm in accord with this study is presented in column 2 of table 4.7. A small variation from this sequence is given in Engineering Manual 1110-2-1411 (U. S. Army, Corps of Engineers 1965). The latter, listed in column 3 of table 4.7, places greater incremental amounts somewhat more toward the end of the 6-hr storm period. In application, the choice of either of these distributions is left to the user since one may prove to be more critical in a specific case than the other.

Table 4.7.--Time sequence for hourly incremental PMP in 6-hr storm

Increment	HMR No. 5[1] Sequence Position	EM1110-2-1411[2] Sequence Position
Largest hourly amount	Third	Fourth
2nd largest	Fourth	Third
3rd largest	Second	Fifth
4th largest	Fifth	Second
5th largest	First	Last
least	Last	First

[1]U. S. Weather Bureau 1947.
[2]U. S. Corps of Engineers 1952.

Also of importance is the sequence of the four 15-min incremental PMP values. We recommend a time distribution, table 4.8, giving the greatest intensity in the first 15-min interval (U.S. Weather Bureau 1947). This is based on data from a broad geographical region. Additional support for this time distribution is found in the reports of specific storms by Keppell (1963) and Osborn and Renard (1969).

Table 4.8.--Time sequence for 15-min incremental PMP within 1 hr.

Increment	Sequence Position
Largest 15-min amount	First
2nd largest	Second
3rd largest	Third
least	Last

4.8 Seasonal Distribution

The time of the year when local-storm PMP is most likely is of interest. Guidance was obtained from analysis of the distribution of maximum 1-hr thunderstorm events through the warm season at the recording stations in Utah, Arizona, and in southern California (south of 37°N and east of the Sierra Nevada ridgeline). The period of record used was for 1940-72 with an average record length for the stations considered of 27 years. The month with the one greatest thunderstorm rainfall for the period of record at each station was noted. The totals of these events for each month, by States, are shown in table 4.9.

Table 4.9.--Seasonal distribution of thunderstorm rainfalls.

(The maximum event at each of 108 stations, period of record 1940-72.)

	Month						
	M	J	J	A	S	O	No. of Cases
Utah	1	5	9	14	5		34
Arizona		4	16	19	4		43
S. Calif.*		14	10	7			31
No. of cases/mo.	1	23	35	40	9	0	

*South of 37°N and east of Sierra Nevada ridgeline.

U.S. Department of Energy—Grand Junction, Colorado

Calculation Cover Sheet

Calc. No.: MOA-02-06-2006-5-08-00 Discipline: Geotechnical No. of Sheets: 8
Doc. No.: X0176000

Location: Attachment 1, Appendix F

Project: Moab UMTRA Project

Site: Crescent Junction Disposal Site

Feature: Crescent Junction Site Hydrology Report

Sources of Data:

Remedial Action Plan (RAP) calculations as referenced in the text.

Sources of Formulae and References:

See "References."

Preliminary Calc. ☐ Final Calc. ☒ Supersedes Calc. No.

Author: Peggy Bailey 5-29-07 (Name / Date)

Checked by: G. Gray (Name) 5/30/07 (Date)

Kathryn Ste (Name) 6/11/07 (Date)

Approved by: John E Elmer (Name) 5/31/07 (Date)

(Name) (Date)

Safety (Name) May 31, 07 (Date)

No text for this page

Problem Statement:

Peak runoff flow rates are determined at specific locations in the vicinity of the Crescent Junction Site for the following storms:

- 25-year, 24-hour storm.
- 100-year, 24-hour storm.
- Probable Maximum Precipitation (PMP), Local Storm.

The 25-year, 24-hour storm is determined for sizing culverts and swales along the access road and Trailer Staging Area. These facilities will be in-place for approximately 25-years to facilitate the placement of the disposal cell. The 100-year flood is used to size the detention facility at the Trailer Staging Area, in compliance with Grand County drainage regulations. A separate drainage report for submittal to the County is being prepared with detention basin calculations. One-hundred-year flows are also generated to compare existing versus "developed" conditions at key drainage points located downhill from the disposal cell. This includes flows at West Kendall Wash at the Railroad crossing located immediately south of the southwest corner of the disposal cell, Kendall Wash at the I-70 crossing and Crescent Wash at the I-70 crossing immediately west of Kendall Wash. The Probable Maximum Flood (PMF) is calculated for use in design of facilities associated with the disposal cell. This includes the PMF for the cell drainage facilities to control run-on and run-off. Major drainages are shown on Figure 1. Sub-basins and proposed-conditions basins are shown in detail on the Master Drainage Plan (Plan), Appendix F of this report.

Method of Solution:

Calculations for runoff hydrographs, routing reaches, and combination of hydrographs for all basins greater than 20 acres are determined using the U.S. Army Corps of Engineers' Hydrologic Modeling System (HEC-HMS) Version 3.0.1. Within this computer model, the following runoff and routing methods are used:

- NRCS classification of the soils within the project site is Type B (Toddler-Ravola-Glenton) described as well draining sands and sandy loams, with a range of final infiltration rates of 4 to 8 millimeters (mm) per hour (0.16 to 0.31 inches per hour). The U.S. Bureau of Reclamation also recommends 0.3 to 0.15 inches per hour (USBR 1987) as the minimum infiltration rates for B soils. For the purpose of this analysis use 0.3 inches per hour in the existing undisturbed watershed and 0.15 inches per hour for the cell site.
- Soil Conservation Service (SCS) curve number (CN) values for B soils with sparse vegetation use 70.
- Manning's N value, K_n, representing the hydraulic characteristics of the drainage network, varies with flow (see discussion in the "User-Specified Unit Hydrograph" subsection), use 0.042 for the PMF and 0.054 for the 25-year and 100-year flow.

For the PMF:

- Loss Method in existing watershed – Initial loss of 0.0 inches, constant loss of 0.3 inches per hour.
- Loss Method for the disposal cell – Initial loss of 0.0 inches, constant loss of 0.15 inches per hour.
- Transform Method – User-specified unit hydrograph.
- Baseflow Method – None.
- Routing Reaches – Kinematic wave.
- Meteorology Model – PMP calculations, no evapotranspiration, no snowmelt.

For the 25-year and 100-year, 24 hour storms:

- Loss Method in existing watershed – SCS CN method with initial loss of 0.86 inches based on CN of 70 and constant loss of 0.3 inches per hour.
- Loss Method for the disposal cell- SCS CN method with initial loss of 0.86 inches based on CN of 70 and constant loss of 0.15 inches per hour

- Transform Method – User-specified unit hydrograph.
- Baseflow Method – None.
- Routing Reaches – Kinematic wave.
- Meteorology Model – Precipitation from National Oceanic and Atmospheric Administration (NOAA) Atlas 14, no evapotranspiration, no snowmelt.

Note that for basins less than 20 acres that do not require PMF determination, runoff is calculated using the Rational Method.

Assumptions:

Standard methods were used to calculate the runoff to the design points for the specific frequency storms.

Calculations:

Basin Delineation

Drainage basins are delineated based on locations of bridges/culverts or other points of concentration. There are four major basins encompassing the study area: Crescent Wash, Basin 1, Basin 2, and Basin 3. These major basins are shown on Figure 1. Seven sub-basins within the major basins are created due to the re-routing of flows around the disposal cell and the access road. These sub-basins are shown on the Plan (Appendix F).

The disposal cell will be isolated from run-on with the construction of a diversion channel, labeled as "North Ditch" on the Plan. These flows, which are ultimately tributary to West Kendall Wash, will be routed to the west past the Disposal Site, and then south in the "West Ditch", back into West Kendall Wash. Runoff from the cell will be diverted to the west at the south toe of the disposal cell, and confluence with the West Ditch at Design Point 4 as shown on the Plan.

User-Specified Unit Hydrograph

The methodology for determining the unit hydrograph is detailed in *Design of Small Dams* (USBR 1987) using the dimensionless unit hydrograph data for the Colorado Plateau regions of Southern California, Nevada, Utah, Arizona, and western Colorado and New Mexico. Basins in this arid region are generally typified by sparse vegetation, fairly well defined drainage networks, and terrain varying from rolling to very rugged in the more mountainous areas. The unit hydrograph lag time is defined as:

$$L_g = C(LL_{ca}/S^{.5})$$

where:

L_g = unit hydrograph lag time, hours

The USBR (1987) defines the unit hydrograph lag time as the time from the midpoint of the unit rainfall excess to the time that 50 percent of the volume of unit runoff from the drainage basin has passed the concentration point (USBR 1987).

C = constant=$26K_n$

K_n = average Manning's n value representing the hydraulic characteristics of the drainage basin. K_n is a function of the magnitude of the flows and normally decreases with increasing discharge. K_n values for the PMF are based on recommendations from *Design of Small Dams* (USBR 1987), which suggests the lowest value representative of the region be used. A regional K_n value of 0.042 represents the lower limit of the accepted range for PMF determination and is typical of the usual desert terrain. For other storm events a higher value is appropriate. Based on the *Design of Small Dams,* the Colorado Plateau regions K_n range from 0.042 to 0.070. A value of 0.054 is selected for the 25-year and 100-year storm events, representing an area of Utah that is relatively close proximity to the project site on the White River (USBR 1987).

L = the length of the longest watercourse from the point of concentration to the boundary of the drainage basin.

L_{ca} = the length along the longest watercourse from the point of concentration to a point opposite the centroid of the drainage basin.

S = the overall slope of the longest watercourse (along *L*).

Hydrologic parameters and spreadsheets are used to create the basin-specific unit hydrographs for use by the HEC-HMS models and are presented in Appendix A.

Frequency Storms

Design storm information is provided in the "Site Drainage—Hydrology Parameters" calculation (RAP Attachment 1, Appendix E), which calculates the local storm PMP for storms of <1 square mile (mi^2) and 22 mi^2. This analysis also includes determination of storms in basins covering 1.4, 2.7, 3.5, 9, and 15 mi^2. Thus additional depth-duration models are developed so that the size of the storm is equivalent to the drainage area contributing to the design point. Calculations are included in Appendix B.

The depth-duration relationships for all of the modeled storms are summarized in Table 1.

Table 1. Depth-Duration for Modeled Storms

Precipitation Depth (inches) for Specified Duration								
Storm Event	**5 min**	**15 min**	**1 hr**	**2 hr**	**3 hr**	**6 hr**	**12 hr**	**24 hr**
25-yr, 24-hr	0.34	0.64	1.07	1.21	1.26	1.42	1.65	1.91
100-yr, 24-hr	0.53	0.99	1.65	1.82	1.84	1.95	2.16	2.35
200-yr, 24-hr	0.65	1.22	2.03	2.23	2.25	2.35	2.47	2.58
PMP – Local								
<1 mi^2	4.5	7.1	8.2	8.8	8.9	9.0		
1.4 mi^2	4.3	6.8	8.0	8.6	8.7	8.9		
2.7 mi^2	4.1	6.5	7.9	8.4	8.5	8.7		
3.5 mi^2	4.0	6.2	7.6	8.3	8.5	8.6		
9 mi^2	3.4	5.4	6.9	7.6	7.7	8.0		
15 mi^2	3.0	4.8	6.4	7.0	7.2	7.7		
22 mi^2	2.7	4.3	6.0	6.7	6.9	7.4		

Routing Reaches

Reach routing is performed in the HEC-HMS modeling using kinematic wave to route hydrographs along ditches and between design points. Design parameters and input are summarized in Appendix B.

HEC-HMS Results

The HEC-HMS model is used to determine hydrographs at the specific design points for each of the four storm events. Model output is provided in Appendix C and summarized in Table 2. For basins less than 20 acres that do not require PMF determination, runoff is calculated using the Rational Method. Rational Method calculations are presented in Appendix D.

Conclusions and Recommendations:

The peak flow rates at each of the design points are summarized in Table 2.

Table 2. Peak Flow Rates, Major Storm Events

Design Point	Area (mi^2)	Peak Flow Rate (cfs)		
		25-yr, 24-hr	100-yr, 24-hr	PMP - Local
Crescent Wash at RR Bridge and I-70 Existing and Proposed	22.56	2,975	5,983	45,197
Basin 1 at RR Bridge (Design Point 6)	2.63			
Existing conditions		-	2,135	21,288
Proposed conditions		-	2,210	21,322
Basin 2 at RR Bridge Existing and Proposed	8.96	1,726	3,453	29,869
Basins 1, 2, and 3 at I-70 CMP	15.09			
Existing conditions		-	5,109	40,835
Proposed conditions		-	5,098	40,871
Proposed Drainage Facilities				
North Ditch	0.52	291	-	5,859
West Ditch (Design Point 4)	0.52	291	-	5,859
Design Point 5	0.90	448	-	8,722
Existing Culvert (Design Point 3)	0.17	75	147	1,488
Culvert C1*	0.09	42	-	-
Culvert C2*	0.05	9	-	-
Culvert C3*	0.02	4	-	-
Culvert C4*	0.10	18	-	-
Culvert C5	1.25	611	-	-
Culvert C6*	0.05	9	-	-
Culvert C7*	0.41	239	-	-

Discussion:

Parameters used to calculate the 25-year and 100-year flows are checked using gaged data available for Crescent Wash through the U.S. Geological Survey (USGS). Two sets of information are available. The first includes 10 years of gaging information (USGS 1999), which indicates the highest flow on record of 4,160 cfs in 1965. The second is a flood-frequency analysis performed by the USGS (Vaill 2000) indicating a 100-year event with a peak discharge of 6,460 cfs. Due to the limited amount of data, this information is considered only a relative check for order of magnitude compared to the computations; however, the results of this analysis are within 3 percent of the USGS results, when adjusted for drainage area. Several additional gaged sites were also checked for peak flows per square mile. Sites selected for comparison are similar in elevation and size and are in similar environmental conditions as the project site. Peak flows were calculated by the USGS using Log-Pearson Type III probability distribution (Vaill 2000). See Appendix E for a detailed discussion and comparison of flows.

References:

U.S. Army Corps of Engineers. *HEC-HMS Hydrologic Modeling System*, Version 3.0.1, Hydrologic Engineering Center, Davis, California.

USGS (U.S. Geological Survey), 1999. *The National Flood-Frequency Program-Methods for Estimating Flood Magnitude and Frequency in Rural Areas in Utah*, U.S. Geological Survey, September.

USBR (U.S. Bureau of Reclamation), 1987. *Design of Small Dams, 3rd Ed.*, U.S. Department of the Interior, U.S. Bureau of Reclamation.

Vaill, J.E., 2000. *Analysis of the Magnitude and Frequency of Floods in Colorado*, U.S. Geological Survey Water-Resources Investigations Report 99-4190.

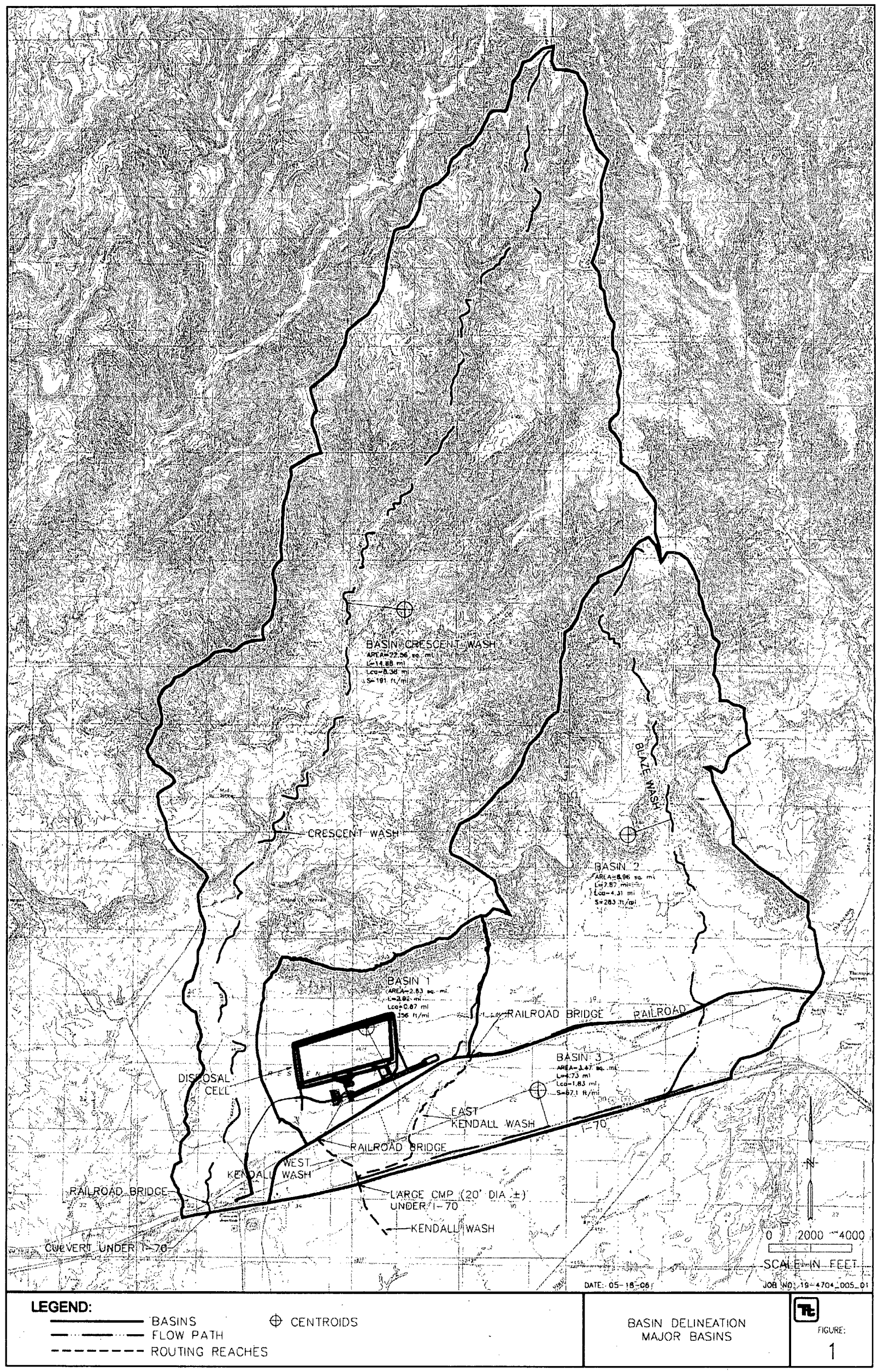

Figure 1. Major Drainage Basins for the Crescent Junction Site

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Appendix A

Unit Hydrographs

COLORADO PLATEAU UNIT HYDROGRAPH 18-May-06

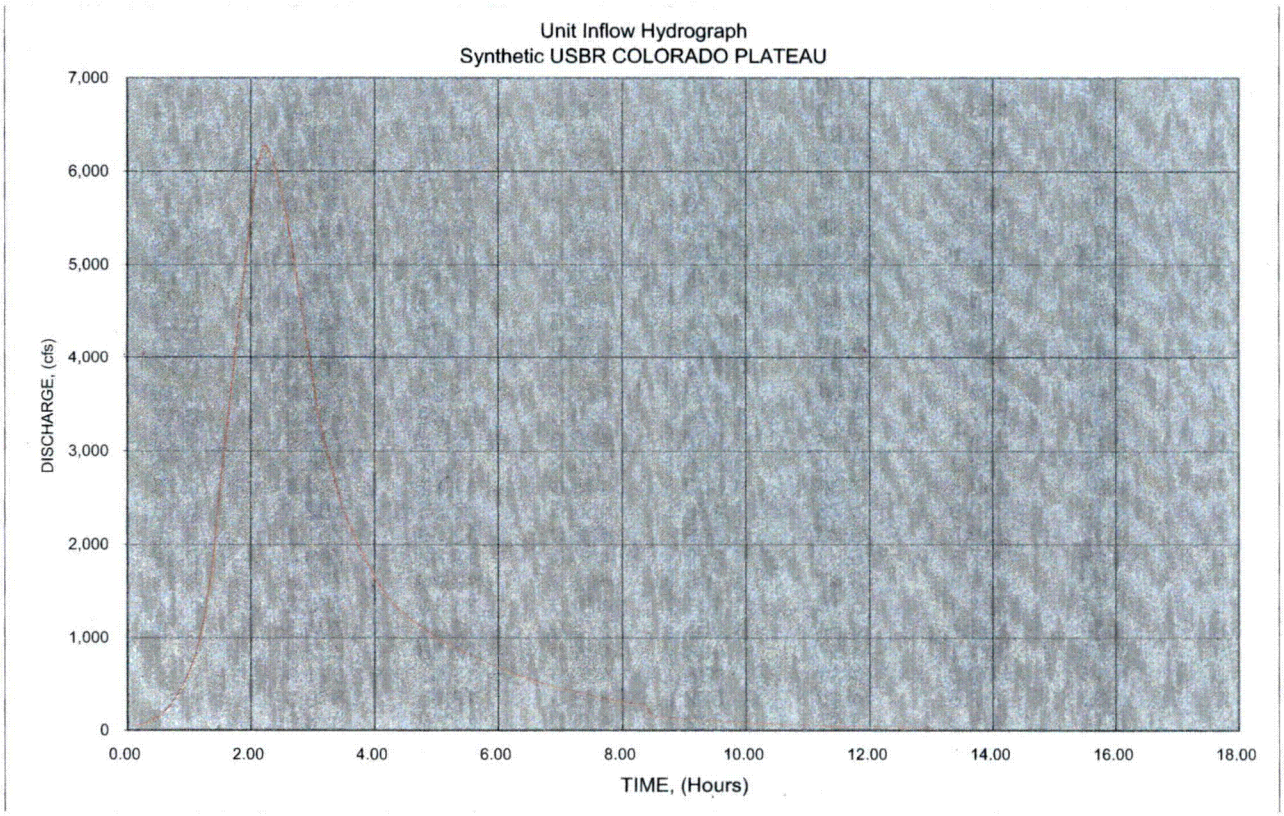
Crescent Wash-10, 25, 100, 200 Existing Conditions

Drainage Area =	22.56	sq. miles	Lg+D/2 =	2.79	Hours
Basin Slope =	209	ft./mile	Basin Factor =	6.63	
L =	13.56	mi., Length of Watercourse	V' =	606.64	cfs/Day
Lca =	7.07	mi., Distance to Centroid	Qs =	217.6	* q, cfs
Kn =	0.054	-, Ave. Weighted Manning's n			

PARAMETERS:

Calculated:	Lag Time, Lg =	2.62 Hours	Unit Duration, D =	28.59	minutes
			Calculated Timestep =	8.36	minutes

Data to be used in Analysis Unit Duration, D = 20 minutes, round down to nearest of 5, 10, 15, 30, 60, 120, 180, or 360
Selected Timestep = 5 minutes, integer value evenly divisible into 60



UI Record - Unit Graph 5 **minute interval**

UI	25	47	64	83	104	138	180	241	313	391
UI	497	612	749	945	1178	1552	1979	2526	3048	3554
UI	4073	4576	5027	5502	5994	6176	6265	6156	5984	5764
UI	5485	5187	4845	4503	4160	3794	3450	3204	2979	2774
UI	2569	2377	2241	2111	1987	1876	1766	1657	1564	1489
UI	1414	1342	1294	1246	1200	1157	1115	1075	1037	1002
UI	968	935	908	879	849	823	798	771	745	720
UI	696	673	651	628	605	587	571	550	531	512
UI	497	482	467	452	437	423	409	396	383	370
UI	358	346	334	323	314	305	296	286	276	267
UI	258	251	241	233	225	218	211	204	196	190
	184	179	174	168	163	157	151	147	143	139
	134	129	125	121	117	113	109	105	102	99
UI	96	92	89	87	84	81	79	76	74	72

UI	70	66	63	61	59	58	57	54	52	51
UI	49	48	47	46	44	43	42	40	39	38
UI	36	35	34	33	33	32	29	27	26	26
UI	26	24	14							
UI										
UI										
UI										
UI										

USBR calculated unitgraph peak = 6291 Interpolated Peak = 6265

Time t, % of Lg+D/2	Hours	Min.	q	Qs cfs	Time t, % of Lg+D/2	Hours	Min.	q	Qs cfs
5.0	0.14	8.4	0.19	41	305.0	8.50	510.2	0.66	144
10.0	0.28	16.7	0.32	70	310.0	8.64	518.5	0.63	137
15.0	0.42	25.1	0.48	104	315.0	8.78	526.9	0.59	128
20.0	0.56	33.5	0.74	161	320.0	8.92	535.3	0.56	122
25.0	0.70	41.8	1.21	263	325.0	9.06	543.6	0.53	115
30.0	0.84	50.2	1.81	394	330.0	9.20	552.0	0.50	109
35.0	0.98	58.5	2.63	572	335.0	9.34	560.4	0.47	102
40.0	1.12	66.9	3.68	801	340.0	9.48	568.7	0.45	98
45.0	1.25	75.3	5.47	1,190	345.0	9.62	577.1	0.42	91
50.0	1.39	83.6	8.41	1,830	350.0	9.76	585.4	0.40	87
55.0	1.53	92.0	12.61	2,744	355.0	9.90	593.8	0.38	83
60.0	1.67	100.4	16.50	3,590	360.0	10.04	602.2	0.36	78
65.0	1.81	108.7	20.50	4,461	365.0	10.18	610.5	0.34	74
70.0	1.95	117.1	23.97	5,216	370.0	10.32	618.9	0.33	72
75.0	2.09	125.5	27.75	6,038	375.0	10.45	627.3	0.30	65
80.0	2.23	133.8	28.91	6,291	380.0	10.59	635.6	0.28	61
85.0	2.37	142.2	28.07	6,108	385.0	10.73	644.0	0.27	59
90.0	2.51	150.5	26.38	5,740	390.0	10.87	652.4	0.26	57
95.0	2.65	158.9	24.18	5,262	395.0	11.01	660.7	0.24	52
100.0	2.79	167.3	21.55	4,689	400.0	11.15	669.1	0.23	50
105.0	2.93	175.6	18.92	4,117	405.0	11.29	677.4	0.22	48
110.0	3.07	184.0	16.08	3,499	410.0	11.43	685.8	0.21	46
115.0	3.21	192.4	14.19	3,088	415.0	11.57	694.2	0.20	44
120.0	3.35	200.7	12.61	2,744	420.0	11.71	702.5	0.19	41
125.0	3.48	209.1	11.04	2,402	425.0	11.85	710.9	0.18	39
130.0	3.62	217.5	9.99	2,174	430.0	11.99	719.3	0.17	37
135.0	3.76	225.8	9.04	1,967	435.0	12.13	727.6	0.16	35
140.0	3.90	234.2	8.20	1,784	440.0	12.27	736.0	0.15	33
145.0	4.04	242.5	7.36	1,602	445.0	12.41	744.4	0.15	33
150.0	4.18	250.9	6.78	1,475	450.0	12.55	752.7	0.13	28
155.0	4.32	259.3	6.20	1,349	455.0	12.68	761.1	0.12	26
160.0	4.46	267.6	5.83	1,269	460.0	12.82	769.4	0.12	26
165.0	4.60	276.0	5.47	1,190	465.0	12.96	777.8	0.11	24
170.0	4.74	284.4	5.15	1,121	470.0	13.10	786.2		
175.0	4.88	292.7	4.84	1,053	475.0	13.24	794.5		
180.0	5.02	301.1	4.57	994	480.0	13.38	802.9		
185.0	5.16	309.5	4.31	938	485.0	13.52	811.3		
190.0	5.30	317.8	4.10	892	490.0	13.66	819.6		
195.0	5.44	326.2	3.87	842	495.0	13.80	828.0		
200.0	5.58	334.5	3.68	801	500.0	13.94	836.4		
205.0	5.72	342.9	3.47	755	505.0	14.08	844.7		
210.0	5.85	351.3	3.28	714	510.0	14.22	853.1		
215.0	5.99	359.6	3.10	675	515.0	14.36	861.4		
220.0	6.13	368.0	2.93	638	520.0	14.50	869.8		
225.0	6.27	376.4	2.75	598	525.0	14.64	878.2		
230.0	6.41	384.7	2.63	572	530.0	14.78	886.5		
235.0	6.55	393.1	2.47	537	535.0	14.91	894.9		
240.0	6.69	401.5	2.33	507	540.0	15.05	903.3		
245.0	6.83	409.8	2.22	483	545.0	15.19	911.6		
250.0	6.97	418.2	2.10	457	550.0	15.33	920.0		
255.0	7.11	426.5	1.99	433	555.0	15.47	928.4		
260.0	7.25	434.9	1.88	409	560.0	15.61	936.7		
265.0	7.39	443.3	1.78	387	565.0	15.75	945.1		
270.0	7.53	451.6	1.68	366	570.0	15.89	953.4		
275.0	7.67	460.0	1.59	346	575.0	16.03	961.8		
280.0	7.81	468.4	1.50	326	580.0	16.17	970.2		
285.0	7.95	476.7	1.43	311	585.0	16.31	978.5		
290.0	8.08	485.1	1.36	296	590.0	16.45	986.9		
295.0	8.22	493.4	1.28	279	595.0	16.59	995.3		
300.0	8.36	501.8	1.21	263	600.0	16.73	1003.6		

NOTES : Use for models including the Crescent Wash Basin for the 10, 25, 100 and 200 year events

COLORADO PLATEAU UNIT HYDROGRAPH 18-May-06

Crescent Wash-PMP Existing Conditions

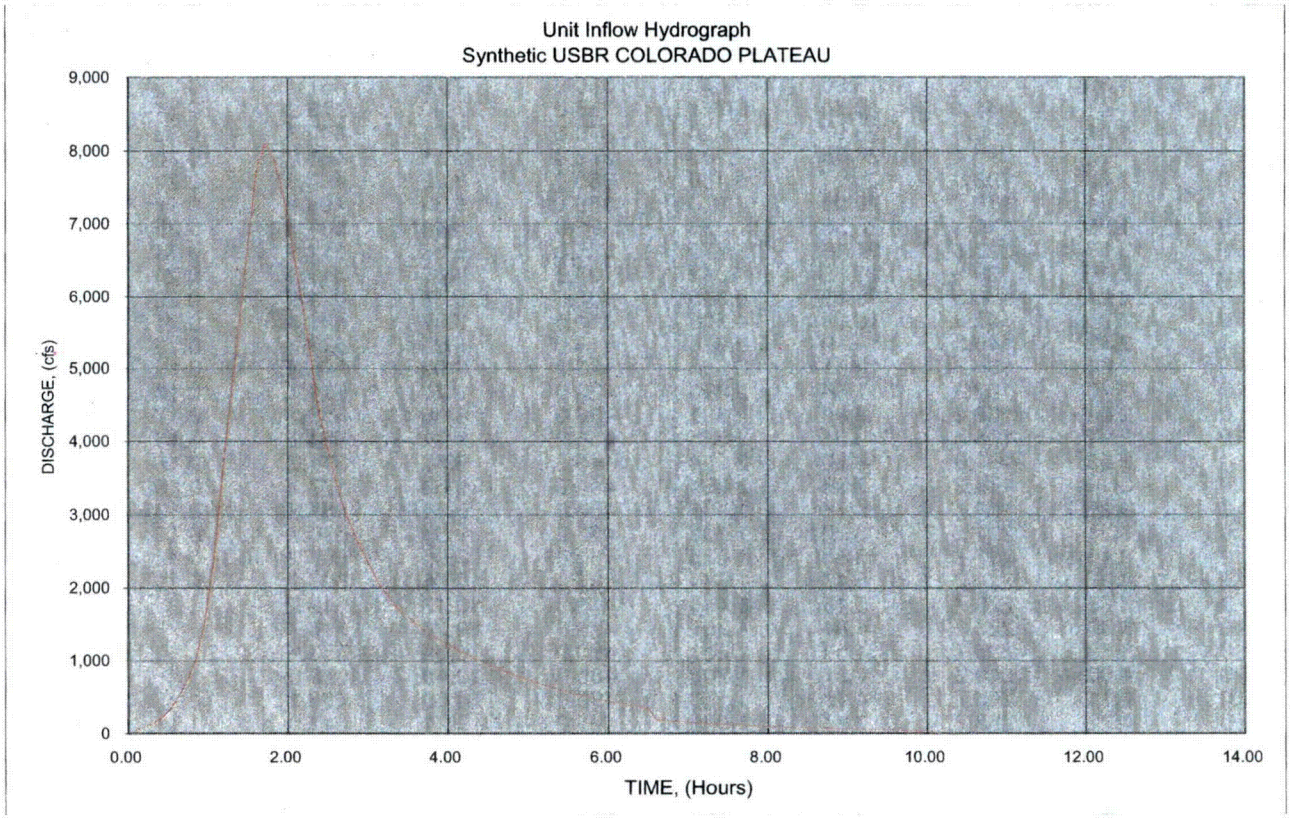
Drainage Area =	22.56	sq. miles	Lg+D/2 =	2.16	Hours
Basin Slope =	209	ft./mile	Basin Factor =	6.63	
L =	13.56	mi., Length of Watercourse	V' =	606.64	cfs/Day
Lca =	7.07	mi., Distance to Centroid	Qs =	280.4	* q, cfs
Kn =	0.042	-, Ave. Weighted Manning's n			

PARAMETERS:

Calculated:	Lag Time, Lg =	2.04 Hours	Unit Duration, D =	22.24	minutes
			Calculated Timestep =	6.49	minutes

Data to be used in Analysis Unit Duration, D = 15 minutes, round down to nearest of 5, 10, 15, 30, 60, 120, 180, or 360

Selected Timestep = 5 minutes, integer value evenly divisible into 60



UI Record - Unit Graph 5 **minute interval**

UI	41	73	104	140	197	289	405	545	722	944
UI	1269	1734	2374	3281	4140	4990	5840	6589	7394	7912
UI	8064	7883	7530	7096	6590	6022	5454	4852	4329	3930
UI	3589	3250	2972	2750	2545	2363	2181	2019	1894	1769
UI	1678	1599	1523	1454	1386	1324	1266	1210	1165	1116
UI	1070	1029	983	941	901	863	826	787	756	728
UI	693	663	637	612	587	563	539	516	495	473
UI	454	434	416	401	386	369	353	338	325	310
UI	296	284	273	260	248	238	230	221	212	203
UI	193	186	180	172	164	157	151	144	138	132
UI	127	121	116	112	107	103	99	95	93	86
UI	81	78	76	73	70	66	64	62	60	58
UI	56	53	51	49	47	45	43	42	40	36
UI	34	34	32	24	0					

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USBR calculated unitgraph peak = 8106 Interpolated Peak = 8064

Time t, % of Lg+D/2	Hours	Min.	q	Qs cfs	Time t, % of Lg+D/2	Hours	Min.	q	Qs cfs
5.0	0.11	6.5	0.19	53	305.0	6.60	396.0	0.66	185
10.0	0.22	13.0	0.32	90	310.0	6.71	402.4	0.63	177
15.0	0.32	19.5	0.48	135	315.0	6.82	408.9	0.59	165
20.0	0.43	26.0	0.74	207	320.0	6.92	415.4	0.56	157
25.0	0.54	32.5	1.21	339	325.0	7.03	421.9	0.53	149
30.0	0.65	38.9	1.81	507	330.0	7.14	428.4	0.50	140
35.0	0.76	45.4	2.63	737	335.0	7.25	434.9	0.47	132
40.0	0.87	51.9	3.68	1,032	340.0	7.36	441.4	0.45	126
45.0	0.97	58.4	5.47	1,534	345.0	7.46	447.9	0.42	118
50.0	1.08	64.9	8.41	2,358	350.0	7.57	454.4	0.40	112
55.0	1.19	71.4	12.61	3,535	355.0	7.68	460.9	0.38	107
60.0	1.30	77.9	16.50	4,626	360.0	7.79	467.4	0.36	101
65.0	1.41	84.4	20.50	5,748	365.0	7.90	473.8	0.34	95
70.0	1.51	90.9	23.97	6,720	370.0	8.01	480.3	0.33	93
75.0	1.62	97.4	27.75	7,780	375.0	8.11	486.8	0.30	84
80.0	1.73	103.9	28.91	8,106	380.0	8.22	493.3	0.28	79
85.0	1.84	110.3	28.07	7,870	385.0	8.33	499.8	0.27	76
90.0	1.95	116.8	26.38	7,396	390.0	8.44	506.3	0.26	73
95.0	2.06	123.3	24.18	6,779	395.0	8.55	512.8	0.24	67
100.0	2.16	129.8	21.55	6,042	400.0	8.65	519.3	0.23	64
105.0	2.27	136.3	18.92	5,305	405.0	8.76	525.8	0.22	62
110.0	2.38	142.8	16.08	4,508	410.0	8.87	532.3	0.21	59
115.0	2.49	149.3	14.19	3,978	415.0	8.98	538.8	0.20	56
120.0	2.60	155.8	12.61	3,535	420.0	9.09	545.3	0.19	53
125.0	2.70	162.3	11.04	3,095	425.0	9.20	551.7	0.18	50
130.0	2.81	168.8	9.99	2,801	430.0	9.30	558.2	0.17	48
135.0	2.92	175.3	9.04	2,535	435.0	9.41	564.7	0.16	45
140.0	3.03	181.8	8.20	2,299	440.0	9.52	571.2	0.15	42
145.0	3.14	188.2	7.36	2,064	445.0	9.63	577.7	0.15	42
150.0	3.25	194.7	6.78	1,901	450.0	9.74	584.2	0.13	36
155.0	3.35	201.2	6.20	1,738	455.0	9.84	590.7	0.12	34
160.0	3.46	207.7	5.83	1,635	460.0	9.95	597.2	0.12	34
165.0	3.57	214.2	5.47	1,534	465.0	10.06	603.7	0.11	31
170.0	3.68	220.7	5.15	1,444	470.0	10.17	610.2		
175.0	3.79	227.2	4.84	1,357	475.0	10.28	616.7		
180.0	3.89	233.7	4.57	1,281	480.0	10.39	623.1		
185.0	4.00	240.2	4.31	1,208	485.0	10.49	629.6		
190.0	4.11	246.7	4.10	1,150	490.0	10.60	636.1		
195.0	4.22	253.2	3.87	1,085	495.0	10.71	642.6		
200.0	4.33	259.6	3.68	1,032	500.0	10.82	649.1		
205.0	4.44	266.1	3.47	973	505.0	10.93	655.6		
210.0	4.54	272.6	3.28	920	510.0	11.03	662.1		
215.0	4.65	279.1	3.10	869	515.0	11.14	668.6		
220.0	4.76	285.6	2.93	821	520.0	11.25	675.1		
225.0	4.87	292.1	2.75	771	525.0	11.36	681.6		
230.0	4.98	298.6	2.63	737	530.0	11.47	688.1		
235.0	5.08	305.1	2.47	693	535.0	11.58	694.5		
240.0	5.19	311.6	2.33	653	540.0	11.68	701.0		
245.0	5.30	318.1	2.22	622	545.0	11.79	707.5		
250.0	5.41	324.6	2.10	589	550.0	11.90	714.0		
255.0	5.52	331.0	1.99	558	555.0	12.01	720.5		
260.0	5.63	337.5	1.88	527	560.0	12.12	727.0		
265.0	5.73	344.0	1.78	499	565.0	12.22	733.5		
270.0	5.84	350.5	1.68	471	570.0	12.33	740.0		
275.0	5.95	357.0	1.59	446	575.0	12.44	746.5		
280.0	6.06	363.5	1.50	421	580.0	12.55	753.0		
285.0	6.17	370.0	1.43	401	585.0	12.66	759.5		
290.0	6.27	376.5	1.36	381	590.0	12.77	765.9		
295.0	6.38	383.0	1.28	359	595.0	12.87	772.4		
300.0	6.49	389.5	1.21	339	600.0	12.98	778.9		

NOTES : Use for models including the Crescent Wash Basin for the PMP Local event

COLORADO PLATEAU UNIT HYDROGRAPH 18-May-06

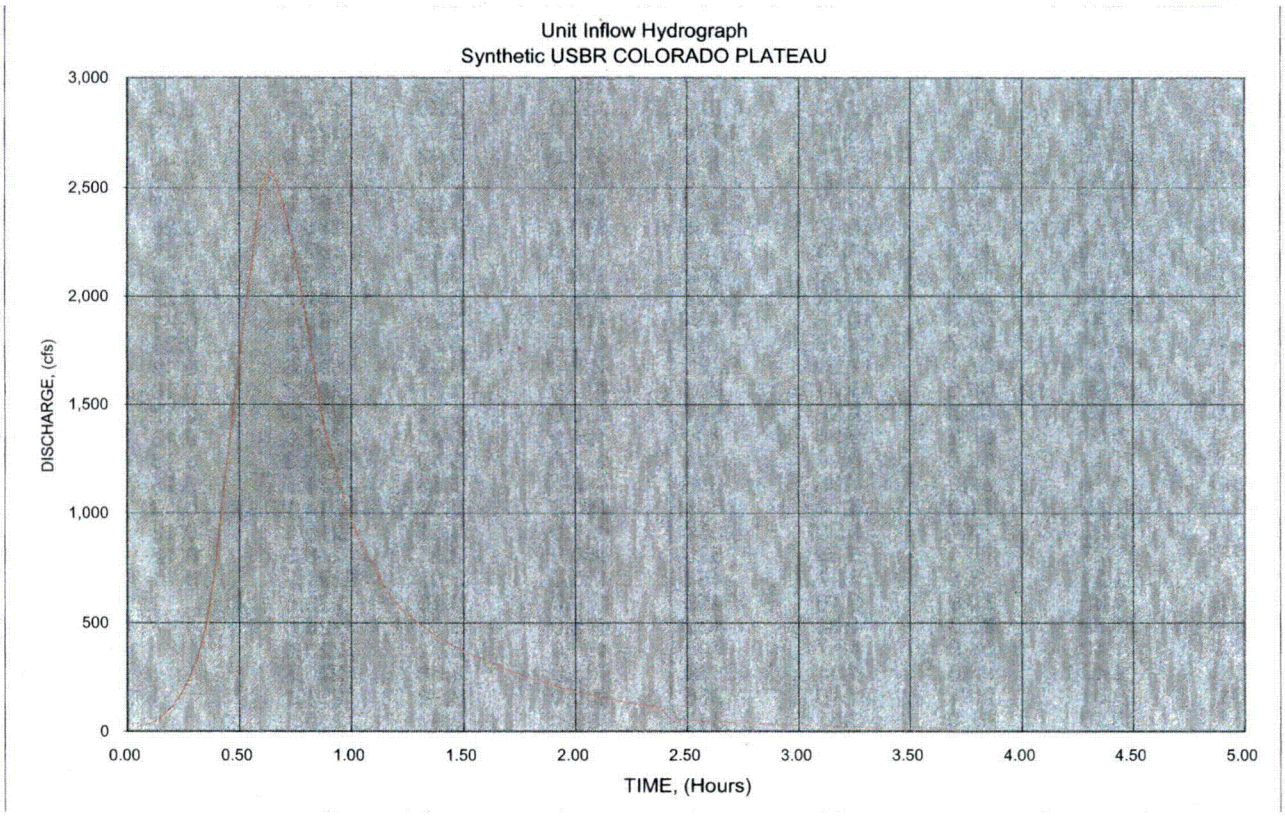
Basin 1-10, 25, 100, 200 Existing Conditions

Drainage Area =	2.63	sq. miles	Lg+D/2 =	0.79	Hours
Basin Slope =	356	ft./mile	Basin Factor =	0.13	
L =	2.92	mi., Length of Watercourse	V' =	70.72	cfs/Day
Lca =	0.87	mi., Distance to Centroid	Qs =	89.2	* q, cfs
Kn =	0.056	-, Ave. Weighted Manning's n			

PARAMETERS:

Calculated:	Lag Time, Lg =	0.75 Hours	Unit Duration, D =	8.20	minutes
			Calculated Timestep =	2.38	minutes

Data to be used in Analysis Unit Duration, D = 5 minutes, round down to nearest of 5, 10, 15, 30, 60, 120, 180, or 360
Selected Timestep = 5 minutes, integer value evenly divisible into 60



UI Record - Unit Graph 5 **minute interval**

UI	30	75	184	393	941	1690	2378	2517	2173	1683
UI	1249	964	782	634	536	470	414	369	329	292
UI	259	231	204	183	163	145	129	115	103	91
UI	80	72	64	58	51	45	41	36	32	29
UI	25	23	20	18	16	15	13	11	10	
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USBR calculated unitgraph peak = 2578 Interpolated Peak = 2517

Time t, % of Lg+D/2	Hours	Min.	q	Qs cfs	Time t, % of Lg+D/2	Hours	Min.	q	Qs cfs
5.0	0.04	2.4	0.19	17	305.0	2.42	145.1	0.66	59
10.0	0.08	4.8	0.32	29	310.0	2.46	147.5	0.63	56
15.0	0.12	7.1	0.48	43	315.0	2.50	149.9	0.59	53
20.0	0.16	9.5	0.74	66	320.0	2.54	152.2	0.56	50
25.0	0.20	11.9	1.21	108	325.0	2.58	154.6	0.53	47
30.0	0.24	14.3	1.81	161	330.0	2.62	157.0	0.50	45
35.0	0.28	16.7	2.63	235	335.0	2.66	159.4	0.47	42
40.0	0.32	19.0	3.68	328	340.0	2.70	161.8	0.45	40
45.0	0.36	21.4	5.47	488	345.0	2.74	164.1	0.42	37
50.0	0.40	23.8	8.41	750	350.0	2.78	166.5	0.40	36
55.0	0.44	26.2	12.61	1,125	355.0	2.81	168.9	0.38	34
60.0	0.48	28.5	16.50	1,472	360.0	2.85	171.3	0.36	32
65.0	0.52	30.9	20.50	1,828	365.0	2.89	173.7	0.34	30
70.0	0.56	33.3	23.97	2,138	370.0	2.93	176.0	0.33	29
75.0	0.59	35.7	27.75	2,475	375.0	2.97	178.4	0.30	27
80.0	0.63	38.1	28.91	2,578	380.0	3.01	180.8	0.28	25
85.0	0.67	40.4	28.07	2,504	385.0	3.05	183.2	0.27	24
90.0	0.71	42.8	26.38	2,353	390.0	3.09	185.5	0.26	23
95.0	0.75	45.2	24.18	2,157	395.0	3.13	187.9	0.24	21
100.0	0.79	47.6	21.55	1,922	400.0	3.17	190.3	0.23	21
105.0	0.83	50.0	18.92	1,687	405.0	3.21	192.7	0.22	20
110.0	0.87	52.3	16.08	1,434	410.0	3.25	195.1	0.21	19
115.0	0.91	54.7	14.19	1,266	415.0	3.29	197.4	0.20	18
120.0	0.95	57.1	12.61	1,125	420.0	3.33	199.8	0.19	17
125.0	0.99	59.5	11.04	985	425.0	3.37	202.2	0.18	16
130.0	1.03	61.8	9.99	891	430.0	3.41	204.6	0.17	15
135.0	1.07	64.2	9.04	806	435.0	3.45	207.0	0.16	14
140.0	1.11	66.6	8.20	731	440.0	3.49	209.3	0.15	13
145.0	1.15	69.0	7.36	656	445.0	3.53	211.7	0.15	13
150.0	1.19	71.4	6.78	605	450.0	3.57	214.1	0.13	12
155.0	1.23	73.7	6.20	553	455.0	3.61	216.5	0.12	11
160.0	1.27	76.1	5.83	520	460.0	3.65	218.8	0.12	11
165.0	1.31	78.5	5.47	488	465.0	3.69	221.2	0.11	10
170.0	1.35	80.9	5.15	459	470.0	3.73	223.6		
175.0	1.39	83.3	4.84	432	475.0	3.77	226.0		
180.0	1.43	85.6	4.57	408	480.0	3.81	228.4		
185.0	1.47	88.0	4.31	384	485.0	3.85	230.7		
190.0	1.51	90.4	4.10	366	490.0	3.89	233.1		
195.0	1.55	92.8	3.87	345	495.0	3.92	235.5		
200.0	1.59	95.2	3.68	328	500.0	3.96	237.9		
205.0	1.63	97.5	3.47	309	505.0	4.00	240.3		
210.0	1.67	99.9	3.28	293	510.0	4.04	242.6		
215.0	1.70	102.3	3.10	276	515.0	4.08	245.0		
220.0	1.74	104.7	2.93	261	520.0	4.12	247.4		
225.0	1.78	107.0	2.75	245	525.0	4.16	249.8		
230.0	1.82	109.4	2.63	235	530.0	4.20	252.2		
235.0	1.86	111.8	2.47	220	535.0	4.24	254.5		
240.0	1.90	114.2	2.33	208	540.0	4.28	256.9		
245.0	1.94	116.6	2.22	198	545.0	4.32	259.3		
250.0	1.98	118.9	2.10	187	550.0	4.36	261.7		
255.0	2.02	121.3	1.99	177	555.0	4.40	264.0		
260.0	2.06	123.7	1.88	168	560.0	4.44	266.4		
265.0	2.10	126.1	1.78	159	565.0	4.48	268.8		
270.0	2.14	128.5	1.68	150	570.0	4.52	271.2		
275.0	2.18	130.8	1.59	142	575.0	4.56	273.6		
280.0	2.22	133.2	1.50	134	580.0	4.60	275.9		
285.0	2.26	135.6	1.43	128	585.0	4.64	278.3		
290.0	2.30	138.0	1.36	121	590.0	4.68	280.7		
295.0	2.34	140.3	1.28	114	595.0	4.72	283.1		
300.0	2.38	142.7	1.21	108	600.0	4.76	285.5		

NOTES : Use for models including Basin 1 for the 10, 25, 100 and 200 year events

COLORADO PLATEAU UNIT HYDROGRAPH 18-May-06

Basin 1-PMP Existing Conditions

Drainage Area =	2.63	sq. miles	Lg+D/2 =	0.61	Hours
Basin Slope =	356	ft./mile	Basin Factor =	0.13	
L =	2.92	mi., Length of Watercourse	V' =	70.72	cfs/Day
Lca =	0.87	mi., Distance to Centroid	Qs =	116.9	* q, cfs
Kn =	0.042	-, Ave. Weighted Manning's n			

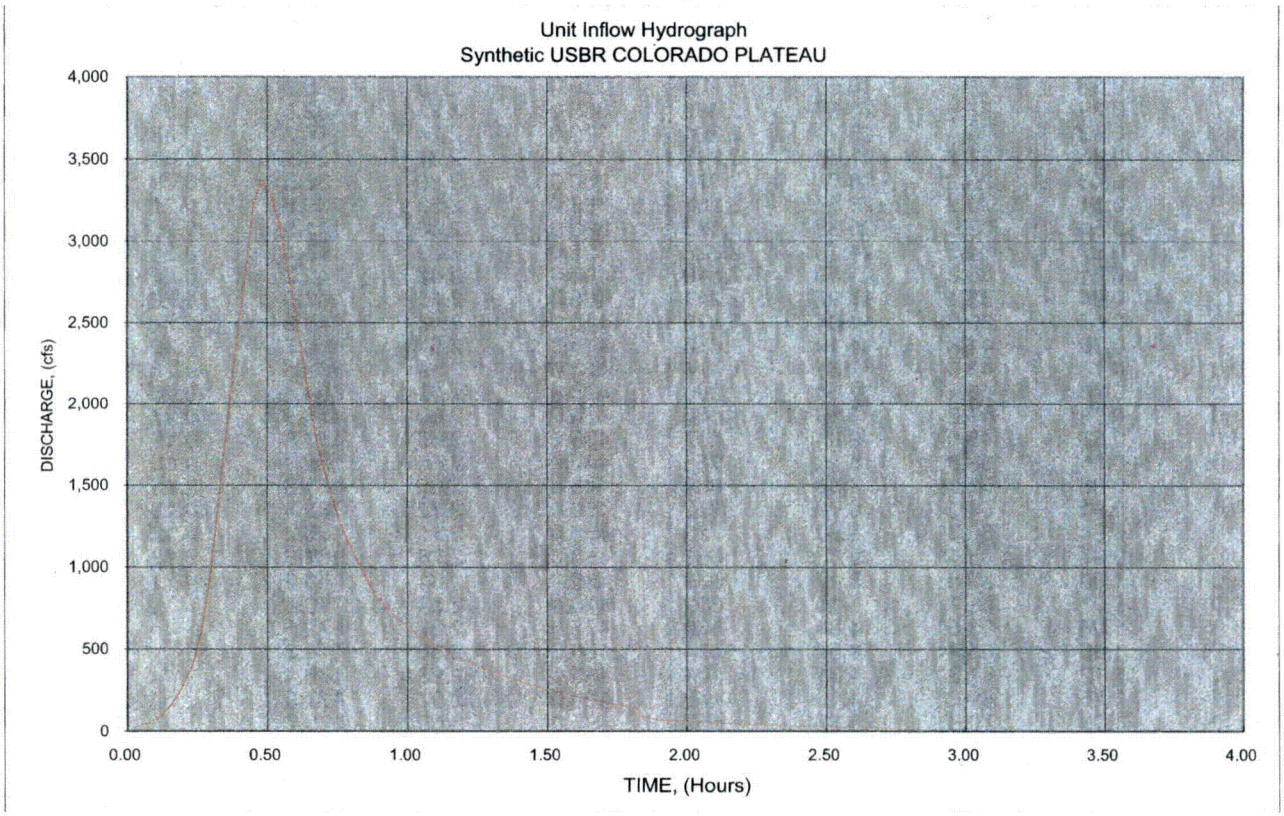
PARAMETERS:

Calculated: Lag Time, Lg = 0.56 Hours Unit Duration, D = 6.15 minutes

Calculated Timestep = 1.82 minutes

Data to be used in Analysis Unit Duration, D = 5 minutes, round down to nearest of 5, 10, 15, 30, 60, 120, 180, or 360

Selected Timestep = 5 minutes, integer value evenly divisible into 60



UI Record - Unit Graph 5 **minute interval**

UI	52	177	485	1482	2709	3327	2740	1872	1329	1003
UI	772	637	540	464	399	341	292	251	216	185
UI	160	137	117	100	87	75	64	55	47	41
UI	34	30	26	23	19	17	14			
UI										
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USBR calculated unitgraph peak = 3379 Interpolated Peak = 3327

Time t, % of Lg+D/2	Hours	Min.	q	Qs cfs	Time t, % of Lg+D/2	Hours	Min.	q	Qs cfs
5.0	0.03	1.8	0.19	22	305.0	1.85	110.7	0.66	77
10.0	0.06	3.6	0.32	37	310.0	1.88	112.6	0.63	74
15.0	0.09	5.4	0.48	56	315.0	1.91	114.4	0.59	69
20.0	0.12	7.3	0.74	86	320.0	1.94	116.2	0.56	65
25.0	0.15	9.1	1.21	141	325.0	1.97	118.0	0.53	62
30.0	0.18	10.9	1.81	212	330.0	2.00	119.8	0.50	58
35.0	0.21	12.7	2.63	307	335.0	2.03	121.6	0.47	55
40.0	0.24	14.5	3.68	430	340.0	2.06	123.4	0.45	53
45.0	0.27	16.3	5.47	639	345.0	2.09	125.3	0.42	49
50.0	0.30	18.2	8.41	983	350.0	2.12	127.1	0.40	47
55.0	0.33	20.0	12.61	1,474	355.0	2.15	128.9	0.38	44
60.0	0.36	21.8	16.50	1,928	360.0	2.18	130.7	0.36	42
65.0	0.39	23.6	20.50	2,396	365.0	2.21	132.5	0.34	40
70.0	0.42	25.4	23.97	2,801	370.0	2.24	134.3	0.33	39
75.0	0.45	27.2	27.75	3,243	375.0	2.27	136.1	0.30	35
80.0	0.48	29.0	28.91	3,379	380.0	2.30	138.0	0.28	33
85.0	0.51	30.9	28.07	3,281	385.0	2.33	139.8	0.27	32
90.0	0.54	32.7	26.38	3,083	390.0	2.36	141.6	0.26	30
95.0	0.57	34.5	24.18	2,826	395.0	2.39	143.4	0.24	28
100.0	0.61	36.3	21.55	2,519	400.0	2.42	145.2	0.23	27
105.0	0.64	38.1	18.92	2,211	405.0	2.45	147.0	0.22	26
110.0	0.67	39.9	16.08	1,879	410.0	2.48	148.9	0.21	25
115.0	0.70	41.8	14.19	1,658	415.0	2.51	150.7	0.20	23
120.0	0.73	43.6	12.61	1,474	420.0	2.54	152.5	0.19	22
125.0	0.76	45.4	11.04	1,290	425.0	2.57	154.3	0.18	21
130.0	0.79	47.2	9.99	1,168	430.0	2.60	156.1	0.17	20
135.0	0.82	49.0	9.04	1,057	435.0	2.63	157.9	0.16	19
140.0	0.85	50.8	8.20	958	440.0	2.66	159.7	0.15	18
145.0	0.88	52.6	7.36	860	445.0	2.69	161.6	0.15	18
150.0	0.91	54.5	6.78	792	450.0	2.72	163.4	0.13	15
155.0	0.94	56.3	6.20	725	455.0	2.75	165.2	0.12	14
160.0	0.97	58.1	5.83	681	460.0	2.78	167.0	0.12	14
165.0	1.00	59.9	5.47	639	465.0	2.81	168.8	0.11	13
170.0	1.03	61.7	5.15	602	470.0	2.84	170.6		
175.0	1.06	63.5	4.84	566	475.0	2.87	172.5		
180.0	1.09	65.4	4.57	534	480.0	2.90	174.3		
185.0	1.12	67.2	4.31	504	485.0	2.93	176.1		
190.0	1.15	69.0	4.10	479	490.0	2.97	177.9		
195.0	1.18	70.8	3.87	452	495.0	3.00	179.7		
200.0	1.21	72.6	3.68	430	500.0	3.03	181.5		
205.0	1.24	74.4	3.47	406	505.0	3.06	183.3		
210.0	1.27	76.2	3.28	383	510.0	3.09	185.2		
215.0	1.30	78.1	3.10	362	515.0	3.12	187.0		
220.0	1.33	79.9	2.93	342	520.0	3.15	188.8		
225.0	1.36	81.7	2.75	321	525.0	3.18	190.6		
230.0	1.39	83.5	2.63	307	530.0	3.21	192.4		
235.0	1.42	85.3	2.47	289	535.0	3.24	194.2		
240.0	1.45	87.1	2.33	272	540.0	3.27	196.1		
245.0	1.48	89.0	2.22	259	545.0	3.30	197.9		
250.0	1.51	90.8	2.10	245	550.0	3.33	199.7		
255.0	1.54	92.6	1.99	233	555.0	3.36	201.5		
260.0	1.57	94.4	1.88	220	560.0	3.39	203.3		
265.0	1.60	96.2	1.78	208	565.0	3.42	205.1		
270.0	1.63	98.0	1.68	196	570.0	3.45	206.9		
275.0	1.66	99.8	1.59	186	575.0	3.48	208.8		
280.0	1.69	101.7	1.50	175	580.0	3.51	210.6		
285.0	1.72	103.5	1.43	167	585.0	3.54	212.4		
290.0	1.75	105.3	1.36	159	590.0	3.57	214.2		
295.0	1.79	107.1	1.28	150	595.0	3.60	216.0		
300.0	1.82	108.9	1.21	141	600.0	3.63	217.8		

NOTES : Use for models including Basin 1 for the PMP Local event

COLORADO PLATEAU UNIT HYDROGRAPH 18-May-06

Basin 2-10, 25, 100, 200 Existing Conditions

Drainage Area =	8.96	sq. miles	Lg+D/2 =	1.88	Hours
Basin Slope =	283	ft./mile	Basin Factor =	1.97	
L =	7.67	mi., Length of Watercourse	V' =	240.93	cfs/Day
Lca =	4.31	mi., Distance to Centroid	Qs =	128.2	* q, cfs
Kn =	0.054	-, Ave. Weighted Manning's n			

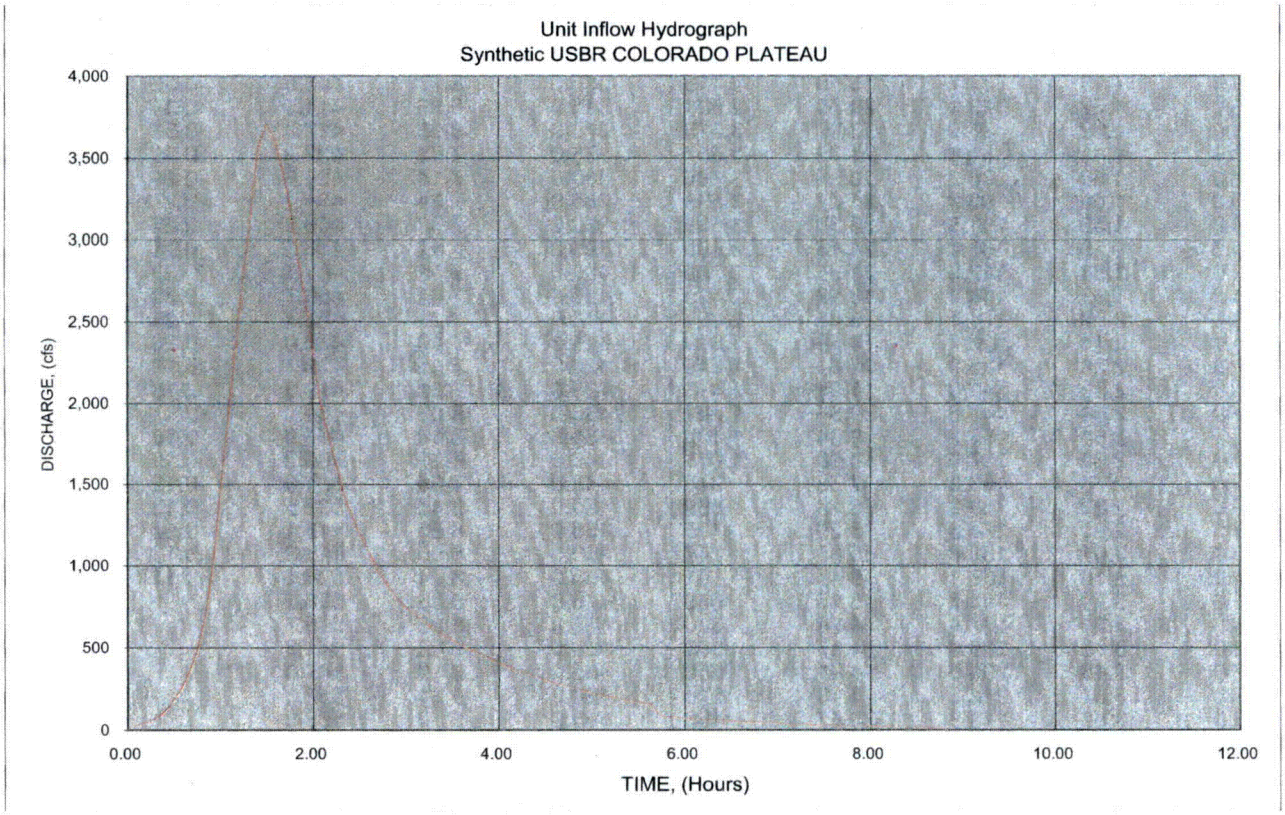
PARAMETERS:

Calculated: Lag Time, Lg = 1.75 Hours Unit Duration, D = 19.14 minutes

Calculated Timestep = 5.64 minutes

Data to be used in Analysis Unit Duration, D = 15 minutes, round down to nearest of 5, 10, 15, 30, 60, 120, 180, or 360

Selected Timestep = 5 minutes, integer value evenly divisible into 60



UI Record - Unit Graph 5 **minute interval**

UI	22	37	55	80	121	180	254	350	469	671
UI	985	1423	1879	2327	2761	3163	3568	3700	3615	3439
UI	3206	2928	2629	2323	2021	1808	1628	1450	1319	1207
UI	1106	1011	924	858	793	751	710	673	637	604
UI	574	546	522	496	474	450	428	407	388	368
UI	349	335	317	301	288	274	262	249	237	226
UI	214	204	194	186	178	169	160	153	146	138
UI	131	125	119	113	108	103	99	94	88	85
UI	81	77	73	70	67	63	60	58	54	52
UI	50	47	45	43	41	38	36	35	34	32
	30	29	28	27	26	24	23	22	21	20
	19	18	16	15	15	14	4			
UI										

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USBR calculated unitgraph peak = 3706 Interpolated Peak = 3700

Time t, % of Lg+D/2	Hours	Min.	q	Qs cfs	Time t, % of Lg+D/2	Hours	Min.	q	Qs cfs
5.0	0.09	5.6	0.19	24	305.0	5.73	344.0	0.66	85
10.0	0.19	11.3	0.32	41	310.0	5.83	349.6	0.63	81
15.0	0.28	16.9	0.48	62	315.0	5.92	355.2	0.59	76
20.0	0.38	22.6	0.74	95	320.0	6.01	360.9	0.56	72
25.0	0.47	28.2	1.21	155	325.0	6.11	366.5	0.53	68
30.0	0.56	33.8	1.81	232	330.0	6.20	372.2	0.50	64
35.0	0.66	39.5	2.63	337	335.0	6.30	377.8	0.47	60
40.0	0.75	45.1	3.68	472	340.0	6.39	383.4	0.45	58
45.0	0.85	50.7	5.47	701	345.0	6.48	389.1	0.42	54
50.0	0.94	56.4	8.41	1,078	350.0	6.58	394.7	0.40	51
55.0	1.03	62.0	12.61	1,616	355.0	6.67	400.4	0.38	49
60.0	1.13	67.7	16.50	2,115	360.0	6.77	406.0	0.36	46
65.0	1.22	73.3	20.50	2,628	365.0	6.86	411.6	0.34	44
70.0	1.32	78.9	23.97	3,073	370.0	6.95	417.3	0.33	42
75.0	1.41	84.6	27.75	3,557	375.0	7.05	422.9	0.30	38
80.0	1.50	90.2	28.91	3,706	380.0	7.14	428.6	0.28	36
85.0	1.60	95.9	28.07	3,598	385.0	7.24	434.2	0.27	35
90.0	1.69	101.5	26.38	3,381	390.0	7.33	439.8	0.26	33
95.0	1.79	107.1	24.18	3,099	395.0	7.42	445.5	0.24	31
100.0	1.88	112.8	21.55	2,762	400.0	7.52	451.1	0.23	29
105.0	1.97	118.4	18.92	2,425	405.0	7.61	456.7	0.22	28
110.0	2.07	124.1	16.08	2,061	410.0	7.71	462.4	0.21	27
115.0	2.16	129.7	14.19	1,819	415.0	7.80	468.0	0.20	26
120.0	2.26	135.3	12.61	1,616	420.0	7.89	473.7	0.19	24
125.0	2.35	141.0	11.04	1,415	425.0	7.99	479.3	0.18	23
130.0	2.44	146.6	9.99	1,281	430.0	8.08	484.9	0.17	22
135.0	2.54	152.2	9.04	1,159	435.0	8.18	490.6	0.16	21
140.0	2.63	157.9	8.20	1,051	440.0	8.27	496.2	0.15	19
145.0	2.73	163.5	7.36	943	445.0	8.36	501.9	0.15	19
150.0	2.82	169.2	6.78	869	450.0	8.46	507.5	0.13	17
155.0	2.91	174.8	6.20	795	455.0	8.55	513.1	0.12	15
160.0	3.01	180.4	5.83	747	460.0	8.65	518.8	0.12	15
165.0	3.10	186.1	5.47	701	465.0	8.74	524.4	0.11	14
170.0	3.20	191.7	5.15	660	470.0	8.83	530.1		
175.0	3.29	197.4	4.84	620	475.0	8.93	535.7		
180.0	3.38	203.0	4.57	586	480.0	9.02	541.3		
185.0	3.48	208.6	4.31	552	485.0	9.12	547.0		
190.0	3.57	214.3	4.10	526	490.0	9.21	552.6		
195.0	3.67	219.9	3.87	496	495.0	9.30	558.2		
200.0	3.76	225.6	3.68	472	500.0	9.40	563.9		
205.0	3.85	231.2	3.47	445	505.0	9.49	569.5		
210.0	3.95	236.8	3.28	420	510.0	9.59	575.2		
215.0	4.04	242.5	3.10	397	515.0	9.68	580.8		
220.0	4.14	248.1	2.93	376	520.0	9.77	586.4		
225.0	4.23	253.7	2.75	353	525.0	9.87	592.1		
230.0	4.32	259.4	2.63	337	530.0	9.96	597.7		
235.0	4.42	265.0	2.47	317	535.0	10.06	603.4		
240.0	4.51	270.7	2.33	299	540.0	10.15	609.0		
245.0	4.61	276.3	2.22	285	545.0	10.24	614.6		
250.0	4.70	281.9	2.10	269	550.0	10.34	620.3		
255.0	4.79	287.6	1.99	255	555.0	10.43	625.9		
260.0	4.89	293.2	1.88	241	560.0	10.53	631.6		
265.0	4.98	298.9	1.78	228	565.0	10.62	637.2		
270.0	5.07	304.5	1.68	215	570.0	10.71	642.8		
275.0	5.17	310.1	1.59	204	575.0	10.81	648.5		
280.0	5.26	315.8	1.50	192	580.0	10.90	654.1		
285.0	5.36	321.4	1.43	183	585.0	11.00	659.7		
290.0	5.45	327.1	1.36	174	590.0	11.09	665.4		
295.0	5.54	332.7	1.28	164	595.0	11.18	671.0		
300.0	5.64	338.3	1.21	155	600.0	11.28	676.7		

NOTES : Use for models including Basin 2 for the 10, 25, 100 and 200 year events

COLORADO PLATEAU UNIT HYDROGRAPH 18-May-06

Basin 2-PMP Existing Conditions

Drainage Area =	8.96	sq. miles	Lg+D/2 =	1.45	Hours
Basin Slope =	283	ft./mile	Basin Factor =	1.97	
L =	7.67	mi., Length of Watercourse	V' =	240.93	cfs/Day
Lca =	4.31	mi., Distance to Centroid	Qs =	166.4	* q, cfs
Kn =	0.042	-, Ave. Weighted Manning's n			

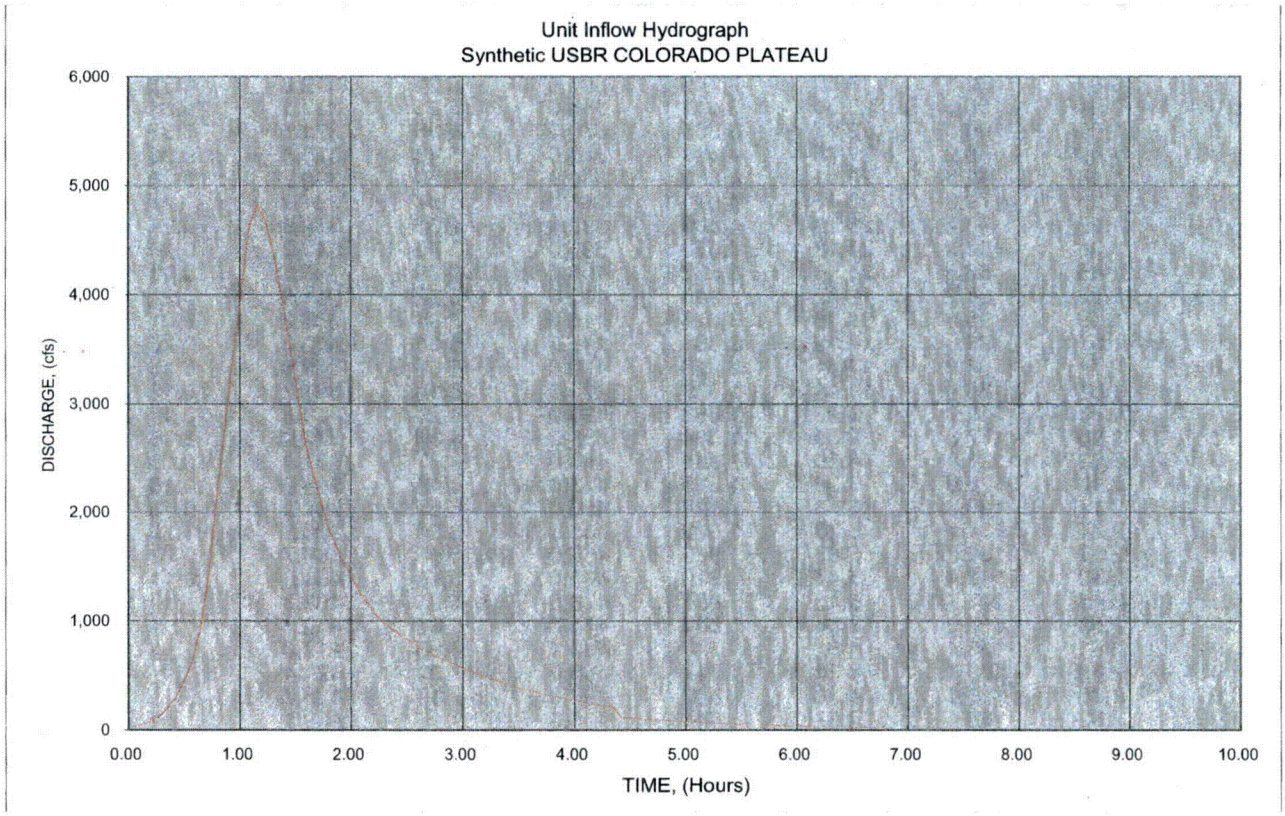
PARAMETERS:

Calculated: Lag Time, Lg = 1.36 Hours Unit Duration, D = 14.89 minutes

Calculated Timestep = 4.34 minutes

Data to be used in Analysis Unit Duration, D = 10 minutes, round down to nearest of 5, 10, 15, 30, 60, 120, 180, or 360

Selected Timestep = 5 minutes, integer value evenly divisible into 60



UI Record - Unit Graph 5 **minute interval**

UI	35	61	99	170	277	425	629	1012	1650	2428
UI	3185	3880	4594	4794	4596	4237	3775	3272	2738	2356
UI	2054	1781	1587	1417	1256	1135	1027	956	890	830
UI	775	724	683	640	602	564	528	495	461	437
UI	407	381	360	338	317	297	278	261	245	232
UI	217	203	191	178	167	157	146	138	130	123
UI	114	108	101	95	89	83	78	74	68	65
UI	61	57	55	49	46	44	41	39	37	35
UI	33	31	29	27	25	25	21	20	19	8

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USBR calculated unitgraph peak = 4810 Interpolated Peak = 4794

Time t, % of Lg+D/2	Hours	Min.	q	Qs cfs	Time t, % of Lg+D/2	Hours	Min.	q	Qs cfs
5.0	0.07	4.3	0.19	32	305.0	4.42	265.0	0.66	110
10.0	0.14	8.7	0.32	53	310.0	4.49	269.3	0.63	105
15.0	0.22	13.0	0.48	80	315.0	4.56	273.7	0.59	98
20.0	0.29	17.4	0.74	123	320.0	4.63	278.0	0.56	93
25.0	0.36	21.7	1.21	201	325.0	4.71	282.4	0.53	88
30.0	0.43	26.1	1.81	301	330.0	4.78	286.7	0.50	83
35.0	0.51	30.4	2.63	438	335.0	4.85	291.1	0.47	78
40.0	0.58	34.8	3.68	612	340.0	4.92	295.4	0.45	75
45.0	0.65	39.1	5.47	910	345.0	5.00	299.7	0.42	70
50.0	0.72	43.4	8.41	1,399	350.0	5.07	304.1	0.40	67
55.0	0.80	47.8	12.61	2,098	355.0	5.14	308.4	0.38	63
60.0	0.87	52.1	16.50	2,745	360.0	5.21	312.8	0.36	60
65.0	0.94	56.5	20.50	3,411	365.0	5.29	317.1	0.34	57
70.0	1.01	60.8	23.97	3,988	370.0	5.36	321.5	0.33	55
75.0	1.09	65.2	27.75	4,617	375.0	5.43	325.8	0.30	50
80.0	1.16	69.5	28.91	4,810	380.0	5.50	330.2	0.28	47
85.0	1.23	73.8	28.07	4,670	385.0	5.57	334.5	0.27	45
90.0	1.30	78.2	26.38	4,389	390.0	5.65	338.8	0.26	43
95.0	1.38	82.5	24.18	4,023	395.0	5.72	343.2	0.24	40
100.0	1.45	86.9	21.55	3,586	400.0	5.79	347.5	0.23	38
105.0	1.52	91.2	18.92	3,148	405.0	5.86	351.9	0.22	37
110.0	1.59	95.6	16.08	2,676	410.0	5.94	356.2	0.21	35
115.0	1.67	99.9	14.19	2,361	415.0	6.01	360.6	0.20	33
120.0	1.74	104.3	12.61	2,098	420.0	6.08	364.9	0.19	32
125.0	1.81	108.6	11.04	1,837	425.0	6.15	369.2	0.18	30
130.0	1.88	112.9	9.99	1,662	430.0	6.23	373.6	0.17	28
135.0	1.95	117.3	9.04	1,504	435.0	6.30	377.9	0.16	27
140.0	2.03	121.6	8.20	1,364	440.0	6.37	382.3	0.15	25
145.0	2.10	126.0	7.36	1,225	445.0	6.44	386.6	0.15	25
150.0	2.17	130.3	6.78	1,128	450.0	6.52	391.0	0.13	22
155.0	2.24	134.7	6.20	1,032	455.0	6.59	395.3	0.12	20
160.0	2.32	139.0	5.83	970	460.0	6.66	399.7	0.12	20
165.0	2.39	143.4	5.47	910	465.0	6.73	404.0	0.11	18
170.0	2.46	147.7	5.15	857	470.0	6.81	408.3		
175.0	2.53	152.0	4.84	805	475.0	6.88	412.7		
180.0	2.61	156.4	4.57	760	480.0	6.95	417.0		
185.0	2.68	160.7	4.31	717	485.0	7.02	421.4		
190.0	2.75	165.1	4.10	682	490.0	7.10	425.7		
195.0	2.82	169.4	3.87	644	495.0	7.17	430.1		
200.0	2.90	173.8	3.68	612	500.0	7.24	434.4		
205.0	2.97	178.1	3.47	577	505.0	7.31	438.8		
210.0	3.04	182.5	3.28	546	510.0	7.38	443.1		
215.0	3.11	186.8	3.10	516	515.0	7.46	447.4		
220.0	3.19	191.1	2.93	488	520.0	7.53	451.8		
225.0	3.26	195.5	2.75	458	525.0	7.60	456.1		
230.0	3.33	199.8	2.63	438	530.0	7.67	460.5		
235.0	3.40	204.2	2.47	411	535.0	7.75	464.8		
240.0	3.48	208.5	2.33	388	540.0	7.82	469.2		
245.0	3.55	212.9	2.22	369	545.0	7.89	473.5		
250.0	3.62	217.2	2.10	349	550.0	7.96	477.9		
255.0	3.69	221.5	1.99	331	555.0	8.04	482.2		
260.0	3.76	225.9	1.88	313	560.0	8.11	486.5		
265.0	3.84	230.2	1.78	296	565.0	8.18	490.9		
270.0	3.91	234.6	1.68	280	570.0	8.25	495.2		
275.0	3.98	238.9	1.59	265	575.0	8.33	499.6		
280.0	4.05	243.3	1.50	250	580.0	8.40	503.9		
285.0	4.13	247.6	1.43	238	585.0	8.47	508.3		
290.0	4.20	252.0	1.36	226	590.0	8.54	512.6		
295.0	4.27	256.3	1.28	213	595.0	8.62	516.9		
300.0	4.34	260.6	1.21	201	600.0	8.69	521.3		

NOTES : Use for models including Basin 2 for the PMP Local event

COLORADO PLATEAU UNIT HYDROGRAPH 18-May-06

Basin 3-10, 25, 100, 200 Existing Conditions

Drainage Area =	3.47	sq. miles	Lg+D/2 =	1.59	Hours
Basin Slope =	57.1	ft./mile	Basin Factor =	1.15	
L =	4.73	mi., Length of Watercourse	V' =	93.31	cfs/Day
Lca =	1.83	mi., Distance to Centroid	Qs =	58.6	* q, cfs
Kn =	0.054	-, Ave. Weighted Manning's n			

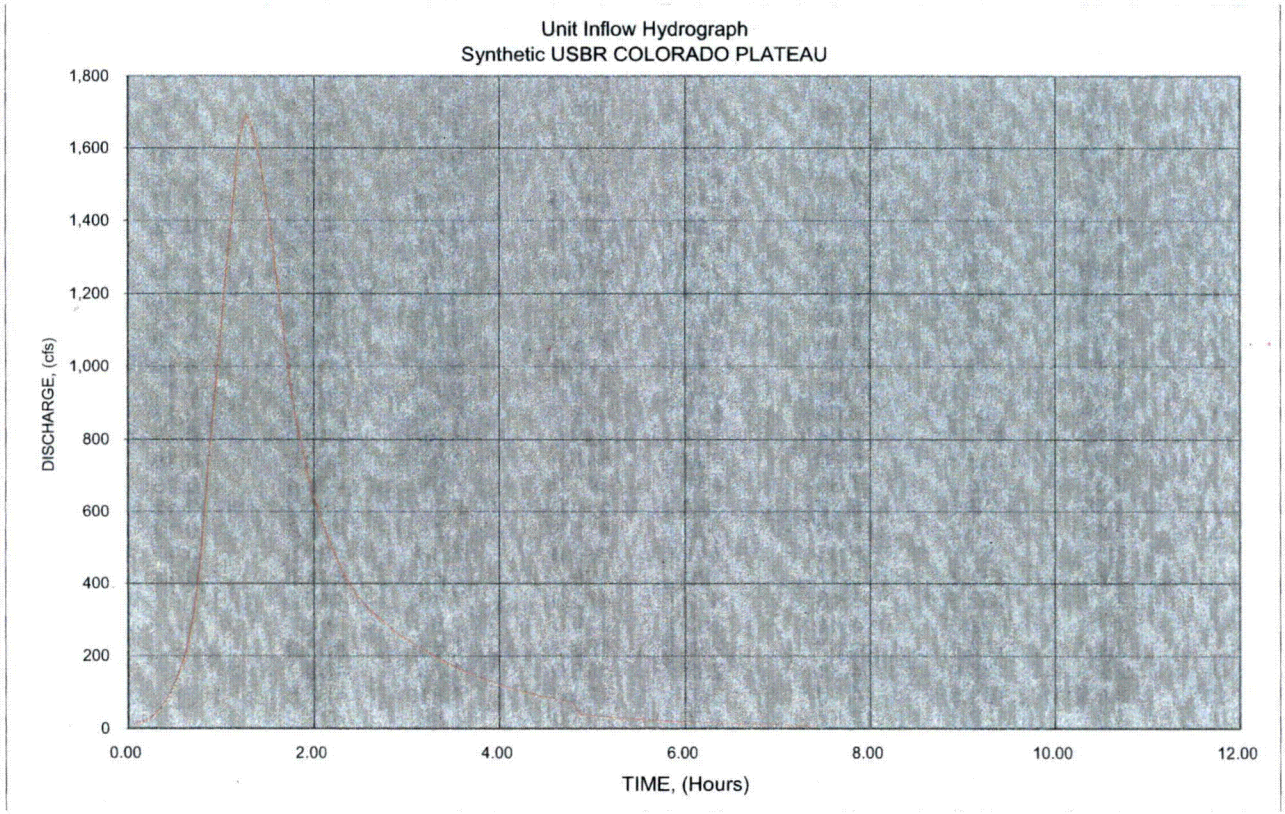
PARAMETERS:

Calculated: Lag Time, Lg = 1.47 Hours Unit Duration, D = 16.02 minutes

Calculated Timestep = 4.78 minutes

Data to be used in Analysis Unit Duration, D = 15 minutes, round down to nearest of 5, 10, 15, 30, 60, 120, 180, or 360

Selected Timestep = 5 minutes, integer value evenly divisible into 60



UI Record - Unit Graph 5 **minute interval**

UI	11	20	30	48	79	119	174	254	392	606
UI	854	1096	1322	1546	1672	1657	1566	1438	1281	1120
UI	947	830	733	640	577	520	468	421	386	355
UI	332	311	292	275	258	244	231	218	206	194
UI	183	172	161	154	144	136	129	122	115	108
UI	102	96	91	86	82	77	72	69	64	61
UI	57	54	51	48	46	43	40	38	36	34
UI	32	30	29	27	26	24	23	22	20	20
UI	18	17	16	15	14	13	13	12	12	11
UI	10	10	9	9	8	7	7	7	3	
UI										

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USBR calculated unitgraph peak = 1693 Interpolated Peak = 1672

Time t, % of Lg+D/2	Hours	Min.	q	Qs cfs	Time t, % of Lg+D/2	Hours	Min.	q	Qs cfs
5.0	0.08	4.8	0.19	11	305.0	4.86	291.6	0.66	39
10.0	0.16	9.6	0.32	19	310.0	4.94	296.4	0.63	37
15.0	0.24	14.3	0.48	28	315.0	5.02	301.1	0.59	35
20.0	0.32	19.1	0.74	43	320.0	5.10	305.9	0.56	33
25.0	0.40	23.9	1.21	71	325.0	5.18	310.7	0.53	31
30.0	0.48	28.7	1.81	106	330.0	5.26	315.5	0.50	29
35.0	0.56	33.5	2.63	154	335.0	5.34	320.3	0.47	28
40.0	0.64	38.2	3.68	216	340.0	5.42	325.0	0.45	26
45.0	0.72	43.0	5.47	320	345.0	5.50	329.8	0.42	25
50.0	0.80	47.8	8.41	492	350.0	5.58	334.6	0.40	23
55.0	0.88	52.6	12.61	738	355.0	5.66	339.4	0.38	22
60.0	0.96	57.4	16.50	966	360.0	5.74	344.2	0.36	21
65.0	1.04	62.1	20.50	1,200	365.0	5.82	348.9	0.34	20
70.0	1.12	66.9	23.97	1,404	370.0	5.90	353.7	0.33	19
75.0	1.20	71.7	27.75	1,625	375.0	5.98	358.5	0.30	18
80.0	1.27	76.5	28.91	1,693	380.0	6.05	363.3	0.28	16
85.0	1.35	81.3	28.07	1,644	385.0	6.13	368.1	0.27	16
90.0	1.43	86.0	26.38	1,545	390.0	6.21	372.8	0.26	15
95.0	1.51	90.8	24.18	1,416	395.0	6.29	377.6	0.24	14
100.0	1.59	95.6	21.55	1,262	400.0	6.37	382.4	0.23	13
105.0	1.67	100.4	18.92	1,108	405.0	6.45	387.2	0.22	13
110.0	1.75	105.2	16.08	942	410.0	6.53	392.0	0.21	12
115.0	1.83	109.9	14.19	831	415.0	6.61	396.7	0.20	12
120.0	1.91	114.7	12.61	738	420.0	6.69	401.5	0.19	11
125.0	1.99	119.5	11.04	647	425.0	6.77	406.3	0.18	11
130.0	2.07	124.3	9.99	585	430.0	6.85	411.1	0.17	10
135.0	2.15	129.1	9.04	529	435.0	6.93	415.9	0.16	9
140.0	2.23	133.8	8.20	480	440.0	7.01	420.6	0.15	9
145.0	2.31	138.6	7.36	431	445.0	7.09	425.4	0.15	9
150.0	2.39	143.4	6.78	397	450.0	7.17	430.2	0.13	8
155.0	2.47	148.2	6.20	363	455.0	7.25	435.0	0.12	7
160.0	2.55	153.0	5.83	341	460.0	7.33	439.8	0.12	7
165.0	2.63	157.7	5.47	320	465.0	7.41	444.5	0.11	6
170.0	2.71	162.5	5.15	302	470.0	7.49	449.3		
175.0	2.79	167.3	4.84	283	475.0	7.57	454.1		
180.0	2.87	172.1	4.57	268	480.0	7.65	458.9		
185.0	2.95	176.9	4.31	252	485.0	7.73	463.7		
190.0	3.03	181.6	4.10	240	490.0	7.81	468.5		
195.0	3.11	186.4	3.87	227	495.0	7.89	473.2		
200.0	3.19	191.2	3.68	216	500.0	7.97	478.0		
205.0	3.27	196.0	3.47	203	505.0	8.05	482.8		
210.0	3.35	200.8	3.28	192	510.0	8.13	487.6		
215.0	3.43	205.5	3.10	182	515.0	8.21	492.4		
220.0	3.51	210.3	2.93	172	520.0	8.29	497.1		
225.0	3.59	215.1	2.75	161	525.0	8.37	501.9		
230.0	3.66	219.9	2.63	154	530.0	8.44	506.7		
235.0	3.74	224.7	2.47	145	535.0	8.52	511.5		
240.0	3.82	229.4	2.33	136	540.0	8.60	516.3		
245.0	3.90	234.2	2.22	130	545.0	8.68	521.0		
250.0	3.98	239.0	2.10	123	550.0	8.76	525.8		
255.0	4.06	243.8	1.99	117	555.0	8.84	530.6		
260.0	4.14	248.6	1.88	110	560.0	8.92	535.4		
265.0	4.22	253.3	1.78	104	565.0	9.00	540.2		
270.0	4.30	258.1	1.68	98	570.0	9.08	544.9		
275.0	4.38	262.9	1.59	93	575.0	9.16	549.7		
280.0	4.46	267.7	1.50	88	580.0	9.24	554.5		
285.0	4.54	272.5	1.43	84	585.0	9.32	559.3		
290.0	4.62	277.2	1.36	80	590.0	9.40	564.1		
295.0	4.70	282.0	1.28	75	595.0	9.48	568.8		
300.0	4.78	286.8	1.21	71	600.0	9.56	573.6		

NOTES : Use for models including Basin 3 for the 10, 25, 100 and 200 year events

COLORADO PLATEAU UNIT HYDROGRAPH 18-May-06

Basin 3-PMP Existing Conditions

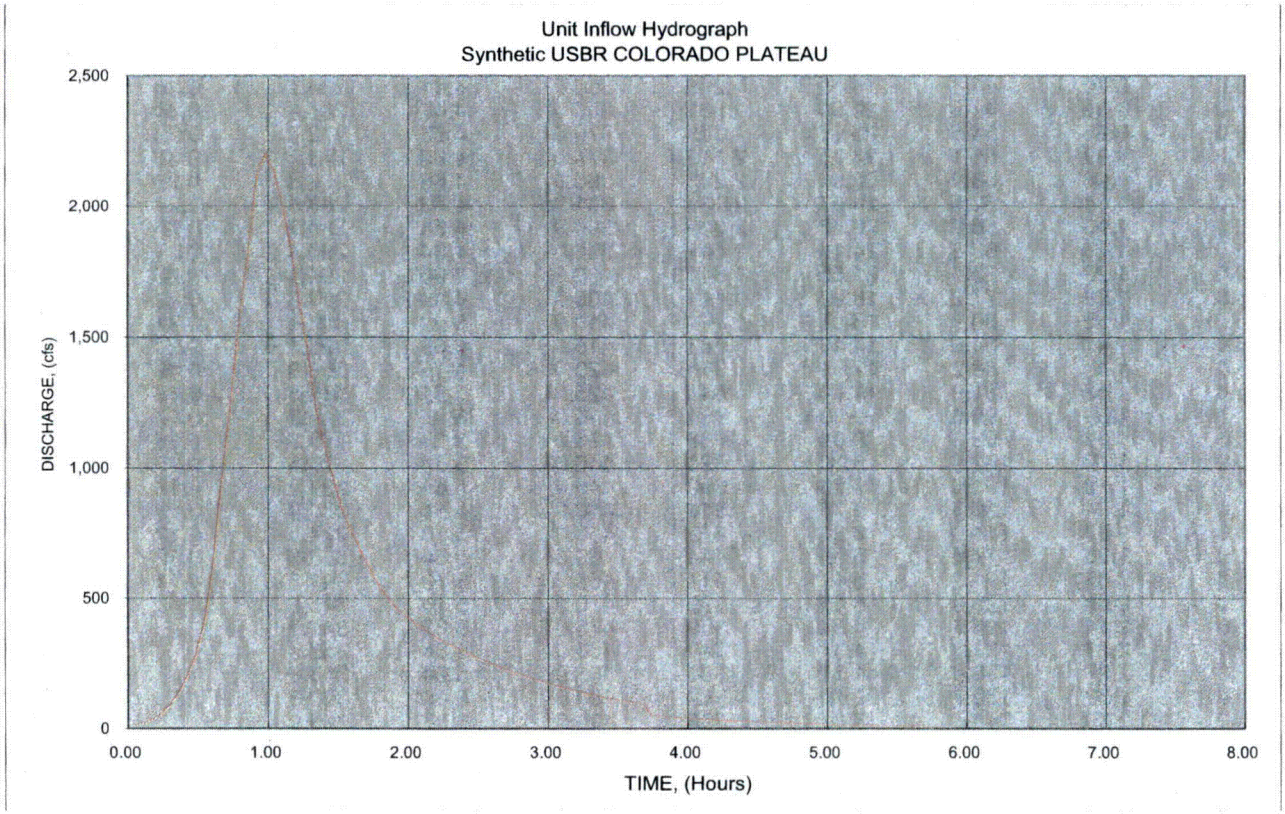
Drainage Area =	3.47	sq. miles	Lg+D/2 =	1.23	Hours
Basin Slope =	57.1	ft./mile	Basin Factor =	1.15	
L =	4.73	mi., Length of Watercourse	V' =	93.31	cfs/Day
Lca =	1.83	mi., Distance to Centroid	Qs =	76.1	* q, cfs
Kn =	0.042	-, Ave. Weighted Manning's n			

PARAMETERS:

Calculated:	Lag Time, Lg =	1.14 Hours	Unit Duration, D =	12.46	minutes
			Calculated Timestep =	3.68	minutes

Data to be used in Analysis Unit Duration, D = 10 minutes, round down to nearest of 5, 10, 15, 30, 60, 120, 180, or 360

Selected Timestep = 5 minutes, integer value evenly divisible into 60



UI Record - Unit Graph 5 **minute interval**

UI	18	33	59	112	188	302	533	922	1330	1720
UI	2102	2181	2050	1833	1561	1276	1066	903	773	675
UI	588	520	464	426	392	361	334	311	288	267
UI	248	229	211	197	182	169	157	146	135	125
UI	116	108	101	93	86	80	74	68	64	59
UI	55	51	48	44	41	38	35	32	30	28
UI	26	24	22	21	19	18	17	16	15	14
UI	13	11	11	9	9	5				
UI										
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USBR calculated unitgraph peak = 2201 Interpolated Peak = 2181

Time t, % of Lg+D/2	Hours	Min.	q	Qs cfs	Time t, % of Lg+D/2	Hours	Min.	q	Qs cfs
5.0	0.06	3.7	0.19	14	305.0	3.74	224.2	0.66	50
10.0	0.12	7.4	0.32	24	310.0	3.80	227.9	0.63	48
15.0	0.18	11.0	0.48	37	315.0	3.86	231.6	0.59	45
20.0	0.25	14.7	0.74	56	320.0	3.92	235.3	0.56	43
25.0	0.31	18.4	1.21	92	325.0	3.98	239.0	0.53	40
30.0	0.37	22.1	1.81	138	330.0	4.04	242.6	0.50	38
35.0	0.43	25.7	2.63	200	335.0	4.11	246.3	0.47	36
40.0	0.49	29.4	3.68	280	340.0	4.17	250.0	0.45	34
45.0	0.55	33.1	5.47	417	345.0	4.23	253.7	0.42	32
50.0	0.61	36.8	8.41	640	350.0	4.29	257.3	0.40	30
55.0	0.67	40.4	12.61	960	355.0	4.35	261.0	0.38	29
60.0	0.74	44.1	16.50	1,256	360.0	4.41	264.7	0.36	27
65.0	0.80	47.8	20.50	1,561	365.0	4.47	268.4	0.34	26
70.0	0.86	51.5	23.97	1,825	370.0	4.53	272.0	0.33	25
75.0	0.92	55.1	27.75	2,113	375.0	4.60	275.7	0.30	23
80.0	0.98	58.8	28.91	2,201	380.0	4.66	279.4	0.28	21
85.0	1.04	62.5	28.07	2,137	385.0	4.72	283.1	0.27	21
90.0	1.10	66.2	26.38	2,009	390.0	4.78	286.7	0.26	20
95.0	1.16	69.8	24.18	1,841	395.0	4.84	290.4	0.24	18
100.0	1.23	73.5	21.55	1,641	400.0	4.90	294.1	0.23	18
105.0	1.29	77.2	18.92	1,441	405.0	4.96	297.8	0.22	17
110.0	1.35	80.9	16.08	1,224	410.0	5.02	301.4	0.21	16
115.0	1.41	84.6	14.19	1,081	415.0	5.09	305.1	0.20	15
120.0	1.47	88.2	12.61	960	420.0	5.15	308.8	0.19	14
125.0	1.53	91.9	11.04	841	425.0	5.21	312.5	0.18	14
130.0	1.59	95.6	9.99	761	430.0	5.27	316.2	0.17	13
135.0	1.65	99.3	9.04	688	435.0	5.33	319.8	0.16	12
140.0	1.72	102.9	8.20	624	440.0	5.39	323.5	0.15	11
145.0	1.78	106.6	7.36	560	445.0	5.45	327.2	0.15	11
150.0	1.84	110.3	6.78	516	450.0	5.51	330.9	0.13	10
155.0	1.90	114.0	6.20	472	455.0	5.58	334.5	0.12	9
160.0	1.96	117.6	5.83	444	460.0	5.64	338.2	0.12	9
165.0	2.02	121.3	5.47	417	465.0	5.70	341.9	0.11	8
170.0	2.08	125.0	5.15	392	470.0	5.76	345.6		
175.0	2.14	128.7	4.84	369	475.0	5.82	349.2		
180.0	2.21	132.3	4.57	348	480.0	5.88	352.9		
185.0	2.27	136.0	4.31	328	485.0	5.94	356.6		
190.0	2.33	139.7	4.10	312	490.0	6.00	360.3		
195.0	2.39	143.4	3.87	295	495.0	6.07	363.9		
200.0	2.45	147.0	3.68	280	500.0	6.13	367.6		
205.0	2.51	150.7	3.47	264	505.0	6.19	371.3		
210.0	2.57	154.4	3.28	250	510.0	6.25	375.0		
215.0	2.63	158.1	3.10	236	515.0	6.31	378.6		
220.0	2.70	161.8	2.93	223	520.0	6.37	382.3		
225.0	2.76	165.4	2.75	209	525.0	6.43	386.0		
230.0	2.82	169.1	2.63	200	530.0	6.49	389.7		
235.0	2.88	172.8	2.47	188	535.0	6.56	393.4		
240.0	2.94	176.5	2.33	177	540.0	6.62	397.0		
245.0	3.00	180.1	2.22	169	545.0	6.68	400.7		
250.0	3.06	183.8	2.10	160	550.0	6.74	404.4		
255.0	3.12	187.5	1.99	152	555.0	6.80	408.1		
260.0	3.19	191.2	1.88	143	560.0	6.86	411.7		
265.0	3.25	194.8	1.78	136	565.0	6.92	415.4		
270.0	3.31	198.5	1.68	128	570.0	6.98	419.1		
275.0	3.37	202.2	1.59	121	575.0	7.05	422.8		
280.0	3.43	205.9	1.50	114	580.0	7.11	426.4		
285.0	3.49	209.5	1.43	109	585.0	7.17	430.1		
290.0	3.55	213.2	1.36	104	590.0	7.23	433.8		
295.0	3.61	216.9	1.28	97	595.0	7.29	437.5		
300.0	3.68	220.6	1.21	92	600.0	7.35	441.1		

NOTES : Use for models including Basin 3 for the PMP Local event

COLORADO PLATEAU UNIT HYDROGRAPH

18-May-06

Design Point 1-10, 25, 100, 200 Existing Conditions

Drainage Area =	0.1839	sq. miles	Lg+D/2 =	0.63	Hours
Basin Slope =	70.74	ft./mile	Basin Factor =	0.07	
L =	1.13	mi., Length of Watercourse	V' =	4.95	cfs/Day
Lca =	0.52	mi., Distance to Centroid	Qs =	7.9	* q, cfs
Kn =	0.054	-, Ave. Weighted Manning's n			

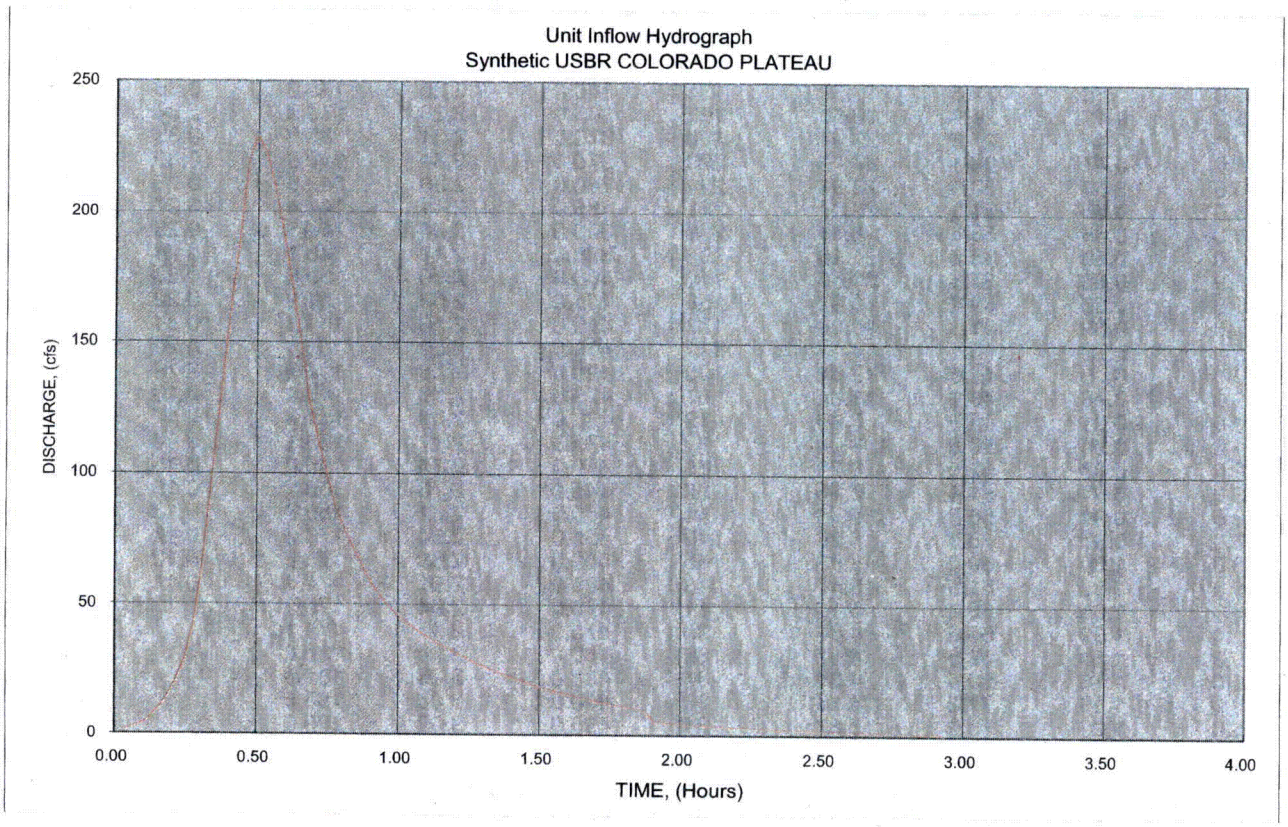
PARAMETERS:

Calculated: Lag Time, Lg = 0.58 Hours — Unit Duration, D = 6.36 minutes

Calculated Timestep = 1.88 minutes

Data to be used in Analysis Unit Duration, D = 5 minutes, round down to nearest of 5, 10, 15, 30, 60, 120, 180, or 360

Selected Timestep = 5 minutes, integer value evenly divisible into 60



UI Record - Unit Graph 5 **minute interval**

UI	3	11	29	89	171	229	197	142	100	74
UI	57	46	39	34	29	25	21	18	16	14
UI	12	10	9	8	7	6	5	4	4	3
UI	3	2	2	2	2	1	1	1	0	
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USBR calculated unitgraph peak = 229 Interpolated Peak = 229

Time t, % of Lg+D/2	Hours	Min.	q	Qs cfs	Time t, % of Lg+D/2	Hours	Min.	q	Qs cfs
5.0	0.03	1.9	0.19	2	305.0	1.91	114.4	0.66	5
10.0	0.06	3.8	0.32	3	310.0	1.94	116.3	0.63	5
15.0	0.09	5.6	0.48	4	315.0	1.97	118.1	0.59	5
20.0	0.13	7.5	0.74	6	320.0	2.00	120.0	0.56	4
25.0	0.16	9.4	1.21	10	325.0	2.03	121.9	0.53	4
30.0	0.19	11.3	1.81	14	330.0	2.06	123.8	0.50	4
35.0	0.22	13.1	2.63	21	335.0	2.09	125.6	0.47	4
40.0	0.25	15.0	3.68	29	340.0	2.13	127.5	0.45	4
45.0	0.28	16.9	5.47	43	345.0	2.16	129.4	0.42	3
50.0	0.31	18.8	8.41	67	350.0	2.19	131.3	0.40	3
55.0	0.34	20.6	12.61	100	355.0	2.22	133.1	0.38	3
60.0	0.38	22.5	16.50	131	360.0	2.25	135.0	0.36	3
65.0	0.41	24.4	20.50	162	365.0	2.28	136.9	0.34	3
70.0	0.44	26.3	23.97	190	370.0	2.31	138.8	0.33	3
75.0	0.47	28.1	27.75	220	375.0	2.34	140.6	0.30	2
80.0	0.50	30.0	28.91	229	380.0	2.38	142.5	0.28	2
85.0	0.53	31.9	28.07	222	385.0	2.41	144.4	0.27	2
90.0	0.56	33.8	26.38	209	390.0	2.44	146.3	0.26	2
95.0	0.59	35.6	24.18	191	395.0	2.47	148.1	0.24	2
100.0	0.63	37.5	21.55	170	400.0	2.50	150.0	0.23	2
105.0	0.66	39.4	18.92	150	405.0	2.53	151.9	0.22	2
110.0	0.69	41.3	16.08	127	410.0	2.56	153.8	0.21	2
115.0	0.72	43.1	14.19	112	415.0	2.59	155.6	0.20	2
120.0	0.75	45.0	12.61	100	420.0	2.63	157.5	0.19	2
125.0	0.78	46.9	11.04	87	425.0	2.66	159.4	0.18	1
130.0	0.81	48.8	9.99	79	430.0	2.69	161.3	0.17	1
135.0	0.84	50.6	9.04	72	435.0	2.72	163.1	0.16	1
140.0	0.88	52.5	8.20	65	440.0	2.75	165.0	0.15	1
145.0	0.91	54.4	7.36	58	445.0	2.78	166.9	0.15	1
150.0	0.94	56.3	6.78	54	450.0	2.81	168.8	0.13	1
155.0	0.97	58.1	6.20	49	455.0	2.84	170.6	0.12	1
160.0	1.00	60.0	5.83	46	460.0	2.88	172.5	0.12	1
165.0	1.03	61.9	5.47	43	465.0	2.91	174.4	0.11	1
170.0	1.06	63.8	5.15	41	470.0	2.94	176.3		
175.0	1.09	65.6	4.84	38	475.0	2.97	178.1		
180.0	1.13	67.5	4.57	36	480.0	3.00	180.0		
185.0	1.16	69.4	4.31	34	485.0	3.03	181.9		
190.0	1.19	71.3	4.10	32	490.0	3.06	183.8		
195.0	1.22	73.1	3.87	31	495.0	3.09	185.6		
200.0	1.25	75.0	3.68	29	500.0	3.13	187.5		
205.0	1.28	76.9	3.47	27	505.0	3.16	189.4		
210.0	1.31	78.8	3.28	26	510.0	3.19	191.3		
215.0	1.34	80.6	3.10	25	515.0	3.22	193.1		
220.0	1.38	82.5	2.93	23	520.0	3.25	195.0		
225.0	1.41	84.4	2.75	22	525.0	3.28	196.9		
230.0	1.44	86.3	2.63	21	530.0	3.31	198.8		
235.0	1.47	88.1	2.47	20	535.0	3.34	200.6		
240.0	1.50	90.0	2.33	18	540.0	3.38	202.5		
245.0	1.53	91.9	2.22	18	545.0	3.41	204.4		
250.0	1.56	93.8	2.10	17	550.0	3.44	206.3		
255.0	1.59	95.6	1.99	16	555.0	3.47	208.1		
260.0	1.63	97.5	1.88	15	560.0	3.50	210.0		
265.0	1.66	99.4	1.78	14	565.0	3.53	211.9		
270.0	1.69	101.3	1.68	13	570.0	3.56	213.8		
275.0	1.72	103.1	1.59	13	575.0	3.59	215.6		
280.0	1.75	105.0	1.50	12	580.0	3.63	217.5		
285.0	1.78	106.9	1.43	11	585.0	3.66	219.4		
290.0	1.81	108.8	1.36	11	590.0	3.69	221.3		
295.0	1.84	110.6	1.28	10	595.0	3.72	223.2		
300.0	1.88	112.5	1.21	10	600.0	3.75	225.0		

NOTES : Use for models including Design Point 1 for the 10, 25, 100 and 200 year events

COLORADO PLATEAU UNIT HYDROGRAPH 18-May-06

Design Point 2-10, 25, 100, 200 Existing Conditions

Drainage Area =	0.0863	sq. miles	Lg+D/2 =	0.66	Hours
Basin Slope =	52.14	ft./mile	Basin Factor =	0.08	
L =	1.04	mi., Length of Watercourse	V' =	2.32	cfs/Day
Lca =	0.59	mi., Distance to Centroid	Qs =	3.5	* q, cfs
Kn =	0.054	-, Ave. Weighted Manning's n			

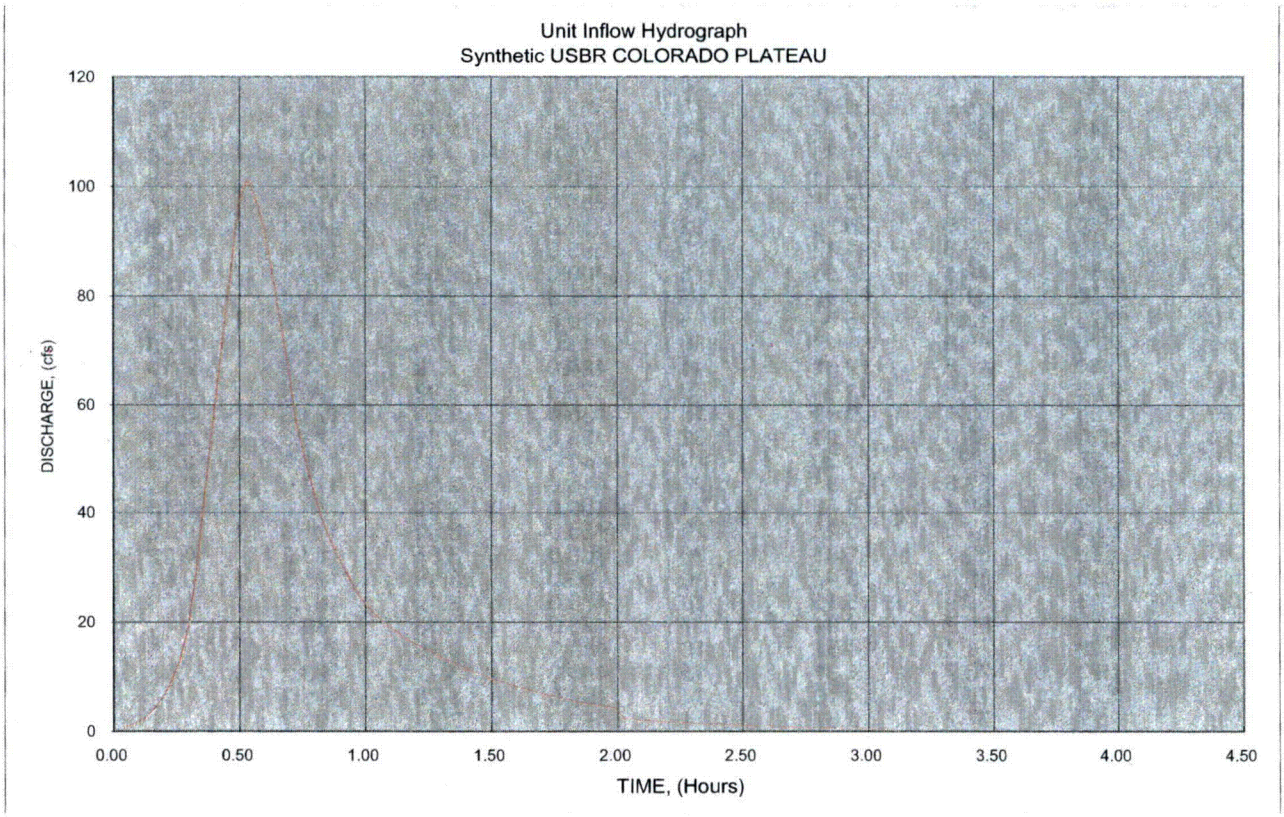
PARAMETERS:

Calculated: Lag Time, Lg = 0.62 Hours Unit Duration, D = 6.79 minutes

Calculated Timestep = 1.99 minutes

Data to be used in Analysis Unit Duration, D = 5 minutes, round down to nearest of 5, 10, 15, 30, 60, 120, 180, or 360

Selected Timestep = 5 minutes, integer value evenly divisible into 60



UI Record - Unit Graph 5 **minute interval**

UI	1	4	11	30	65	97	95	75	52	38
UI	30	23	20	17	15	13	11	10	8	7
UI	6	5	5	4	4	3	3	2	2	2
UI	2	1	1	1	1	1	1	1	1	0
UI	0									
UI										
UI										
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USBR calculated unitgraph peak = 101 Interpolated Peak = 97

Time t, % of Lg+D/2	Hours	Min.	q	Qs cfs	Time t, % of Lg+D/2	Hours	Min.	q	Qs cfs
5.0	0.03	2.0	0.19	1	305.0	2.03	121.5	0.66	2
10.0	0.07	4.0	0.32	1	310.0	2.06	123.5	0.63	2
15.0	0.10	6.0	0.48	2	315.0	2.09	125.5	0.59	2
20.0	0.13	8.0	0.74	3	320.0	2.12	127.5	0.56	2
25.0	0.17	10.0	1.21	4	325.0	2.16	129.5	0.53	2
30.0	0.20	12.0	1.81	6	330.0	2.19	131.5	0.50	2
35.0	0.23	13.9	2.63	9	335.0	2.22	133.5	0.47	2
40.0	0.27	15.9	3.68	13	340.0	2.26	135.5	0.45	2
45.0	0.30	17.9	5.47	19	345.0	2.29	137.5	0.42	1
50.0	0.33	19.9	8.41	29	350.0	2.32	139.4	0.40	1
55.0	0.37	21.9	12.61	44	355.0	2.36	141.4	0.38	1
60.0	0.40	23.9	16.50	58	360.0	2.39	143.4	0.36	1
65.0	0.43	25.9	20.50	72	365.0	2.42	145.4	0.34	1
70.0	0.46	27.9	23.97	84	370.0	2.46	147.4	0.33	1
75.0	0.50	29.9	27.75	97	375.0	2.49	149.4	0.30	1
80.0	0.53	31.9	28.91	101	380.0	2.52	151.4	0.28	1
85.0	0.56	33.9	28.07	98	385.0	2.56	153.4	0.27	1
90.0	0.60	35.9	26.38	92	390.0	2.59	155.4	0.26	1
95.0	0.63	37.8	24.18	85	395.0	2.62	157.4	0.24	1
100.0	0.66	39.8	21.55	75	400.0	2.66	159.4	0.23	1
105.0	0.70	41.8	18.92	66	405.0	2.69	161.4	0.22	1
110.0	0.73	43.8	16.08	56	410.0	2.72	163.3	0.21	1
115.0	0.76	45.8	14.19	50	415.0	2.76	165.3	0.20	1
120.0	0.80	47.8	12.61	44	420.0	2.79	167.3	0.19	1
125.0	0.83	49.8	11.04	39	425.0	2.82	169.3	0.18	1
130.0	0.86	51.8	9.99	35	430.0	2.86	171.3	0.17	1
135.0	0.90	53.8	9.04	32	435.0	2.89	173.3	0.16	1
140.0	0.93	55.8	8.20	29	440.0	2.92	175.3	0.15	1
145.0	0.96	57.8	7.36	26	445.0	2.95	177.3	0.15	1
150.0	1.00	59.8	6.78	24	450.0	2.99	179.3	0.13	0
155.0	1.03	61.8	6.20	22	455.0	3.02	181.3	0.12	0
160.0	1.06	63.7	5.83	20	460.0	3.05	183.3	0.12	0
165.0	1.10	65.7	5.47	19	465.0	3.09	185.3	0.11	0
170.0	1.13	67.7	5.15	18	470.0	3.12	187.3		
175.0	1.16	69.7	4.84	17	475.0	3.15	189.2		
180.0	1.20	71.7	4.57	16	480.0	3.19	191.2		
185.0	1.23	73.7	4.31	15	485.0	3.22	193.2		
190.0	1.26	75.7	4.10	14	490.0	3.25	195.2		
195.0	1.29	77.7	3.87	14	495.0	3.29	197.2		
200.0	1.33	79.7	3.68	13	500.0	3.32	199.2		
205.0	1.36	81.7	3.47	12	505.0	3.35	201.2		
210.0	1.39	83.7	3.28	11	510.0	3.39	203.2		
215.0	1.43	85.7	3.10	11	515.0	3.42	205.2		
220.0	1.46	87.7	2.93	10	520.0	3.45	207.2		
225.0	1.49	89.6	2.75	10	525.0	3.49	209.2		
230.0	1.53	91.6	2.63	9	530.0	3.52	211.2		
235.0	1.56	93.6	2.47	9	535.0	3.55	213.1		
240.0	1.59	95.6	2.33	8	540.0	3.59	215.1		
245.0	1.63	97.6	2.22	8	545.0	3.62	217.1		
250.0	1.66	99.6	2.10	7	550.0	3.65	219.1		
255.0	1.69	101.6	1.99	7	555.0	3.69	221.1		
260.0	1.73	103.6	1.88	7	560.0	3.72	223.1		
265.0	1.76	105.6	1.78	6	565.0	3.75	225.1		
270.0	1.79	107.6	1.68	6	570.0	3.78	227.1		
275.0	1.83	109.6	1.59	6	575.0	3.82	229.1		
280.0	1.86	111.6	1.50	5	580.0	3.85	231.1		
285.0	1.89	113.5	1.43	5	585.0	3.88	233.1		
290.0	1.93	115.5	1.36	5	590.0	3.92	235.1		
295.0	1.96	117.5	1.28	4	595.0	3.95	237.1		
300.0	1.99	119.5	1.21	4	600.0	3.98	239.0		

NOTES : Use for models including Design Point 2 for the 10, 25, 100 and 200 year events

COLORADO PLATEAU UNIT HYDROGRAPH 18-May-06

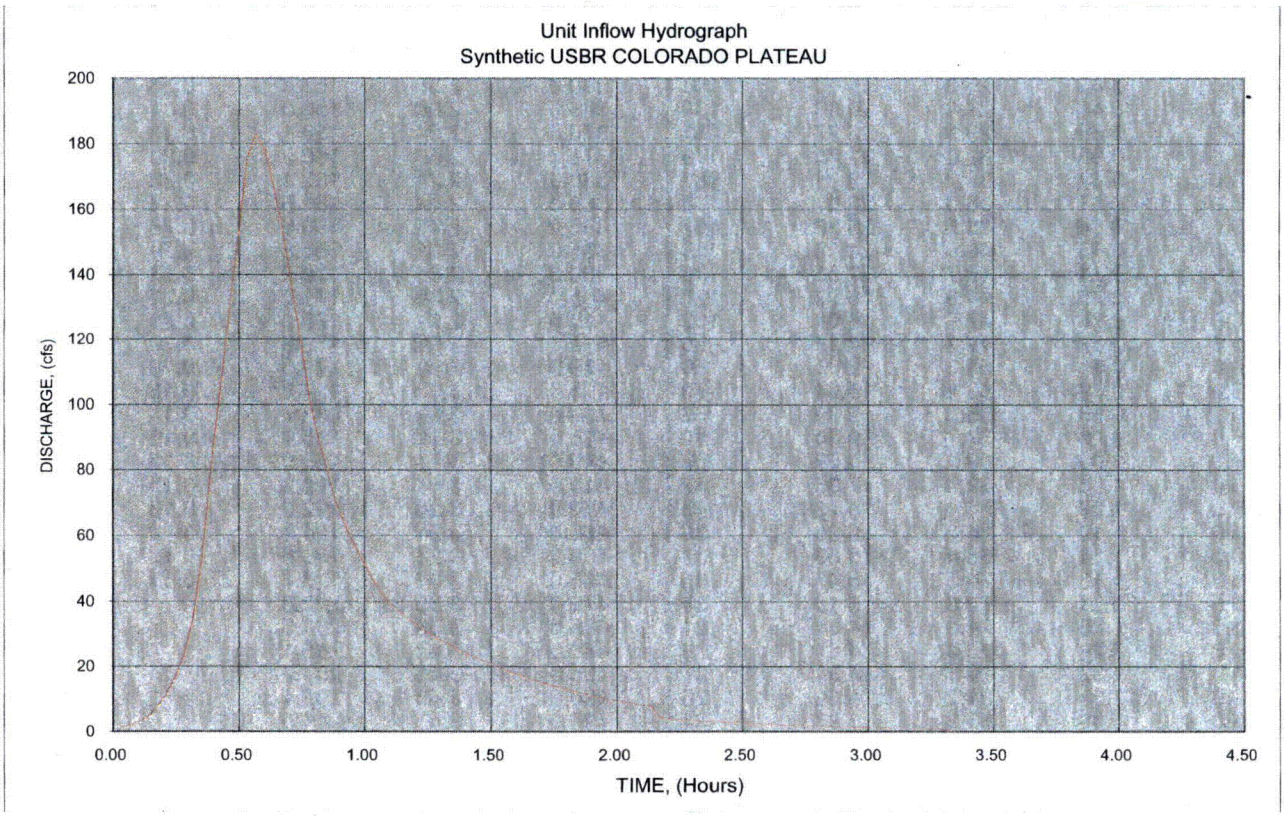
Design Point 3-10, 25, 100, 200 Existing Conditions

Drainage Area =	0.1675	sq. miles	Lg+D/2 =	0.71	Hours
Basin Slope =	77.56	ft./mile	Basin Factor =	0.11	
L =	1.34	mi., Length of Watercourse	V' =	4.50	cfs/Day
Lca =	0.7	mi., Distance to Centroid	Qs =	6.3	* q, cfs
Kn =	0.054	-, Ave. Weighted Manning's n			

PARAMETERS:

Calculated:	Lag Time, Lg =	0.67 Hours	Unit Duration, D =	7.31	minutes
			Calculated Timestep =	2.14	minutes

Data to be used in Analysis Unit Duration, D = 5 minutes, round down to nearest of 5, 10, 15, 30, 60, 120, 180, or 360
Selected Timestep = 5 minutes, integer value evenly divisible into 60



UI Record - Unit Graph 5 **minute interval**

UI	2	7	17	41	97	153	181	157	119	86
UI	65	51	41	35	30	27	24	21	18	16
UI	14	12	11	9	8	7	6	6	5	4
UI	4	3	3	3	2	2	2	2	1	1
UI	1	1	1	1						
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USBR calculated unitgraph peak = 183 Interpolated Peak = 181

Time t, % of Lg+D/2	Hours	Min.	q	Qs cfs	Time t, % of Lg+D/2	Hours	Min.	q	Qs cfs
5.0	0.04	2.1	0.19	1	305.0	2.17	130.3	0.66	4
10.0	0.07	4.3	0.32	2	310.0	2.21	132.5	0.63	4
15.0	0.11	6.4	0.48	3	315.0	2.24	134.6	0.59	4
20.0	0.14	8.5	0.74	5	320.0	2.28	136.7	0.56	4
25.0	0.18	10.7	1.21	8	325.0	2.31	138.9	0.53	3
30.0	0.21	12.8	1.81	11	330.0	2.35	141.0	0.50	3
35.0	0.25	15.0	2.63	17	335.0	2.39	143.1	0.47	3
40.0	0.28	17.1	3.68	23	340.0	2.42	145.3	0.45	3
45.0	0.32	19.2	5.47	35	345.0	2.46	147.4	0.42	3
50.0	0.36	21.4	8.41	53	350.0	2.49	149.6	0.40	3
55.0	0.39	23.5	12.61	80	355.0	2.53	151.7	0.38	2
60.0	0.43	25.6	16.50	104	360.0	2.56	153.8	0.36	2
65.0	0.46	27.8	20.50	130	365.0	2.60	156.0	0.34	2
70.0	0.50	29.9	23.97	152	370.0	2.64	158.1	0.33	2
75.0	0.53	32.0	27.75	176	375.0	2.67	160.2	0.30	2
80.0	0.57	34.2	28.91	183	380.0	2.71	162.4	0.28	2
85.0	0.61	36.3	28.07	178	385.0	2.74	164.5	0.27	2
90.0	0.64	38.5	26.38	167	390.0	2.78	166.6	0.26	2
95.0	0.68	40.6	24.18	153	395.0	2.81	168.8	0.24	2
100.0	0.71	42.7	21.55	136	400.0	2.85	170.9	0.23	1
105.0	0.75	44.9	18.92	120	405.0	2.88	173.1	0.22	1
110.0	0.78	47.0	16.08	102	410.0	2.92	175.2	0.21	1
115.0	0.82	49.1	14.19	90	415.0	2.96	177.3	0.20	1
120.0	0.85	51.3	12.61	80	420.0	2.99	179.5	0.19	1
125.0	0.89	53.4	11.04	70	425.0	3.03	181.6	0.18	1
130.0	0.93	55.5	9.99	63	430.0	3.06	183.7	0.17	1
135.0	0.96	57.7	9.04	57	435.0	3.10	185.9	0.16	1
140.0	1.00	59.8	8.20	52	440.0	3.13	188.0	0.15	1
145.0	1.03	62.0	7.36	47	445.0	3.17	190.2	0.15	1
150.0	1.07	64.1	6.78	43	450.0	3.20	192.3	0.13	1
155.0	1.10	66.2	6.20	39	455.0	3.24	194.4	0.12	1
160.0	1.14	68.4	5.83	37	460.0	3.28	196.6	0.12	1
165.0	1.18	70.5	5.47	35	465.0	3.31	198.7	0.11	1
170.0	1.21	72.6	5.15	33	470.0	3.35	200.8		
175.0	1.25	74.8	4.84	31	475.0	3.38	203.0		
180.0	1.28	76.9	4.57	29	480.0	3.42	205.1		
185.0	1.32	79.1	4.31	27	485.0	3.45	207.2		
190.0	1.35	81.2	4.10	26	490.0	3.49	209.4		
195.0	1.39	83.3	3.87	24	495.0	3.53	211.5		
200.0	1.42	85.5	3.68	23	500.0	3.56	213.7		
205.0	1.46	87.6	3.47	22	505.0	3.60	215.8		
210.0	1.50	89.7	3.28	21	510.0	3.63	217.9		
215.0	1.53	91.9	3.10	20	515.0	3.67	220.1		
220.0	1.57	94.0	2.93	19	520.0	3.70	222.2		
225.0	1.60	96.1	2.75	17	525.0	3.74	224.3		
230.0	1.64	98.3	2.63	17	530.0	3.77	226.5		
235.0	1.67	100.4	2.47	16	535.0	3.81	228.6		
240.0	1.71	102.6	2.33	15	540.0	3.85	230.7		
245.0	1.74	104.7	2.22	14	545.0	3.88	232.9		
250.0	1.78	106.8	2.10	13	550.0	3.92	235.0		
255.0	1.82	109.0	1.99	13	555.0	3.95	237.2		
260.0	1.85	111.1	1.88	12	560.0	3.99	239.3		
265.0	1.89	113.2	1.78	11	565.0	4.02	241.4		
270.0	1.92	115.4	1.68	11	570.0	4.06	243.6		
275.0	1.96	117.5	1.59	10	575.0	4.10	245.7		
280.0	1.99	119.6	1.50	9	580.0	4.13	247.8		
285.0	2.03	121.8	1.43	9	585.0	4.17	250.0		
290.0	2.07	123.9	1.36	9	590.0	4.20	252.1		
295.0	2.10	126.1	1.28	8	595.0	4.24	254.2		
300.0	2.14	128.2	1.21	8	600.0	4.27	256.4		

NOTES : Use for models including Design Point 3 for the 10, 25, 100 and 200 year events

COLORADO PLATEAU UNIT HYDROGRAPH 18-May-06

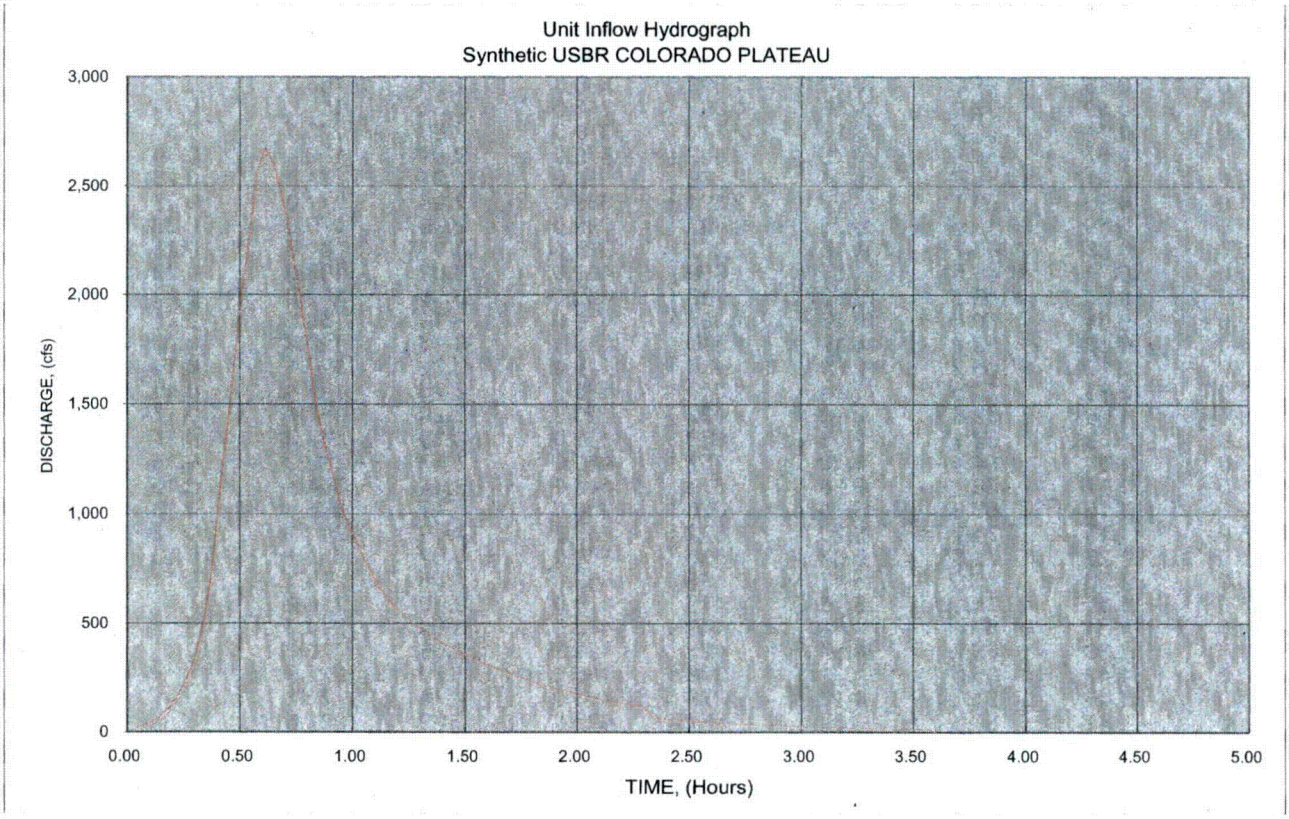
Basin 1-10, 25, 100, 200 Proposed Conditions

Drainage Area =	2.63	sq. miles	Lg+D/2 =	0.77	Hours
Basin Slope =	356	ft./mile	Basin Factor =	0.13	
L =	2.92	mi., Length of Watercourse	V' =	70.72	cfs/Day
Lca =	0.87	mi., Distance to Centroid	Qs =	92.3	* q, cfs
Kn =	0.054	-, Ave. Weighted Manning's n			

PARAMETERS:

Calculated:	Lag Time, Lg =	0.72 Hours	Unit Duration, D =	7.90	minutes
			Calculated Timestep =	2.30	minutes

Data to be used in Analysis Unit Duration, D = 5 minutes, round down to nearest of 5, 10, 15, 30, 60, 120, 180, or 360
Selected Timestep = 5 minutes, integer value evenly divisible into 60



UI Record - Unit Graph 5 **minute interval**

UI	32	84	207	456	1117	1909	2586	2528	2091	1549
UI	1174	913	735	601	517	452	398	354	314	278
UI	246	217	193	172	152	135	120	107	94	83
UI	74	65	59	52	46	41	36	32	28	25
UI	22	20	18	16	14	12	11			
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USBR calculated unitgraph peak = 2669 Interpolated Peak = 2586

Time t, % of Lg+D/2	Hours	Min.	q	Qs cfs	Time t, % of Lg+D/2	Hours	Min.	q	Qs cfs
5.0	0.04	2.3	0.19	18	305.0	2.34	140.2	0.66	61
10.0	0.08	4.6	0.32	30	310.0	2.37	142.5	0.63	58
15.0	0.11	6.9	0.48	44	315.0	2.41	144.8	0.59	54
20.0	0.15	9.2	0.74	68	320.0	2.45	147.1	0.56	52
25.0	0.19	11.5	1.21	112	325.0	2.49	149.4	0.53	49
30.0	0.23	13.8	1.81	167	330.0	2.53	151.7	0.50	46
35.0	0.27	16.1	2.63	243	335.0	2.57	154.0	0.47	43
40.0	0.31	18.4	3.68	340	340.0	2.60	156.3	0.45	42
45.0	0.34	20.7	5.47	505	345.0	2.64	158.6	0.42	39
50.0	0.38	23.0	8.41	776	350.0	2.68	160.9	0.40	37
55.0	0.42	25.3	12.61	1,164	355.0	2.72	163.2	0.38	35
60.0	0.46	27.6	16.50	1,523	360.0	2.76	165.5	0.36	33
65.0	0.50	29.9	20.50	1,892	365.0	2.80	167.8	0.34	31
70.0	0.54	32.2	23.97	2,213	370.0	2.83	170.1	0.33	30
75.0	0.57	34.5	27.75	2,562	375.0	2.87	172.4	0.30	28
80.0	0.61	36.8	28.91	2,669	380.0	2.91	174.7	0.28	26
85.0	0.65	39.1	28.07	2,591	385.0	2.95	177.0	0.27	25
90.0	0.69	41.4	26.38	2,435	390.0	2.99	179.3	0.26	24
95.0	0.73	43.7	24.18	2,232	395.0	3.03	181.6	0.24	22
100.0	0.77	46.0	21.55	1,989	400.0	3.06	183.9	0.23	21
105.0	0.80	48.3	18.92	1,747	405.0	3.10	186.2	0.22	20
110.0	0.84	50.6	16.08	1,484	410.0	3.14	188.5	0.21	19
115.0	0.88	52.9	14.19	1,310	415.0	3.18	190.8	0.20	18
120.0	0.92	55.2	12.61	1,164	420.0	3.22	193.1	0.19	18
125.0	0.96	57.5	11.04	1,019	425.0	3.26	195.4	0.18	17
130.0	1.00	59.8	9.99	922	430.0	3.29	197.7	0.17	16
135.0	1.03	62.1	9.04	835	435.0	3.33	200.0	0.16	15
140.0	1.07	64.4	8.20	757	440.0	3.37	202.2	0.15	14
145.0	1.11	66.7	7.36	679	445.0	3.41	204.5	0.15	14
150.0	1.15	68.9	6.78	626	450.0	3.45	206.8	0.13	12
155.0	1.19	71.2	6.20	572	455.0	3.49	209.1	0.12	11
160.0	1.23	73.5	5.83	538	460.0	3.52	211.4	0.12	11
165.0	1.26	75.8	5.47	505	465.0	3.56	213.7	0.11	10
170.0	1.30	78.1	5.15	475	470.0	3.60	216.0		
175.0	1.34	80.4	4.84	447	475.0	3.64	218.3		
180.0	1.38	82.7	4.57	422	480.0	3.68	220.6		
185.0	1.42	85.0	4.31	398	485.0	3.72	222.9		
190.0	1.46	87.3	4.10	378	490.0	3.75	225.2		
195.0	1.49	89.6	3.87	357	495.0	3.79	227.5		
200.0	1.53	91.9	3.68	340	500.0	3.83	229.8		
205.0	1.57	94.2	3.47	320	505.0	3.87	232.1		
210.0	1.61	96.5	3.28	303	510.0	3.91	234.4		
215.0	1.65	98.8	3.10	286	515.0	3.95	236.7		
220.0	1.69	101.1	2.93	270	520.0	3.98	239.0		
225.0	1.72	103.4	2.75	254	525.0	4.02	241.3		
230.0	1.76	105.7	2.63	243	530.0	4.06	243.6		
235.0	1.80	108.0	2.47	228	535.0	4.10	245.9		
240.0	1.84	110.3	2.33	215	540.0	4.14	248.2		
245.0	1.88	112.6	2.22	205	545.0	4.18	250.5		
250.0	1.92	114.9	2.10	194	550.0	4.21	252.8		
255.0	1.95	117.2	1.99	184	555.0	4.25	255.1		
260.0	1.99	119.5	1.88	174	560.0	4.29	257.4		
265.0	2.03	121.8	1.78	164	565.0	4.33	259.7		
270.0	2.07	124.1	1.68	155	570.0	4.37	262.0		
275.0	2.11	126.4	1.59	147	575.0	4.41	264.3		
280.0	2.15	128.7	1.50	138	580.0	4.44	266.6		
285.0	2.18	131.0	1.43	132	585.0	4.48	268.9		
290.0	2.22	133.3	1.36	126	590.0	4.52	271.2		
295.0	2.26	135.6	1.28	118	595.0	4.56	273.5		
300.0	2.30	137.9	1.21	112	600.0	4.60	275.8		

NOTES : Use for models including Basin 1 for the 10, 25, 100 and 200 year events

COLORADO PLATEAU UNIT HYDROGRAPH 18-May-06

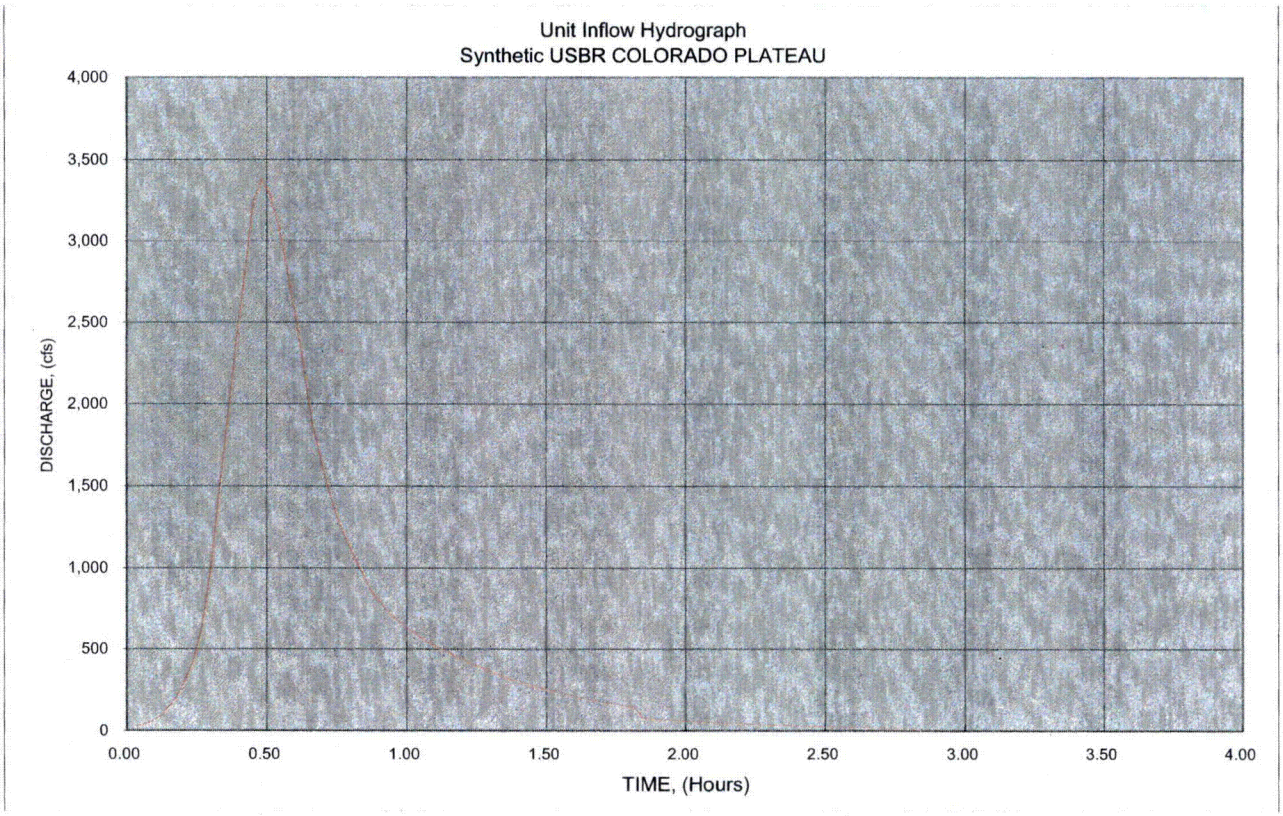
Basin 1-PMP Proposed Conditions

Drainage Area =	2.63	sq. miles	Lg+D/2 =	0.61	Hours
Basin Slope =	356	ft./mile	Basin Factor =	0.13	
L =	2.92	mi., Length of Watercourse	V' =	70.72	cfs/Day
Lca =	0.87	mi., Distance to Centroid	Qs =	116.9	* q, cfs
Kn =	0.042	-, Ave. Weighted Manning's n			

PARAMETERS:

Calculated:	Lag Time, Lg =	0.56 Hours	Unit Duration, D =	6.15	minutes
			Calculated Timestep =	1.82	minutes

Data to be used in Analysis Unit Duration, D = 5 minutes, round down to nearest of 5, 10, 15, 30, 60, 120, 180, or 360
Selected Timestep = 5 minutes, integer value evenly divisible into 60



UI Record - Unit Graph 5 **minute interval**

UI	52	177	485	1482	2709	3327	2740	1872	1329	1003
UI	772	637	540	464	399	341	292	251	216	185
UI	160	137	117	100	87	75	64	55	47	41
UI	34	30	26	23	19	17	14			
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UI										
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USBR calculated unitgraph peak = 3379 Interpolated Peak = 3327

Time t, % of Lg+D/2	Hours	Min.	q	Qs cfs	Time t, % of Lg+D/2	Hours	Min.	q	Qs cfs
5.0	0.03	1.8	0.19	22	305.0	1.85	110.7	0.66	77
10.0	0.06	3.6	0.32	37	310.0	1.88	112.6	0.63	74
15.0	0.09	5.4	0.48	56	315.0	1.91	114.4	0.59	69
20.0	0.12	7.3	0.74	86	320.0	1.94	116.2	0.56	65
25.0	0.15	9.1	1.21	141	325.0	1.97	118.0	0.53	62
30.0	0.18	10.9	1.81	212	330.0	2.00	119.8	0.50	58
35.0	0.21	12.7	2.63	307	335.0	2.03	121.6	0.47	55
40.0	0.24	14.5	3.68	430	340.0	2.06	123.4	0.45	53
45.0	0.27	16.3	5.47	639	345.0	2.09	125.3	0.42	49
50.0	0.30	18.2	8.41	983	350.0	2.12	127.1	0.40	47
55.0	0.33	20.0	12.61	1,474	355.0	2.15	128.9	0.38	44
60.0	0.36	21.8	16.50	1,928	360.0	2.18	130.7	0.36	42
65.0	0.39	23.6	20.50	2,396	365.0	2.21	132.5	0.34	40
70.0	0.42	25.4	23.97	2,801	370.0	2.24	134.3	0.33	39
75.0	0.45	27.2	27.75	3,243	375.0	2.27	136.1	0.30	35
80.0	0.48	29.0	28.91	3,379	380.0	2.30	138.0	0.28	33
85.0	0.51	30.9	28.07	3,281	385.0	2.33	139.8	0.27	32
90.0	0.54	32.7	26.38	3,083	390.0	2.36	141.6	0.26	30
95.0	0.57	34.5	24.18	2,826	395.0	2.39	143.4	0.24	28
100.0	0.61	36.3	21.55	2,519	400.0	2.42	145.2	0.23	27
105.0	0.64	38.1	18.92	2,211	405.0	2.45	147.0	0.22	26
110.0	0.67	39.9	16.08	1,879	410.0	2.48	148.9	0.21	25
115.0	0.70	41.8	14.19	1,658	415.0	2.51	150.7	0.20	23
120.0	0.73	43.6	12.61	1,474	420.0	2.54	152.5	0.19	22
125.0	0.76	45.4	11.04	1,290	425.0	2.57	154.3	0.18	21
130.0	0.79	47.2	9.99	1,168	430.0	2.60	156.1	0.17	20
135.0	0.82	49.0	9.04	1,057	435.0	2.63	157.9	0.16	19
140.0	0.85	50.8	8.20	958	440.0	2.66	159.7	0.15	18
145.0	0.88	52.6	7.36	860	445.0	2.69	161.6	0.15	18
150.0	0.91	54.5	6.78	792	450.0	2.72	163.4	0.13	15
155.0	0.94	56.3	6.20	725	455.0	2.75	165.2	0.12	14
160.0	0.97	58.1	5.83	681	460.0	2.78	167.0	0.12	14
165.0	1.00	59.9	5.47	639	465.0	2.81	168.8	0.11	13
170.0	1.03	61.7	5.15	602	470.0	2.84	170.6		
175.0	1.06	63.5	4.84	566	475.0	2.87	172.5		
180.0	1.09	65.4	4.57	534	480.0	2.90	174.3		
185.0	1.12	67.2	4.31	504	485.0	2.93	176.1		
190.0	1.15	69.0	4.10	479	490.0	2.97	177.9		
195.0	1.18	70.8	3.87	452	495.0	3.00	179.7		
200.0	1.21	72.6	3.68	430	500.0	3.03	181.5		
205.0	1.24	74.4	3.47	406	505.0	3.06	183.3		
210.0	1.27	76.2	3.28	383	510.0	3.09	185.2		
215.0	1.30	78.1	3.10	362	515.0	3.12	187.0		
220.0	1.33	79.9	2.93	342	520.0	3.15	188.8		
225.0	1.36	81.7	2.75	321	525.0	3.18	190.6		
230.0	1.39	83.5	2.63	307	530.0	3.21	192.4		
235.0	1.42	85.3	2.47	289	535.0	3.24	194.2		
240.0	1.45	87.1	2.33	272	540.0	3.27	196.1		
245.0	1.48	89.0	2.22	259	545.0	3.30	197.9		
250.0	1.51	90.8	2.10	245	550.0	3.33	199.7		
255.0	1.54	92.6	1.99	233	555.0	3.36	201.5		
260.0	1.57	94.4	1.88	220	560.0	3.39	203.3		
265.0	1.60	96.2	1.78	208	565.0	3.42	205.1		
270.0	1.63	98.0	1.68	196	570.0	3.45	206.9		
275.0	1.66	99.8	1.59	186	575.0	3.48	208.8		
280.0	1.69	101.7	1.50	175	580.0	3.51	210.6		
285.0	1.72	103.5	1.43	167	585.0	3.54	212.4		
290.0	1.75	105.3	1.36	159	590.0	3.57	214.2		
295.0	1.79	107.1	1.28	150	595.0	3.60	216.0		
300.0	1.82	108.9	1.21	141	600.0	3.63	217.8		

NOTES : Use for models including Basin 1 for the PMP Local event

COLORADO PLATEAU UNIT HYDROGRAPH 18-May-06

Basin 2-10, 25, 100, 200 Proposed Conditions

Drainage Area =	8.96	sq. miles	Lg+D/2 =	1.88	Hours
Basin Slope =	283	ft./mile	Basin Factor =	1.97	
L =	7.67	mi., Length of Watercourse	V' =	240.93	cfs/Day
Lca =	4.31	mi., Distance to Centroid	Qs =	128.2	* q, cfs
Kn =	0.054	-, Ave. Weighted Manning's n			

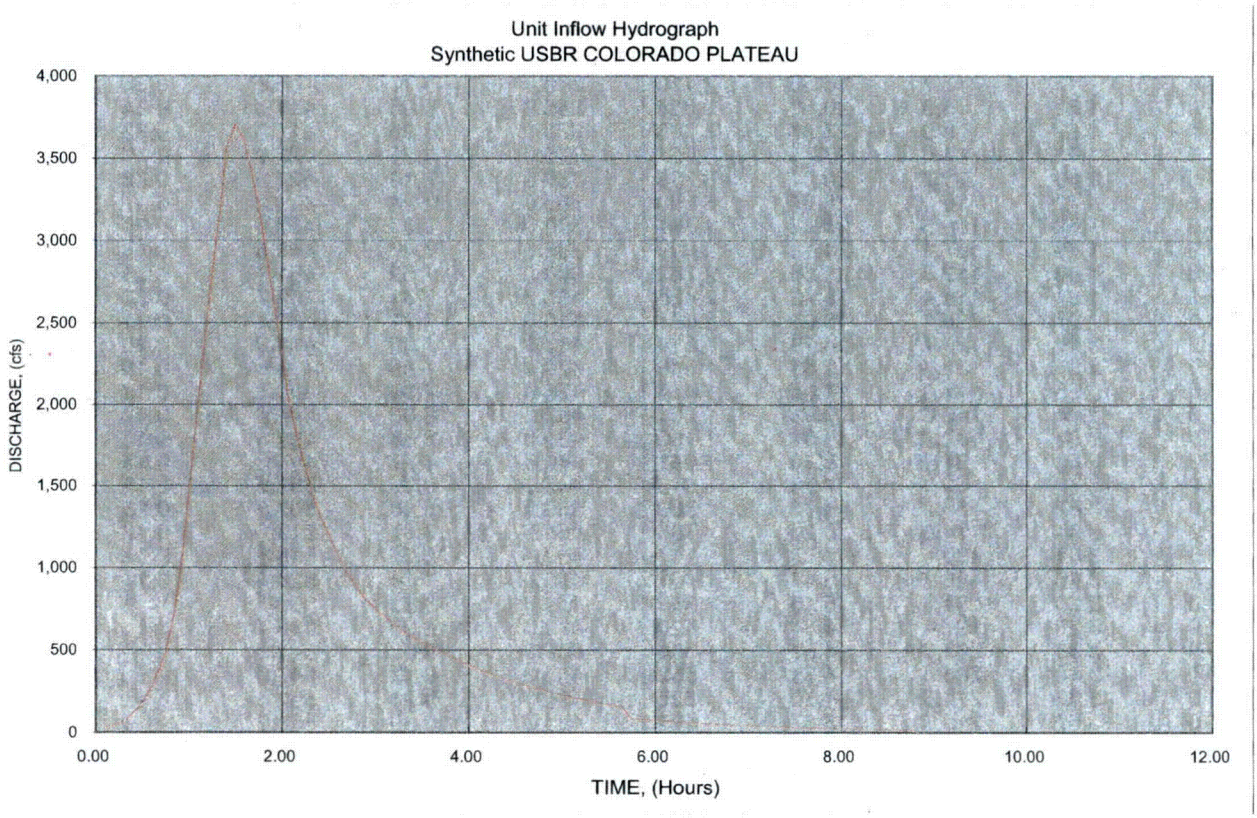
PARAMETERS:

Calculated: Lag Time, Lg = 1.75 Hours Unit Duration, D = 19.14 minutes

Calculated Timestep = 5.64 minutes

Data to be used in Analysis Unit Duration, D = 15 minutes, round down to nearest of 5, 10, 15, 30, 60, 120, 180, or 360

Selected Timestep = 5 minutes, integer value evenly divisible into 60



UI Record - Unit Graph 5 **minute interval**

UI	22	37	55	80	121	180	254	350	469	671
UI	985	1423	1879	2327	2761	3163	3568	3700	3615	3439
UI	3206	2928	2629	2323	2021	1808	1628	1450	1319	1207
UI	1106	1011	924	858	793	751	710	673	637	604
UI	574	546	522	496	474	450	428	407	388	368
UI	349	335	317	301	288	274	262	249	237	226
UI	214	204	194	186	178	169	160	153	146	138
UI	131	125	119	113	108	103	99	94	88	85
UI	81	77	73	70	67	63	60	58	54	52
UI	50	47	45	43	41	38	36	35	34	32
UI	30	29	28	27	26	24	23	22	21	20
UI	19	18	16	15	15	14	4			

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USBR calculated unitgraph peak = 3706 Interpolated Peak = 3700

Time t, % of Lg+D/2	Hours	Min.	q	Qs cfs	Time t, % of Lg+D/2	Hours	Min.	q	Qs cfs
5.0	0.09	5.6	0.19	24	305.0	5.73	344.0	0.66	85
10.0	0.19	11.3	0.32	41	310.0	5.83	349.6	0.63	81
15.0	0.28	16.9	0.48	62	315.0	5.92	355.2	0.59	76
20.0	0.38	22.6	0.74	95	320.0	6.01	360.9	0.56	72
25.0	0.47	28.2	1.21	155	325.0	6.11	366.5	0.53	68
30.0	0.56	33.8	1.81	232	330.0	6.20	372.2	0.50	64
35.0	0.66	39.5	2.63	337	335.0	6.30	377.8	0.47	60
40.0	0.75	45.1	3.68	472	340.0	6.39	383.4	0.45	58
45.0	0.85	50.7	5.47	701	345.0	6.48	389.1	0.42	54
50.0	0.94	56.4	8.41	1,078	350.0	6.58	394.7	0.40	51
55.0	1.03	62.0	12.61	1,616	355.0	6.67	400.4	0.38	49
60.0	1.13	67.7	16.50	2,115	360.0	6.77	406.0	0.36	46
65.0	1.22	73.3	20.50	2,628	365.0	6.86	411.6	0.34	44
70.0	1.32	78.9	23.97	3,073	370.0	6.95	417.3	0.33	42
75.0	1.41	84.6	27.75	3,557	375.0	7.05	422.9	0.30	38
80.0	1.50	90.2	28.91	3,706	380.0	7.14	428.6	0.28	36
85.0	1.60	95.9	28.07	3,598	385.0	7.24	434.2	0.27	35
90.0	1.69	101.5	26.38	3,381	390.0	7.33	439.8	0.26	33
95.0	1.79	107.1	24.18	3,099	395.0	7.42	445.5	0.24	31
100.0	1.88	112.8	21.55	2,762	400.0	7.52	451.1	0.23	29
105.0	1.97	118.4	18.92	2,425	405.0	7.61	456.7	0.22	28
110.0	2.07	124.1	16.08	2,061	410.0	7.71	462.4	0.21	27
115.0	2.16	129.7	14.19	1,819	415.0	7.80	468.0	0.20	26
120.0	2.26	135.3	12.61	1,616	420.0	7.89	473.7	0.19	24
125.0	2.35	141.0	11.04	1,415	425.0	7.99	479.3	0.18	23
130.0	2.44	146.6	9.99	1,281	430.0	8.08	484.9	0.17	22
135.0	2.54	152.2	9.04	1,159	435.0	8.18	490.6	0.16	21
140.0	2.63	157.9	8.20	1,051	440.0	8.27	496.2	0.15	19
145.0	2.73	163.5	7.36	943	445.0	8.36	501.9	0.15	19
150.0	2.82	169.2	6.78	869	450.0	8.46	507.5	0.13	17
155.0	2.91	174.8	6.20	795	455.0	8.55	513.1	0.12	15
160.0	3.01	180.4	5.83	747	460.0	8.65	518.8	0.12	15
165.0	3.10	186.1	5.47	701	465.0	8.74	524.4	0.11	14
170.0	3.20	191.7	5.15	660	470.0	8.83	530.1		
175.0	3.29	197.4	4.84	620	475.0	8.93	535.7		
180.0	3.38	203.0	4.57	586	480.0	9.02	541.3		
185.0	3.48	208.6	4.31	552	485.0	9.12	547.0		
190.0	3.57	214.3	4.10	526	490.0	9.21	552.6		
195.0	3.67	219.9	3.87	496	495.0	9.30	558.2		
200.0	3.76	225.6	3.68	472	500.0	9.40	563.9		
205.0	3.85	231.2	3.47	445	505.0	9.49	569.5		
210.0	3.95	236.8	3.28	420	510.0	9.59	575.2		
215.0	4.04	242.5	3.10	397	515.0	9.68	580.8		
220.0	4.14	248.1	2.93	376	520.0	9.77	586.4		
225.0	4.23	253.7	2.75	353	525.0	9.87	592.1		
230.0	4.32	259.4	2.63	337	530.0	9.96	597.7		
235.0	4.42	265.0	2.47	317	535.0	10.06	603.4		
240.0	4.51	270.7	2.33	299	540.0	10.15	609.0		
245.0	4.61	276.3	2.22	285	545.0	10.24	614.6		
250.0	4.70	281.9	2.10	269	550.0	10.34	620.3		
255.0	4.79	287.6	1.99	255	555.0	10.43	625.9		
260.0	4.89	293.2	1.88	241	560.0	10.53	631.6		
265.0	4.98	298.9	1.78	228	565.0	10.62	637.2		
270.0	5.07	304.5	1.68	215	570.0	10.71	642.8		
275.0	5.17	310.1	1.59	204	575.0	10.81	648.5		
280.0	5.26	315.8	1.50	192	580.0	10.90	654.1		
285.0	5.36	321.4	1.43	183	585.0	11.00	659.7		
290.0	5.45	327.1	1.36	174	590.0	11.09	665.4		
295.0	5.54	332.7	1.28	164	595.0	11.18	671.0		
300.0	5.64	338.3	1.21	155	600.0	11.28	676.7		

NOTES : Use for models including Basin 2 for the 10, 25, 100 and 200 year events

COLORADO PLATEAU UNIT HYDROGRAPH 18-May-06

Basin 2-PMP Proposed Conditions

Drainage Area =	8.96	sq. miles	Lg+D/2 =	1.45	Hours
Basin Slope =	283	ft./mile	Basin Factor =	1.97	
L =	7.67	mi., Length of Watercourse	V' =	240.93	cfs/Day
Lca =	4.31	mi., Distance to Centroid	Qs =	166.4	* q, cfs
Kn =	0.042	-, Ave. Weighted Manning's n			

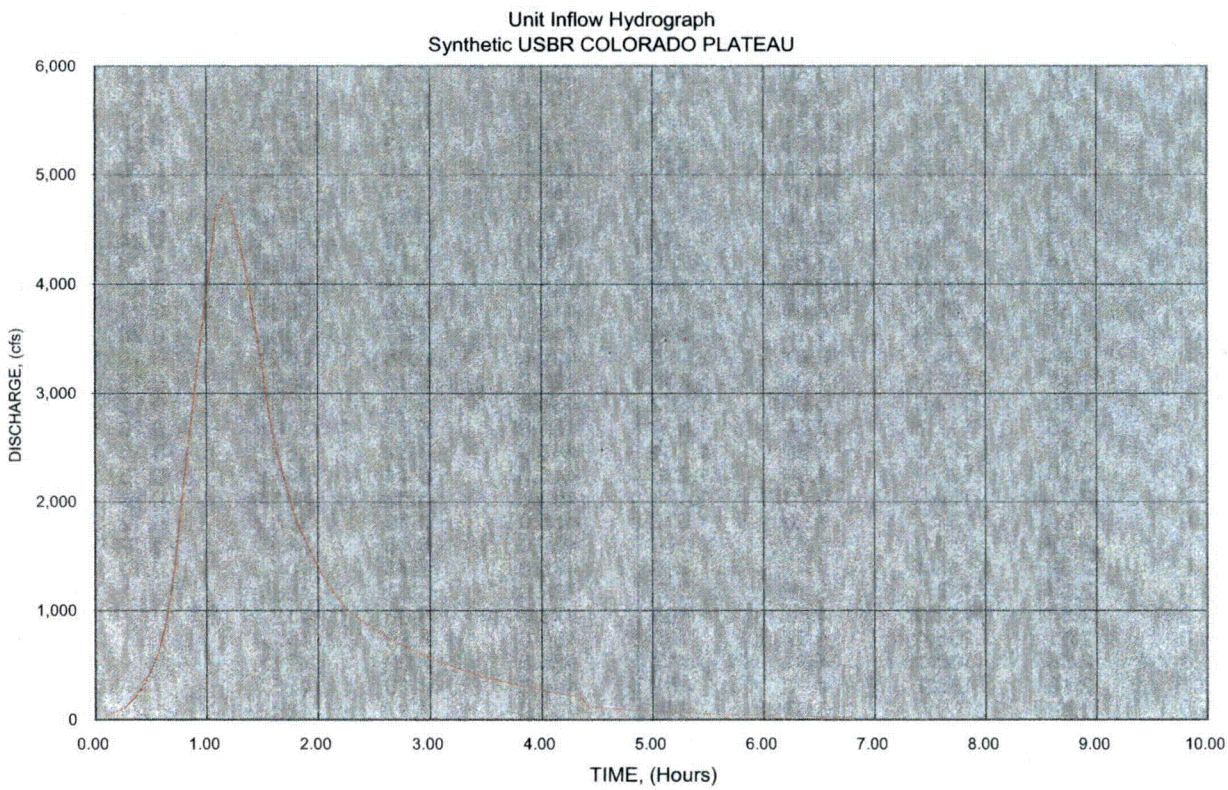
PARAMETERS:

Calculated: Lag Time, Lg = 1.36 Hours Unit Duration, D = 14.89 minutes

Calculated Timestep = 4.34 minutes

Data to be used in Analysis Unit Duration, D = 10 minutes, round down to nearest of 5, 10, 15, 30, 60, 120, 180, or 360

Selected Timestep = 5 minutes, integer value evenly divisible into 60



UI Record - Unit Graph 5 **minute interval**

UI	35	61	99	170	277	425	629	1012	1650	2428
UI	3185	3880	4594	4794	4596	4237	3775	3272	2738	2356
UI	2054	1781	1587	1417	1256	1135	1027	956	890	830
UI	775	724	683	640	602	564	528	495	461	437
UI	407	381	360	338	317	297	278	261	245	232
UI	217	203	191	178	167	157	146	138	130	123
UI	114	108	101	95	89	83	78	74	68	65
UI	61	57	55	49	46	44	41	39	37	35
UI	33	31	29	27	25	25	21	20	19	8

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USBR calculated unitgraph peak = 4810 Interpolated Peak = 4794

Time t, % of Lg+D/2	Hours	Min.	q	Qs cfs	Time t, % of Lg+D/2	Hours	Min.	q	Qs cfs
5.0	0.07	4.3	0.19	32	305.0	4.42	265.0	0.66	110
10.0	0.14	8.7	0.32	53	310.0	4.49	269.3	0.63	105
15.0	0.22	13.0	0.48	80	315.0	4.56	273.7	0.59	98
20.0	0.29	17.4	0.74	123	320.0	4.63	278.0	0.56	93
25.0	0.36	21.7	1.21	201	325.0	4.71	282.4	0.53	88
30.0	0.43	26.1	1.81	301	330.0	4.78	286.7	0.50	83
35.0	0.51	30.4	2.63	438	335.0	4.85	291.1	0.47	78
40.0	0.58	34.8	3.68	612	340.0	4.92	295.4	0.45	75
45.0	0.65	39.1	5.47	910	345.0	5.00	299.7	0.42	70
50.0	0.72	43.4	8.41	1,399	350.0	5.07	304.1	0.40	67
55.0	0.80	47.8	12.61	2,098	355.0	5.14	308.4	0.38	63
60.0	0.87	52.1	16.50	2,745	360.0	5.21	312.8	0.36	60
65.0	0.94	56.5	20.50	3,411	365.0	5.29	317.1	0.34	57
70.0	1.01	60.8	23.97	3,988	370.0	5.36	321.5	0.33	55
75.0	1.09	65.2	27.75	4,617	375.0	5.43	325.8	0.30	50
80.0	1.16	69.5	28.91	4,810	380.0	5.50	330.2	0.28	47
85.0	1.23	73.8	28.07	4,670	385.0	5.57	334.5	0.27	45
90.0	1.30	78.2	26.38	4,389	390.0	5.65	338.8	0.26	43
95.0	1.38	82.5	24.18	4,023	395.0	5.72	343.2	0.24	40
100.0	1.45	86.9	21.55	3,586	400.0	5.79	347.5	0.23	38
105.0	1.52	91.2	18.92	3,148	405.0	5.86	351.9	0.22	37
110.0	1.59	95.6	16.08	2,676	410.0	5.94	356.2	0.21	35
115.0	1.67	99.9	14.19	2,361	415.0	6.01	360.6	0.20	33
120.0	1.74	104.3	12.61	2,098	420.0	6.08	364.9	0.19	32
125.0	1.81	108.6	11.04	1,837	425.0	6.15	369.2	0.18	30
130.0	1.88	112.9	9.99	1,662	430.0	6.23	373.6	0.17	28
135.0	1.95	117.3	9.04	1,504	435.0	6.30	377.9	0.16	27
140.0	2.03	121.6	8.20	1,364	440.0	6.37	382.3	0.15	25
145.0	2.10	126.0	7.36	1,225	445.0	6.44	386.6	0.15	25
150.0	2.17	130.3	6.78	1,128	450.0	6.52	391.0	0.13	22
155.0	2.24	134.7	6.20	1,032	455.0	6.59	395.3	0.12	20
160.0	2.32	139.0	5.83	970	460.0	6.66	399.7	0.12	20
165.0	2.39	143.4	5.47	910	465.0	6.73	404.0	0.11	18
170.0	2.46	147.7	5.15	857	470.0	6.81	408.3		
175.0	2.53	152.0	4.84	805	475.0	6.88	412.7		
180.0	2.61	156.4	4.57	760	480.0	6.95	417.0		
185.0	2.68	160.7	4.31	717	485.0	7.02	421.4		
190.0	2.75	165.1	4.10	682	490.0	7.10	425.7		
195.0	2.82	169.4	3.87	644	495.0	7.17	430.1		
200.0	2.90	173.8	3.68	612	500.0	7.24	434.4		
205.0	2.97	178.1	3.47	577	505.0	7.31	438.8		
210.0	3.04	182.5	3.28	546	510.0	7.38	443.1		
215.0	3.11	186.8	3.10	516	515.0	7.46	447.4		
220.0	3.19	191.1	2.93	488	520.0	7.53	451.8		
225.0	3.26	195.5	2.75	458	525.0	7.60	456.1		
230.0	3.33	199.8	2.63	438	530.0	7.67	460.5		
235.0	3.40	204.2	2.47	411	535.0	7.75	464.8		
240.0	3.48	208.5	2.33	388	540.0	7.82	469.2		
245.0	3.55	212.9	2.22	369	545.0	7.89	473.5		
250.0	3.62	217.2	2.10	349	550.0	7.96	477.9		
255.0	3.69	221.5	1.99	331	555.0	8.04	482.2		
260.0	3.76	225.9	1.88	313	560.0	8.11	486.5		
265.0	3.84	230.2	1.78	296	565.0	8.18	490.9		
270.0	3.91	234.6	1.68	280	570.0	8.25	495.2		
275.0	3.98	238.9	1.59	265	575.0	8.33	499.6		
280.0	4.05	243.3	1.50	250	580.0	8.40	503.9		
285.0	4.13	247.6	1.43	238	585.0	8.47	508.3		
290.0	4.20	252.0	1.36	226	590.0	8.54	512.6		
295.0	4.27	256.3	1.28	213	595.0	8.62	516.9		
300.0	4.34	260.6	1.21	201	600.0	8.69	521.3		

NOTES : Use for models including Basin 2 for the PMP Local event

COLORADO PLATEAU UNIT HYDROGRAPH 18-May-06

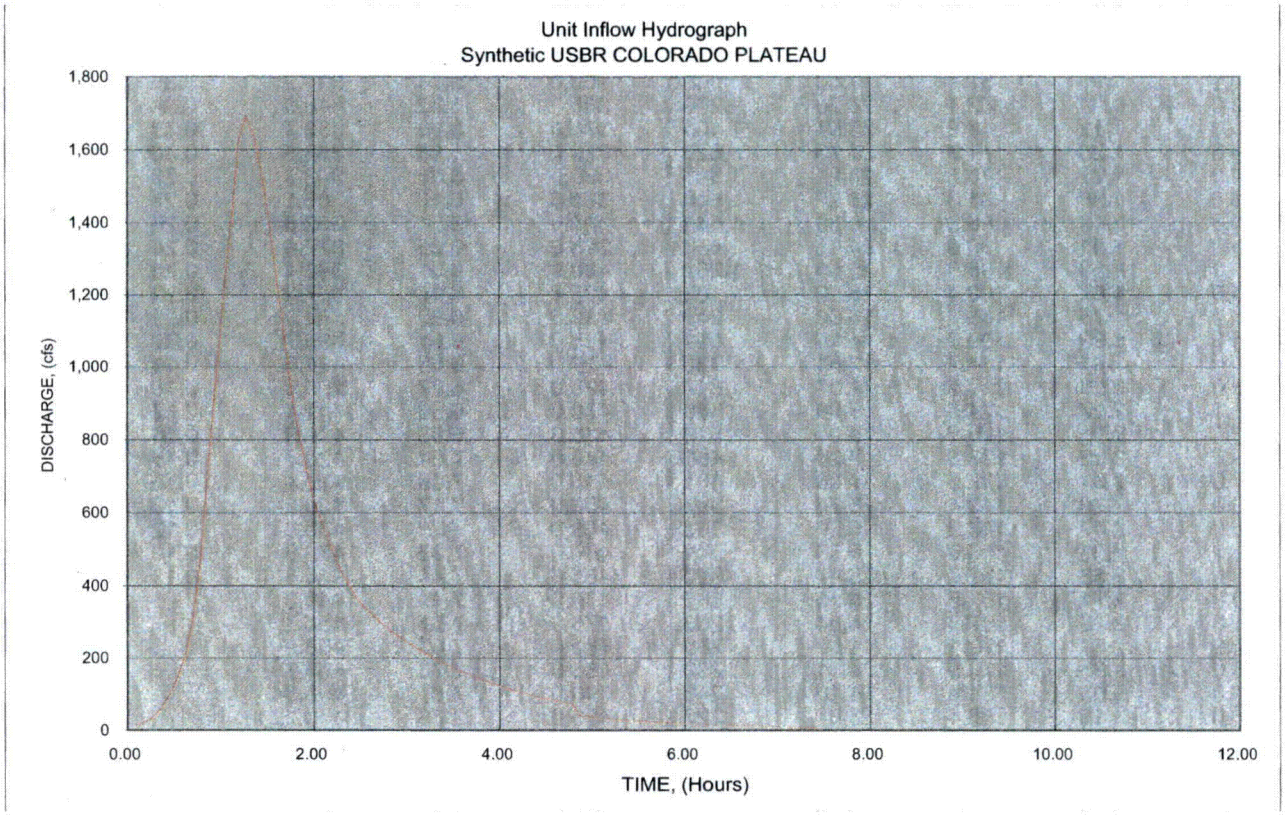
Basin 3-10, 25, 100, 200 Proposed Conditions

Drainage Area =	3.47	sq. miles	Lg+D/2 =	1.59	Hours
Basin Slope =	57.1	ft./mile	Basin Factor =	1.15	
L =	4.73	mi., Length of Watercourse	V' =	93.31	cfs/Day
Lca =	1.83	mi., Distance to Centroid	Qs =	58.6	* q, cfs
Kn =	0.054	-, Ave. Weighted Manning's n			

PARAMETERS:

Calculated:	Lag Time, Lg =	1.47 Hours	Unit Duration, D =	16.02	minutes
			Calculated Timestep =	4.78	minutes

Data to be used in Analysis Unit Duration, D = 15 minutes, round down to nearest of 5, 10, 15, 30, 60, 120, 180, or 360
Selected Timestep = 5 minutes, integer value evenly divisible into 60



UI Record - Unit Graph 5 **minute interval**

UI	11	20	30	48	79	119	174	254	392	606
UI	854	1096	1322	1546	1672	1657	1566	1438	1281	1120
UI	947	830	733	640	577	520	468	421	386	355
UI	332	311	292	275	258	244	231	218	206	194
UI	183	172	161	154	144	136	129	122	115	108
UI	102	96	91	86	82	77	72	69	64	61
UI	57	54	51	48	46	43	40	38	36	34
UI	32	30	29	27	26	24	23	22	20	20
UI	18	17	16	15	14	13	13	12	12	11
'I	10	10	9	9	8	7	7	7	3	

UI

UI
UI
UI
UI
UI
UI
UI
UI

USBR calculated unitgraph peak = 1693 Interpolated Peak = 1672

Time t, % of Lg+D/2	Hours	Min.	q	Qs cfs	Time t, % of Lg+D/2	Hours	Min.	q	Qs cfs
5.0	0.08	4.8	0.19	11	305.0	4.86	291.6	0.66	39
10.0	0.16	9.6	0.32	19	310.0	4.94	296.4	0.63	37
15.0	0.24	14.3	0.48	28	315.0	5.02	301.1	0.59	35
20.0	0.32	19.1	0.74	43	320.0	5.10	305.9	0.56	33
25.0	0.40	23.9	1.21	71	325.0	5.18	310.7	0.53	31
30.0	0.48	28.7	1.81	106	330.0	5.26	315.5	0.50	29
35.0	0.56	33.5	2.63	154	335.0	5.34	320.3	0.47	28
40.0	0.64	38.2	3.68	216	340.0	5.42	325.0	0.45	26
45.0	0.72	43.0	5.47	320	345.0	5.50	329.8	0.42	25
50.0	0.80	47.8	8.41	492	350.0	5.58	334.6	0.40	23
55.0	0.88	52.6	12.61	738	355.0	5.66	339.4	0.38	22
60.0	0.96	57.4	16.50	966	360.0	5.74	344.2	0.36	21
65.0	1.04	62.1	20.50	1,200	365.0	5.82	348.9	0.34	20
70.0	1.12	66.9	23.97	1,404	370.0	5.90	353.7	0.33	19
75.0	1.20	71.7	27.75	1,625	375.0	5.98	358.5	0.30	18
80.0	1.27	76.5	28.91	1,693	380.0	6.05	363.3	0.28	16
85.0	1.35	81.3	28.07	1,644	385.0	6.13	368.1	0.27	16
90.0	1.43	86.0	26.38	1,545	390.0	6.21	372.8	0.26	15
95.0	1.51	90.8	24.18	1,416	395.0	6.29	377.6	0.24	14
100.0	1.59	95.6	21.55	1,262	400.0	6.37	382.4	0.23	13
105.0	1.67	100.4	18.92	1,108	405.0	6.45	387.2	0.22	13
110.0	1.75	105.2	16.08	942	410.0	6.53	392.0	0.21	12
115.0	1.83	109.9	14.19	831	415.0	6.61	396.7	0.20	12
120.0	1.91	114.7	12.61	738	420.0	6.69	401.5	0.19	11
125.0	1.99	119.5	11.04	647	425.0	6.77	406.3	0.18	11
130.0	2.07	124.3	9.99	585	430.0	6.85	411.1	0.17	10
135.0	2.15	129.1	9.04	529	435.0	6.93	415.9	0.16	9
140.0	2.23	133.8	8.20	480	440.0	7.01	420.6	0.15	9
145.0	2.31	138.6	7.36	431	445.0	7.09	425.4	0.15	9
150.0	2.39	143.4	6.78	397	450.0	7.17	430.2	0.13	8
155.0	2.47	148.2	6.20	363	455.0	7.25	435.0	0.12	7
160.0	2.55	153.0	5.83	341	460.0	7.33	439.8	0.12	7
165.0	2.63	157.7	5.47	320	465.0	7.41	444.5	0.11	6
170.0	2.71	162.5	5.15	302	470.0	7.49	449.3		
175.0	2.79	167.3	4.84	283	475.0	7.57	454.1		
180.0	2.87	172.1	4.57	268	480.0	7.65	458.9		
185.0	2.95	176.9	4.31	252	485.0	7.73	463.7		
190.0	3.03	181.6	4.10	240	490.0	7.81	468.5		
195.0	3.11	186.4	3.87	227	495.0	7.89	473.2		
200.0	3.19	191.2	3.68	216	500.0	7.97	478.0		
205.0	3.27	196.0	3.47	203	505.0	8.05	482.8		
210.0	3.35	200.8	3.28	192	510.0	8.13	487.6		
215.0	3.43	205.5	3.10	182	515.0	8.21	492.4		
220.0	3.51	210.3	2.93	172	520.0	8.29	497.1		
225.0	3.59	215.1	2.75	161	525.0	8.37	501.9		
230.0	3.66	219.9	2.63	154	530.0	8.44	506.7		
235.0	3.74	224.7	2.47	145	535.0	8.52	511.5		
240.0	3.82	229.4	2.33	136	540.0	8.60	516.3		
245.0	3.90	234.2	2.22	130	545.0	8.68	521.0		
250.0	3.98	239.0	2.10	123	550.0	8.76	525.8		
255.0	4.06	243.8	1.99	117	555.0	8.84	530.6		
260.0	4.14	248.6	1.88	110	560.0	8.92	535.4		
265.0	4.22	253.3	1.78	104	565.0	9.00	540.2		
270.0	4.30	258.1	1.68	98	570.0	9.08	544.9		
275.0	4.38	262.9	1.59	93	575.0	9.16	549.7		
280.0	4.46	267.7	1.50	88	580.0	9.24	554.5		
285.0	4.54	272.5	1.43	84	585.0	9.32	559.3		
290.0	4.62	277.2	1.36	80	590.0	9.40	564.1		
295.0	4.70	282.0	1.28	75	595.0	9.48	568.8		
300.0	4.78	286.8	1.21	71	600.0	9.56	573.6		

NOTES : Use for models including Basin 3 for the 10, 25, 100 and 200 year events