Amir Motamedi
FCDMC

Home of the 1996 Olympic Village
Georgia Institute of Technology

Hydrologic Engineering for Dam Design

October 26-28, 1998
Atlanta, Georgia

Distance Learning, Continuing Education, and Outreach

Georgia Institute of Technology
A Unit of the University System of Georgia

Preparing You For A World Of Change

Hydrologic Engineering for Dam Design

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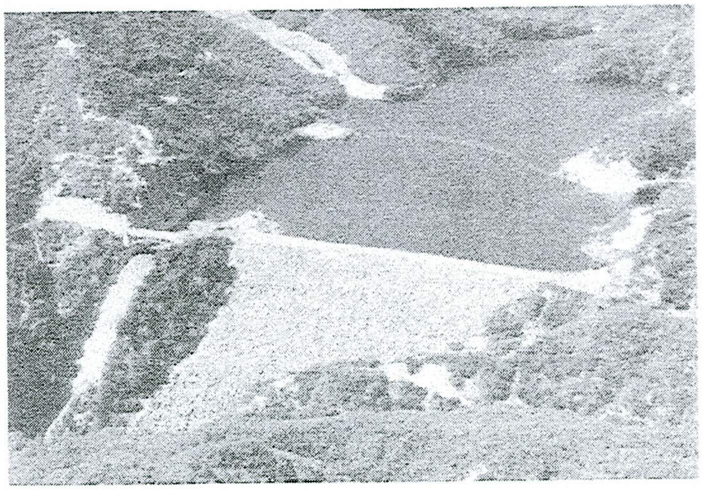
770-986-6120



The School of Civil and Environmental Engineering
and
The Water Resources Institute

Georgia Institute of Technology

Distance Learning, Continuing Education and Outreach

October 26-28, 1998
Atlanta, Georgia

Monday, October 26, 1998

Session 1 8:15 AM - 10:00 AM ***Welcome, introduction, and course overview***

- Student introductions, backgrounds, expectations
- Course overview, procedures
- Dam statistics
- Types of dams
- Failures
- Classification of reservoirs
- Reservoir purposes
- Reservoir zones
- Water quantity considerations
- Water quality considerations
- Regional hydrologic differences
- Defining the drainage basin
- Defining the reservoir

Design of
Small Canal Struct.
1974
B.O.R.

Session 2 10:30 AM - 12:00 PM ***Precipitation***

- Depth, area, duration, frequency, intensity
- Rainfall data
- Probable maximum precipitation
- Hyetograph

Session 3 1:00 PM - 2:30 PM ***Reservoir Inflow***

- Soil survey
- Infiltration/loss computation
- Hydrologic travel time
- Unit hydrograph
- Inflow hydrograph
- Routing
- Hydrologic models

Session 4 3:00 PM - 5:00 PM ***Computer Lab***

- Probable maximum precipitation

404 - 894 - 3162
404 - 894 - 3159 (Mary) ←

Tuesday, October 27, 1998

Session 5 8:15 AM - 10:00 PM ***Reservoir Outflow***

- Principal spillway
- Emergency spillway
- Tailwater
- Emptying the reservoir
- Types of spillways
- Spillway rating curves
- Defining the outflow

Session 6 10:30 AM - 12:00 ***Top of Dam Elevation Computation***

- Inflow design hydrograph
- Reservoir routing
- Elevation-area-volume
- Sedimentation
- Normal reservoir elevation
- Freeboard

Session 7 1:00 PM - 2:30 PM ***Hydrologic Modeling***

- **HEC-1**
- **HEC-HMS**

Session 8 3: 00 PM - 5:00 PM ***Computer Lab***

- ***HEC-HMS***

Wednesday October 28, 1998

Session 9 8:15 AM - 10:00 AM ***Frequency Analysis***

- Flow frequency data
- Flow frequency computation
- Regional flow frequency equations
- Coincidental frequency

Session 10 10:30 AM - 12:00 ***Water Surface Profiles***

- Hydrologic models
- Hydraulic models
- Dam break models

Session 11 1:00 PM - 2:30 PM ***Computer Lab***

- Freeboard

Session 12 3:00 PM - 5:00 PM ***Course Review and Conclusion***

Course Overview

Procedure

- Lectures
- Discussions
- Exercises
- Computer labs
- Design computations

Outline

- Precipitation
- Reservoir inflow
- Reservoir outflow
- Top of dam elevation
- Hydrologic modeling
- Frequency analysis
- Water surface profiles

Criteria

- U. S. Army Corps of Engineers
- National Weather Service
- Soil Conservation Service
- U. S. Geological Survey
- U. S. Forest Service
- Bureau of Reclamation
- Various states

Software

- HMR52
- HEC-1, HEC-HMS
- HEC-2, HEC-RAS
- Wind setup and wave run up
- FLDWAV, SMPDBK
- Spillway H-Q

World's Highest Dams

Order	Name	River	Country	Type	Height (meters)	Year Completed
1	Rogun	Vakhsh	Tadjikistan	E-R	335	UC
2	Nurek	Vakhsh	Tadjikistan	E	300	1980
3	Grande Dixence	Dixence	Switzerland	G	285	1961
4	Inguri	Inguri	Georgia	A	272	1980
5	Vajont	Vajont	Italy	A	262	1960
6	Manuel M. Torres (Chicoasen)	Grijalva	Mexico	E	261	1980
7	Tehri	Bhagirathi	India	E	261	UC
8	Alvaro Obregon (El Gallinero)	Tenasco	Mexico	G	260	1946
9	Mauvoisin	Drance de Bagnes	Switzerland	A	250	1957
10	Alberto Lleras C.	Guavio	Colombia	R	243	1989

U.S. Highest Dams

Order	Name	River	State	Type	Height (meters)	Year Completed
1	Oroville	Feather	California	E	235	1968
2	Cyprus	Bruno Creek	Idaho	E	226	1982
3	Hoover	Colorado	Nevada	A-G	223	1936
4	Dworshak	North Fork Clearwater	Idaho	G	219	1973
5	Glen Canyon	Colorado	Arizona	A-G	216	1964
6	New Bullards Bar	North Yuba	California	A	194	1969
7	New Melones	Stanislaus	California	E-R	191	1979
8	Shasta	Sacramento	California	E-R-G	183	1945
9	New Don Pedro	Tuolumne	California	R	178	1971
10	Yankee Doodle Tailings	Yankee Doodle & Silver Bow	Montana	R	174	1972

World's Largest Capacity Dams

Order	Name	River	Country	Capacity (MW)	Year Completed
1	Itaipu	Parana	Brazil/Paraguay	12600	1983
2	Guri	Caroni	Venezuela	10300	1986
3	Sayano-Shushensk	Yenisei	Russia	6400	1989
4	Grand Coulee	Columbia	U.S.A.	6180	1942
5	Krasnoyacsk	Yenisei	Russia	6000	1968
6	Church Falls	Churchill	Canada	5428	1971
7	La Grande 2	La Grande	Canada	5328	1979
8	Bratsk	Angara	Russia	4500	1961
9	Ust-Ilim	Angara	Russia	4320	1977
10	Tucurui	Tocantins	Brazil	3960	1984

U.S. Largest Capacity Dams

Order	Name	River	Location	Capacity (MW)
1	Grand Coulee	Columbia	Washington	6180
2	Chief Joseph	Columbia	Washington	2457
3	John Day	Columbia	Oregon	2160
4	Bath County P/S	Little Back Creek	Virginia	2100
5	Robert Moses - Niagara	Niagara	New York	1950
6	The Dalles	Columbia	Oregon	1805
7	Luddington	Lake Michigan	Michigan	1657
8	Raccoon Mountain	Tennessee River	Tennessee	1530
9	Hoover	Colorado	Nevada	1434
10	Pyramid	California Aqueduct	California	1250

Source: USCOLD Register of Dams

Largest U.S. Reservoirs

Order	Name	Reservoir	State	Capacity (Cubic Meters)	Year Completed
1	Hoover	Lake Mead	Nevada	34850000	1936
2	Glen Canyon	lake Powell	Arizona	33300000	1966
3	Garrison	Lake Sakakawea	North Dakota	27920000	1953
4	Oahe	Lake Oahe	South Dakota	27430000	1958
5	Fort Peck	Fort Peck Lake	Montana	22120000	1937
6	Grand Coulee	F.D.Roosevelt Lake	Washington	11790000	1942
7	Libby	Lake Koocanusa	Montana	7170000	1973
8	Fort Randall	Lake Francis Case	South Dakota	5700000	1952
9	Shasta	lake Shasta	California	5610000	1945
10	Toledo Bend	Toledo Bend Lake	Lousiana	5520000	1968

Source: USCOLD Register of Dams

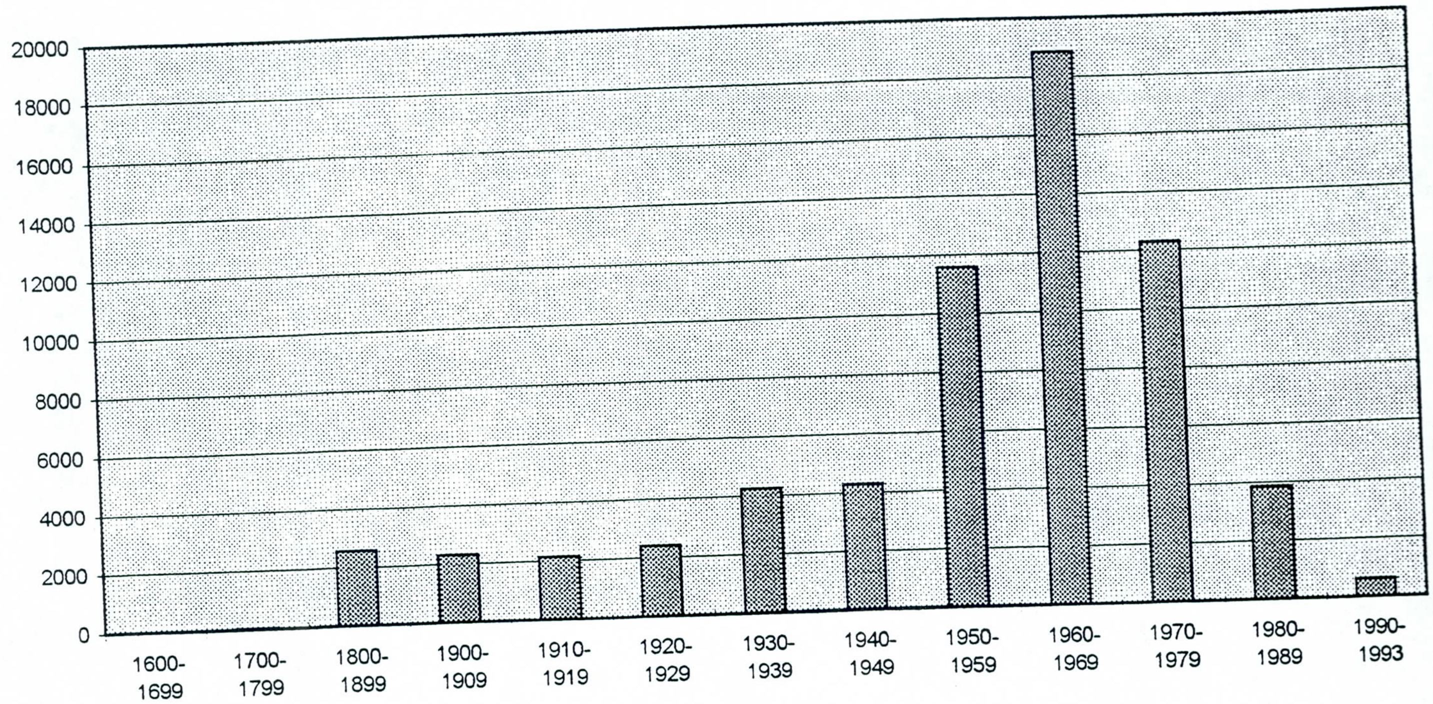
Number of Dams by State

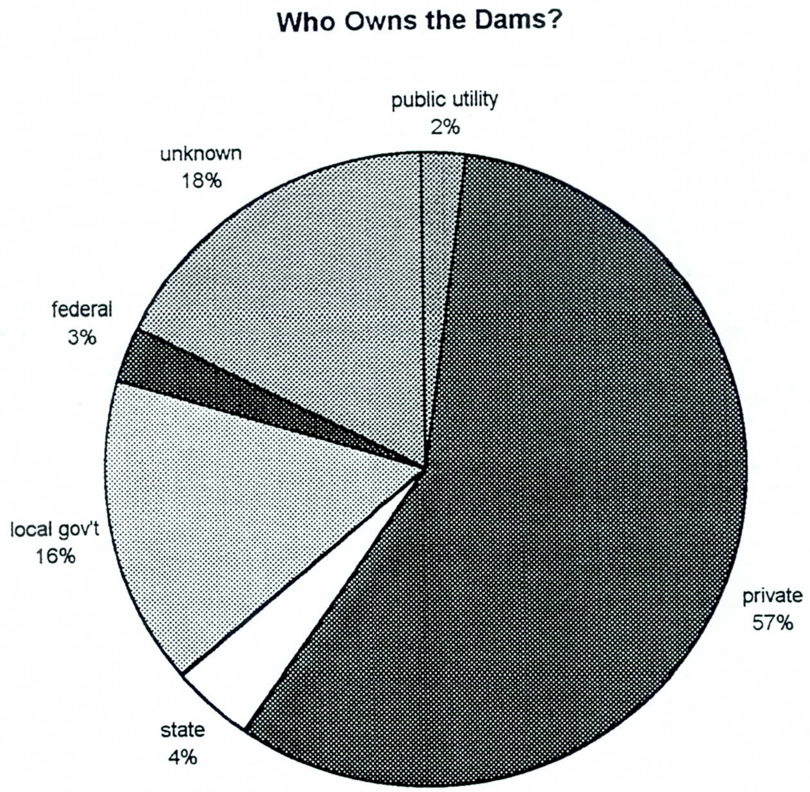
(25 ft or heigher)

Alabama	1571
Alaska	146
Arizona	430
Arkansas	1179
California	1580
Colorado	1946
Connecticut	739
Delaware	73
Florida	570
Georgia	**4331**
Guam	2
Hawaii	129
Idaho	416
Illinois	1100
Indiana	866
Iowa	2465
Kansas	5699
Kentucky	1096
Louisiana	346
Maine	601
Maryland	262
Massachusetts	1541
Michigan	902
Minnesota	774
Mississippi	3193
Missouri	3541
Montana	**3282**
Nebraska	2125
Nevada	399
New Hampshire	631
New Jersey	792
New Mexico	491
New York	1970 (over 6,000)
North Carolina	2685
North Dakota	492
Ohio	1665
Oklahoma	4532
Oregon	835
Pennsylvania	1300
Puerto Rico	40
Rhode Island	189
South Carolina	2257
South Dakota	2336
Tennessee	1009
Texas	6342
Trust Territories	2
Utah	617
Vermont	335
Virgin Islands	6
Virginia	**1518**
Washington	**709**
West Virginia	572
Wisconsin	1197
Wyoming	1765

"National Inventory of Dams"
(U.S. only)

Dams by Decade




Who Owns the Dams?
public utility
2%
unknown
18%
federal
3%
local gov't
16%
state
4%
private
57%

DAM FAILURES

causes

- overtopping
- seepage or piping through the dam
- slope embankment slides
- earthquake damage
- liquefaction
- land slide generated waves within the reservoir

recent failures

Teton Dam Flood - June 5, 1976

- 300 foot high earth dam
- 3000 feet long
- 250,000 ac-ft stored water

⇒ 11 people killed
⇒ 25,000 homeless
⇒ $400 M damages
⇒ computed outflow hydrograph peak 1,652,300 cfs - 20 times greater than the flood of record
⇒ 150 foot wide breach formed over a one hour period

Buffalo Creek Flood - February 26, 1972

- 40 foot high earth dam
- 500 ac-ft stored water

⇒ most catastrophic flood in West Virginia's history
⇒ 118 people killed
⇒ 500 homes lost
⇒ $50 M property damage
⇒ time of failure - 5 minutes
⇒ time to empty 500 ac-ft water - 15 minutes

Toccoa Dam

Lake Blackshear (Crisp County Dam) Tallassee Shoals - Tropical Storm Alberto

~~the~~

Causes of failure

large Inflow 38%

seepage/piping = 33%

foundation probl. = 23%

Other (Slope Slide/liquid, etc.) = 6%

(Federal Guidelines)

CLASSIFICATION OF DAMS AND RESERVOIRS

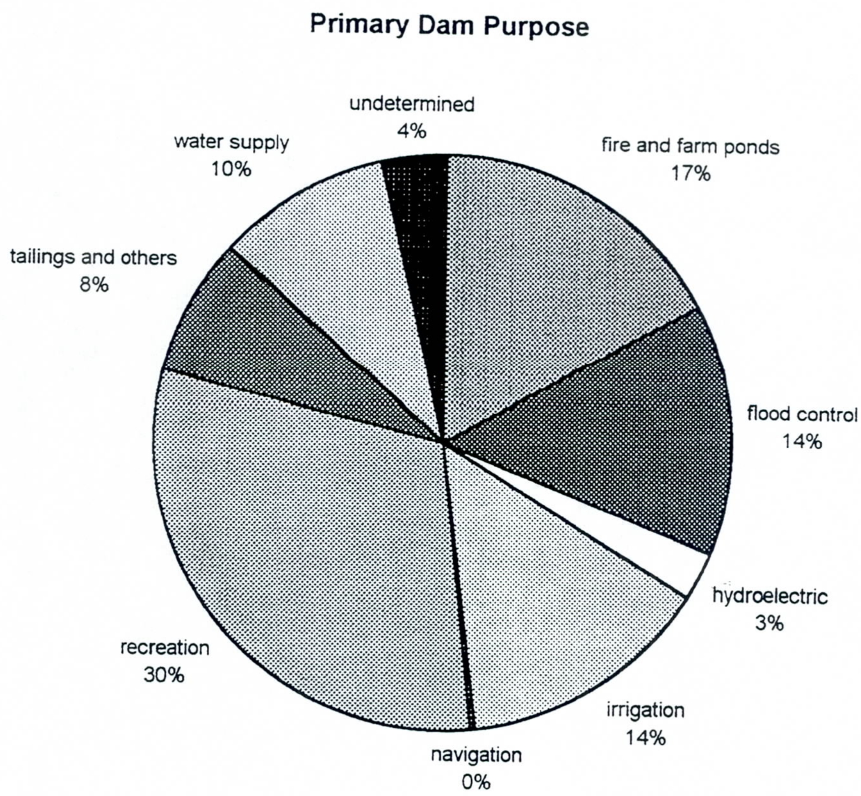
- dam height
- volume of water impounded
- character of the downstream development

size of dam	impoundment (acre-feet)	height of dam in feet
small	50 to 1000	less than 40
intermediate	1000 to 50,000	40 to 100
large	over 50,000	over 100

Hazard Potential Classification

category	loss of life	economic loss
low	none expected	minimal
significant	few	appreciable
high	more than a few	excessive

(P.A.R.) @ Population Risk


Primary Dam Purpose
undetermined
4%
fire and farm ponds
17%
water supply
10%
tailings and others
8%
flood control
14%
hydroelectric
3%
recreation
30%
irrigation
14%
navigation
0%

HYDROLOGIC CYCLE

interception - vegetation

depression storage

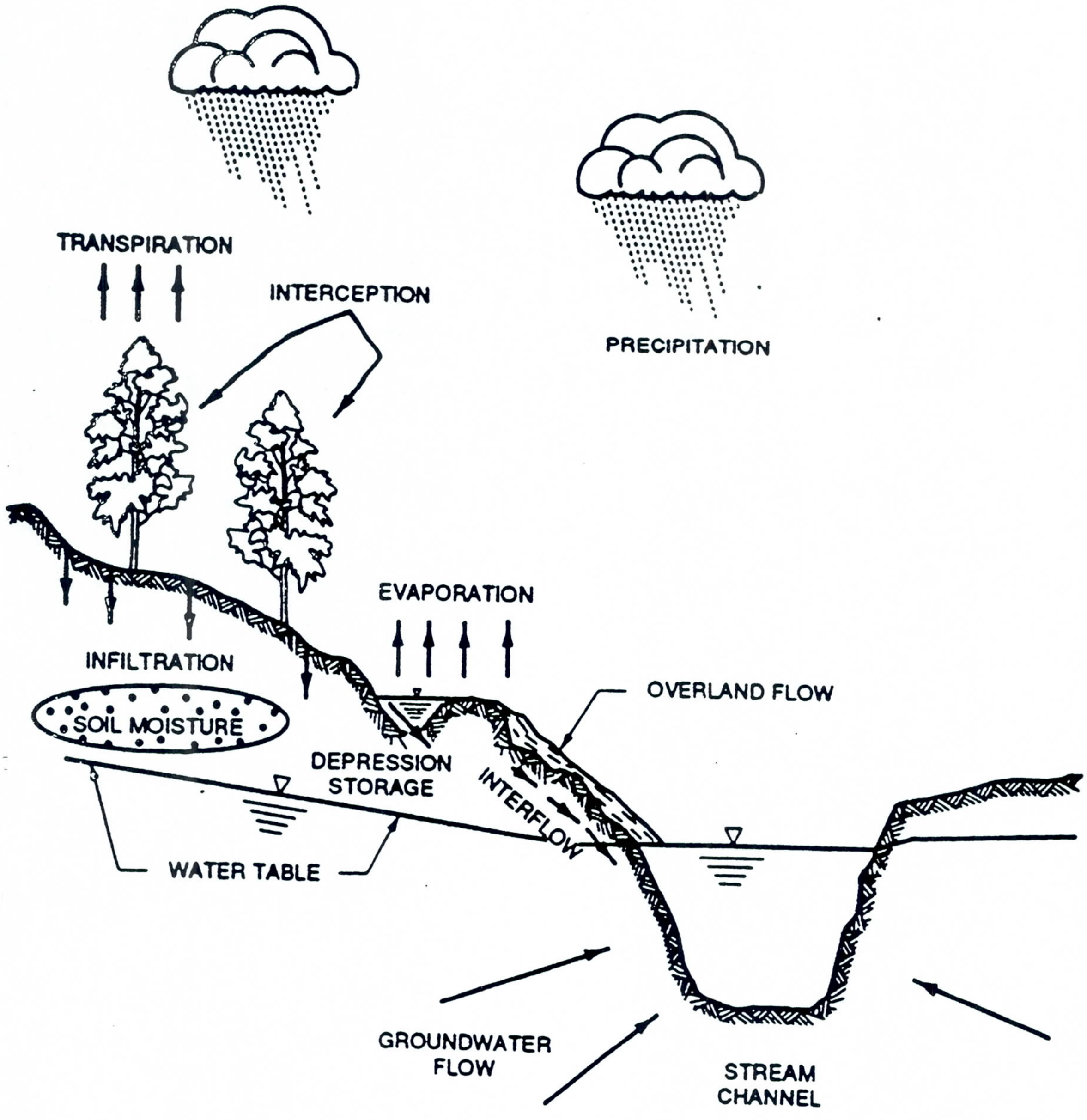
soil moisture

basin recharge - precipitation which does not contribute to steamflow or groundwater

rainfall can reach a stream by *direct runoff*-
traveling overland - surface runoff
interflow- traveling underground
or as groundwater

effluent streams - stream channels which are below the groundwater table

influent streams or intermittent streams - go dry from time to time; channels are above groundwater


TRANSPIRATION
INTERCEPTION
PRECIPITATION
EVAPORATION
INFILTRATION
SOIL MOISTURE
OVERLAND FLOW
DEPRESSION
STORAGE
INTERFLOW
WATER TABLE
GROUNDWATER
FLOW
STREAM
CHANNEL

among the heaviest rainfalls ever recorded:

- 1.23 inches in 1 minute in Unionville, Maryland
- 12 inches in 42 minutes in Holt, Missouri
- 19 inches in 70 minutes in Rockport, West Virginia

regional differences

precipitation average annual : Georgia 50 inches
Montana 15 inches
national average 30 inches per year

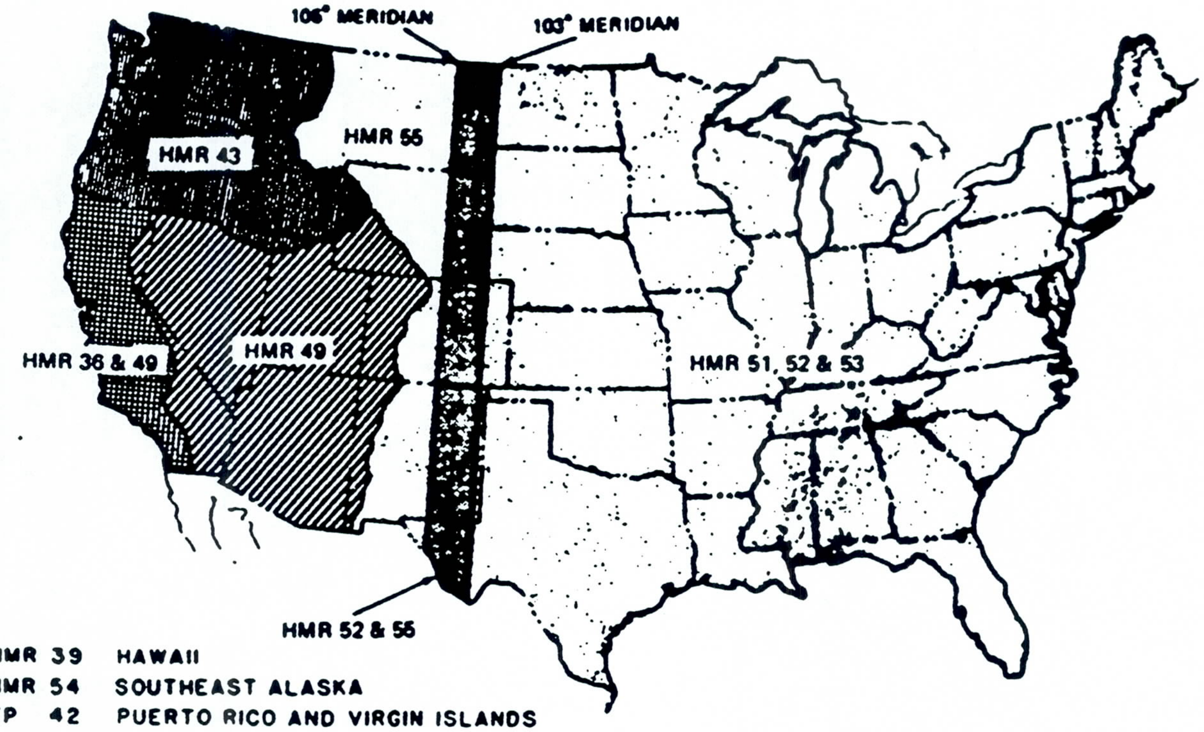
snowfall: Atlanta, 2 inches per year
Great falls, MT 60 inches per year

evaporation:
from open water surfaces-
Atlanta 42 inches per year
Great Falls 36 inches per year

potential evapotranspiration:
Atlanta 24-36 inches per year
Great Falls less than 24 inches per year

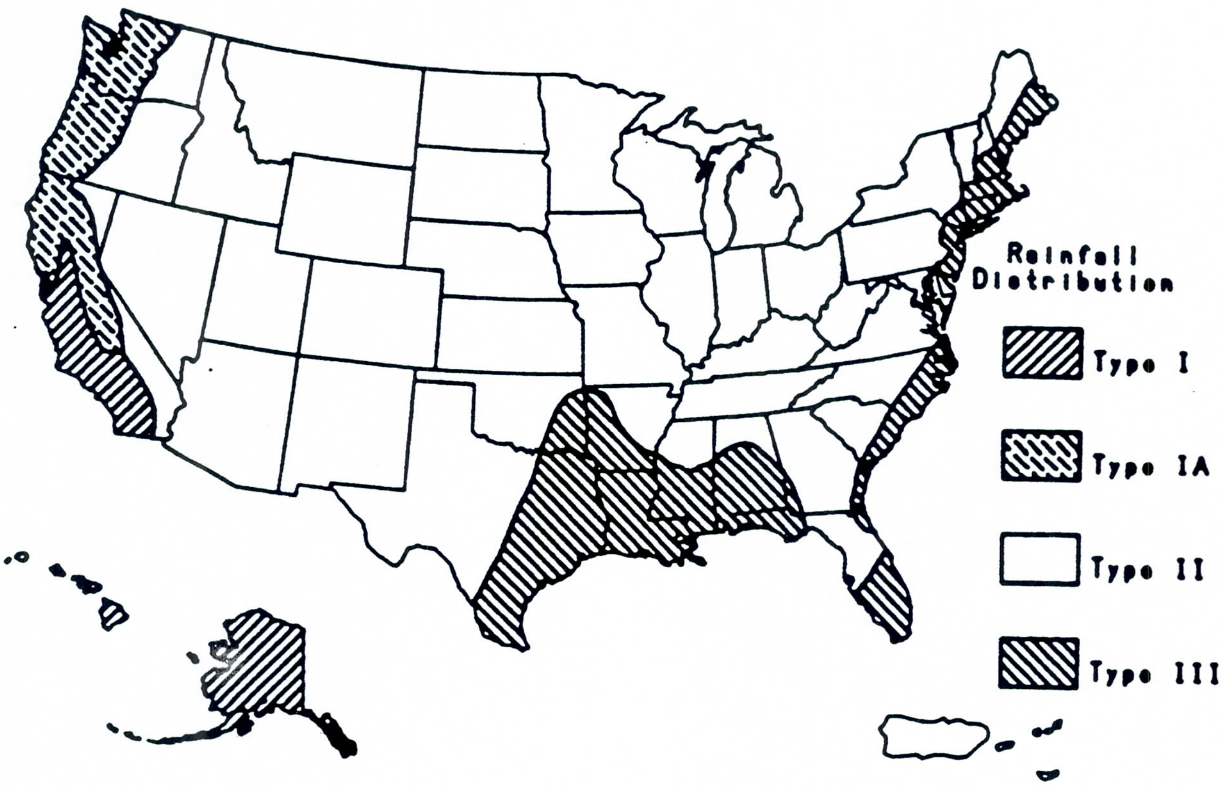
surface water runoff: Atlanta 17.5 inches per year
Great Falls 1 inch per year

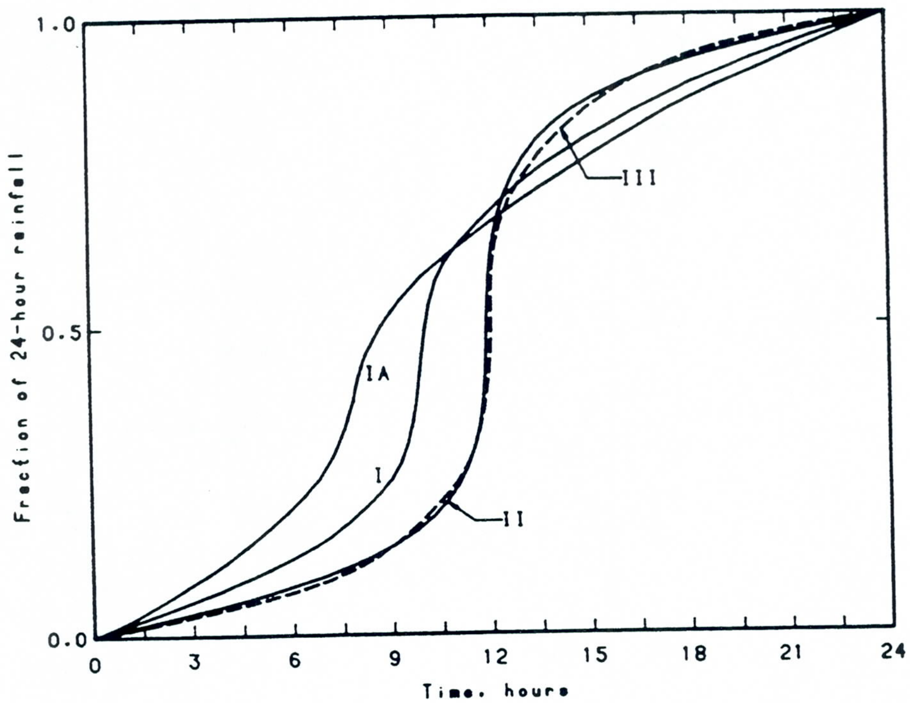
REGIONS COVERED BY GENERALIZED PMP STUDIES



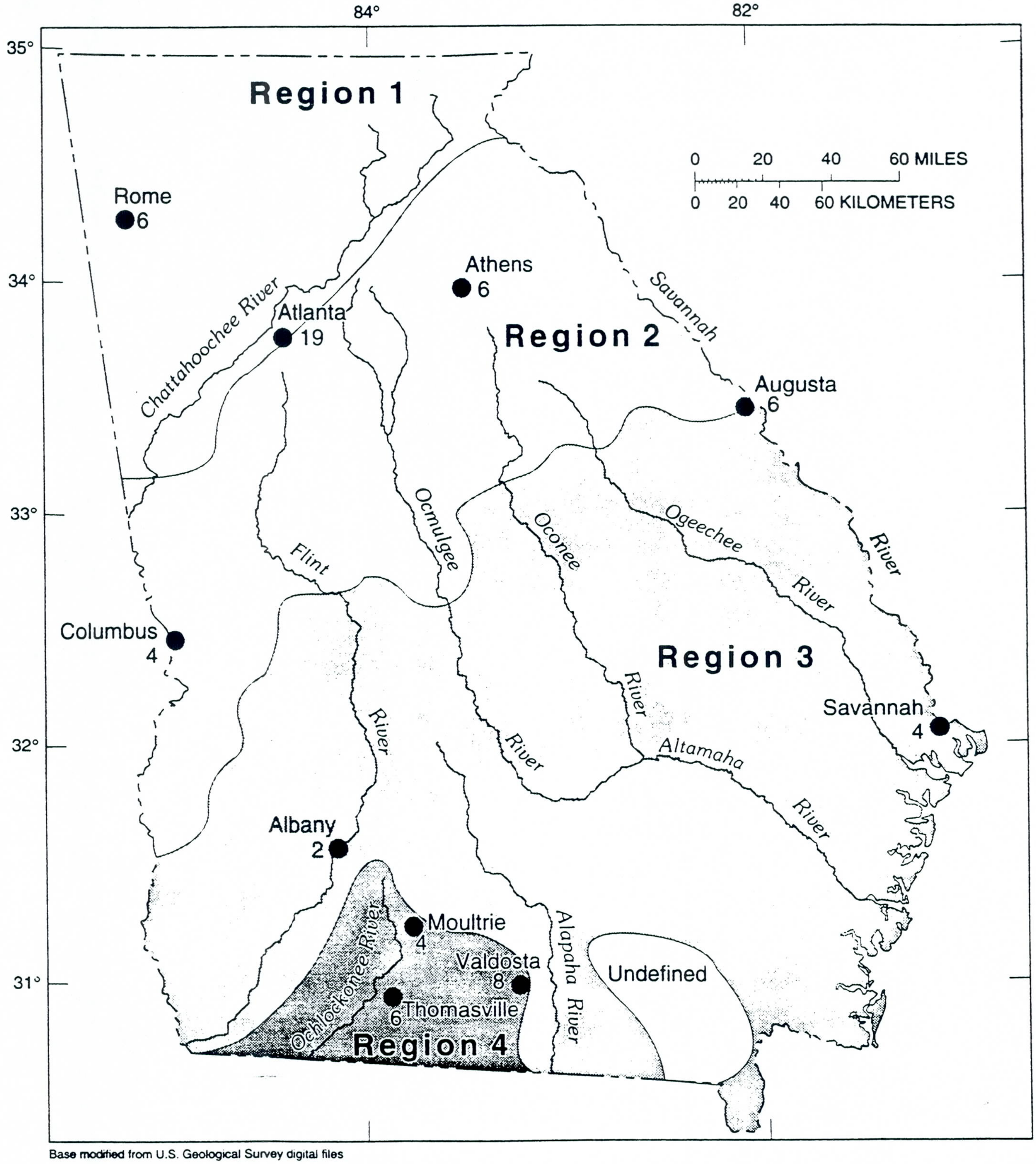
HMR 39 HAWAII
HMR 54 SOUTHEAST ALASKA
TP 42 PUERTO RICO AND VIRGIN ISLANDS
TP 47 ALASKA

APPROXIMATE GEOGRAPHIC BOUNDARIES FOR SCS RAINFALL DISTRIBUTIONS





SCS 24-hour rainfall distributions.


84°
82°
35°
34°
33°
32°
31°
Region 1
Region 2
Region 3
Region 4
0 20 40 60 MILES
0 20 40 60 KILOMETERS
Rome 6
Athens 6
Atlanta 19
Augusta 6
Columbus 4
Savannah 4
Albany 2
Moultrie 4
Valdosta 8
Thomasville 6
Chattahoochee River
Savannah River
Ocmulgee River
Flint River
Oconee River
Ogeechee River
Altamaha River
Ochlockonee River
Alapaha River
Undefined
Base modified from U.S. Geological Survey digital files

Regional flood-frequency relations for rural streams in Georgia

Flood discharge, Q_T, for T-year recurrence interval	Flood-frequency relations for indicated regions (fig. 1) in the form $Q_T=aA^b$, where A is the drainage area, in square miles, and a and b are as presented below			
	1	2	3	4
RQ_2	$207A^{0.654}$	$182A^{0.622}$	$76A^{0.620}$	$142A^{0.591}$
RQ_5	$357A^{0.632}$	$311A^{0.616}$	$133A^{0.620}$	$288A^{0.589}$
RQ_{10}	$482A^{0.619}$	$411A^{0.613}$	$176A^{0.621}$	$410A^{0.591}$
RQ_{25}	$666A^{0.605}$	$552A^{0.610}$	$237A^{0.623}$	$591A^{0.595}$
RQ_{50}	$827A^{0.595}$	$669A^{0.607}$	$287A^{0.625}$	$748A^{0.599}$
RQ_{100}	$1{,}010A^{0.584}$	$794A^{0.605}$	$340A^{0.627}$	$926A^{0.602}$
RQ_{200}	$1.220A^{0.575}$	$931A^{0.603}$	$396A^{0.629}$	$1{,}120^{0.606}$
RQ_{500}	$1{,}530A^{0.563}$	$1{,}130A^{0.601}$	$474A^{0.632}$	$1{,}420^{0.611}$

ional Flood-Frequency Equations for California

NORTH COAST REGION[1]

$Q_2 = 3.52\,A^{.90}\,p^{.89}\,H^{-.47}$ (1)
$Q_5 = 5.04\,A^{.89}\,p^{.91}\,H^{-.35}$ (2)
$Q_{10} = 6.21\,A^{.88}\,p^{.93}\,H^{-.27}$ (3)
$Q_{25} = 7.64\,A^{.87}\,p^{.94}\,H^{-.17}$ (4)
$Q_{50} = 8.57\,A^{.87}\,p^{.96}\,H^{-.08}$ (5)
$Q_{100} = 9.23\,A^{.87}\,p^{.97}$ (6)

NORTH EAST REGION[2]

$Q_2 = 22\,A^{.40}$ (7)
$Q_5 = 46\,A^{.45}$ (8)
$Q_{10} = 61\,A^{.49}$ (9)
$Q_{25} = 84\,A^{.54}$ (10)
$Q_{50} = 103\,A^{.57}$ (11)
$Q_{100} = 125\,A^{.59}$ (12)

SIERRA REGION

$Q_2 = 0.24\,A^{.88}\,p^{1.58}\,H^{-.80}$ (13)
$Q_5 = 1.20\,A^{.82}\,p^{1.37}\,H^{-.64}$ (14)
$Q_{10} = 2.63\,A^{.80}\,p^{1.25}\,H^{-.58}$ (15)
$Q_{25} = 6.55\,A^{.79}\,p^{1.12}\,H^{-.52}$ (16)
$Q_{50} = 10.4\,A^{.78}\,p^{1.06}\,H^{-.48}$ (17)
$Q_{100} = 15.7\,A^{.77}\,p^{1.02}\,H^{-.43}$ (18)

CENTRAL COAST REGION

$Q_2 = 0.0061\,A^{.92}\,p^{2.54}\,H^{-1.10}$ (19)
$Q_5 = 0.118\,A^{.91}\,p^{1.95}\,H^{-.79}$ (20)
$Q_{10} = 0.583\,A^{.90}\,p^{1.61}\,H^{-.64}$ (21)
$Q_{25} = 2.91\,A^{.89}\,p^{1.26}\,H^{-.50}$ (22)
$Q_{50} = 8.20\,A^{.89}\,p^{1.03}\,H^{-.41}$ (23)
$Q_{100} = 19.7\,A^{.88}\,p^{0.84}\,H^{-.33}$ (24)

SOUTH COAST REGION
REGION[2]

$Q_2 = 0.41\,A^{.72}\,p^{1.62}$ (25)
$Q_5 = 0.40\,A^{.77}\,p^{1.69}$ (26)
$Q_{10} = 0.63\,A^{.79}\,p^{1.75}$ (27)
$Q_{25} = 1.10\,A^{.81}\,p^{1.81}$ (28)
$Q_{50} = 1.50\,A^{.82}\,p^{1.85}$ (29)
$Q_{100} = 1.95\,A^{.83}\,p^{1.87}$ (30)

SOUTH - COLORADO DESERT

$Q_2 = 7.3\,A^{.30}$ (31)
$Q_5 = 53\,A^{.44}$ (32)
$Q_{10} = 150\,A^{.53}$ (33)
$Q_{25} = 410\,A^{.63}$ (34)
$Q_{50} = 700\,A^{.68}$ (35)
$Q_{100} = 1080\,A^{.71}$ (36)

where:

Q = Peak discharge, in cubic feet per second

A = Drainage area, in square miles

P = Mean annual precipitation, in inches

H = Altitude index, in thousands of feet

Notes:
1 In the north coast region, use a minimum value of 1.0 for altitude index (H).
2 These equations are defined only for basins of 25 square miles or less.

Precipitation

depth - inches as measured in a raingage

area - square miles of land surface receiving rainfall

duration - lenght of rainfall in hours

intensity - inches per hour

frequency - return period of a rainfall intensity in years

point rainfall - rainfall measured at a rain gage

water year

hydroperiod

Safety of Dams, Flood & Earth Quake Criteria
George W. Housner, Caltech
1985
(web) → Nat. Academy Press
2101 Constitution Ave, N.W.
Washington, D.C. 20418

Safety of Existing Dams, Evaluation & Impr.
S.A.A. 1983

PMP definition:

1. Physically possible
2. given duration
3. given size area
4. particular location

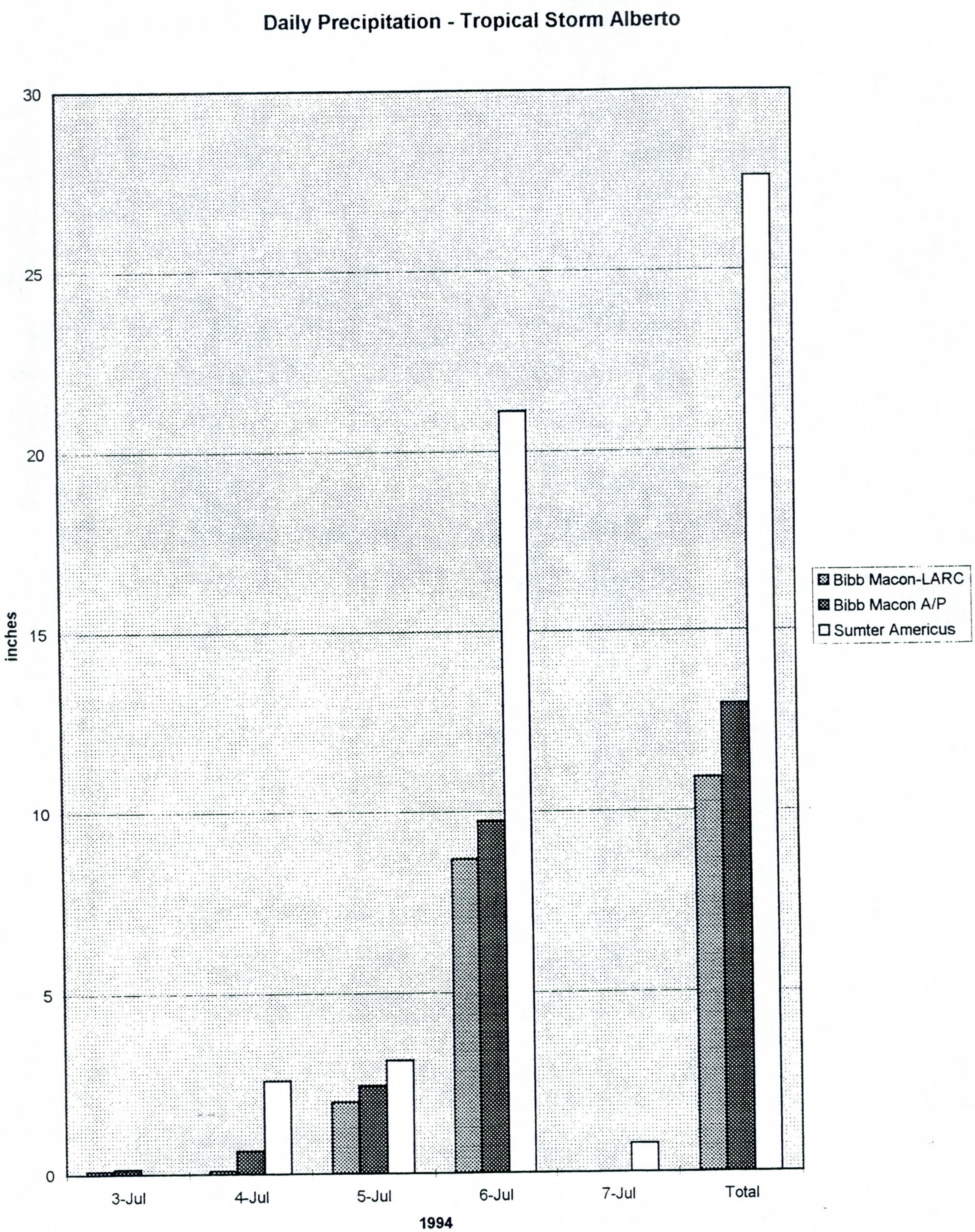
Major Recorded Storms

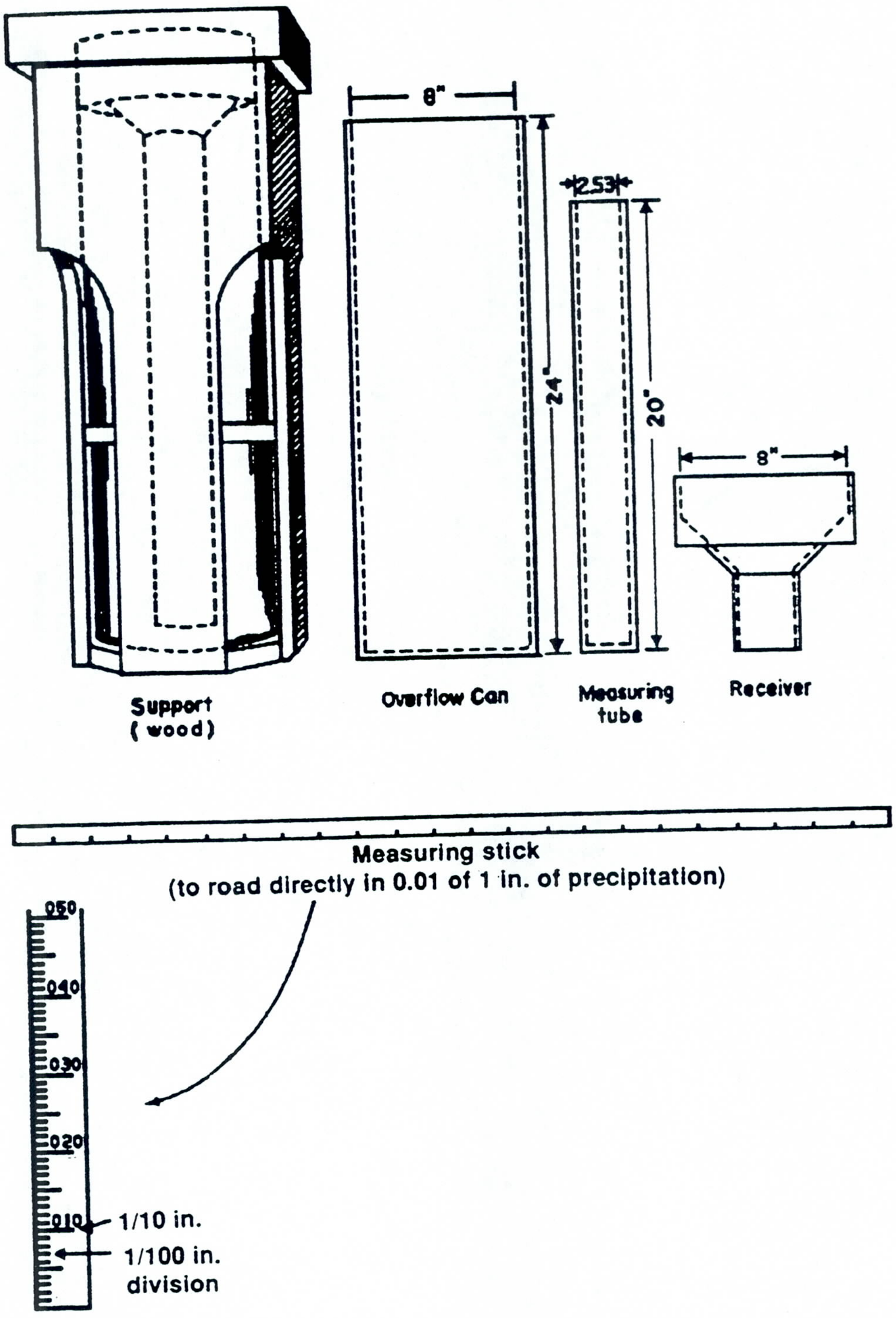
storm center location	date	total storm duration (hours)	total storm area size (square miles)
Jefferson, Ohio	9/10-13/**1878**	84	90,000
Wellsboro, PA	5/30-6/1/**1889**	60	82,000
Greeley, NE	6/4-7/**1896**	78	84,000
Lambert, MN	7/18-22/**1897**	102	80,000
Jewell, MO	7/26-29/**1897**	96	32,000
Hearne, TX	6/27-7/1/**1899**	108	78,000
Eutaw, AL	4/15-18/**1900**	84	75,000
Paterson, NJ	10/7-11/**1903**	96	35,000
Medford, WI	6/3-8/**1905**	120	67,000
Bonaparte, IA	6/9-10/**1905**	12	20,000
Warrick, MT	6/6-8/**1906**	54	40,000
Knickerbocker, TX	8/4-6/**1906**	48	24,600
Meeker, OK	10/19-24/**1908**	126	80,000
Beaulieu, MN	7/18-23/**1909**	108	5,000
Merryville, LA	3/24-28/**1914**	96	125,000
Cooper, MI	8/31-9/1/**1914**	6	1200
Altapass, NC	7/15-17/**1916**	108	37,000
Meek, NM	9/15-17/**1919**	54	75,000
Springbrook, MN	6/17-21/**1921**	108	52,600
Thrall, TX	9/8-10/**1921**	48	12,500
Savageton, WY	9/27-10/1/**1923**	108	95,000
Boyden, LA	9/17-19/**1926**	54	63,000
Kinsman Notch, NH	11/2-4/**1927**	60	60,000
Elba, AL	3/11-16/**1929**	114	100,000
St. Fish Hatchery, TX	6/30-7/2/**1932**	42	30,000
Scituate, RI	9/16-17/**1932**	48	10,000
Ripogenus Dam, ME	9/16-17/**1932**	30	10,000
Cheyenne, OK	4/3-4/**1934**	18	2,200
Simmesport, LA	5/16-20/**1935**	102	75,000
Hale, CO	5/30-31/**1935**	24	6,300
Woodward Ranch, TX	5/31/35	10	7,000
Hector, NY	7/6-10/**1935**	90	38,500
Snyder, TX	6/19-20/**1939**	6	2,000
Grant Township, NE	6/3-4/**1940**	20	20,000
Ewan, NJ	9/1/40	12	2,000
Hallett, OK	9/2-6/**1940**	90	20,000
Hayward, WI	8/28-31/**1941**	78	60,000
Smethport, PA	7/17-18/**1942**	24	4,300
Big Meadows, VA	10/11-17/**1942**	156	25,000

Major Recorded Storms

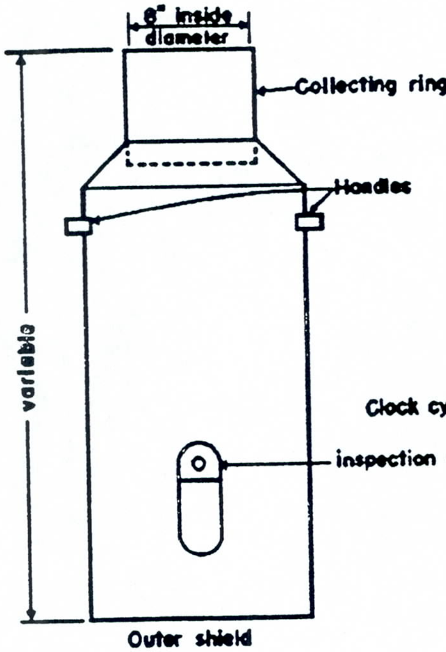
continued

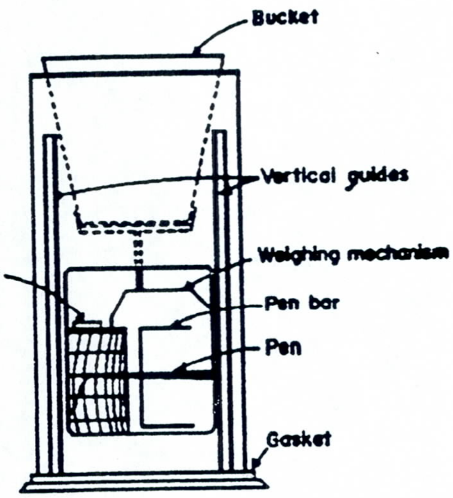
storm center location	date	total storm duration	total storm area size
		hours	square miles
Warner, OK	5/6-12/**1943**	144	212,000
Stanton, NE	6/10-13/**1944**	78	16,000
Collinsville, IL	8/12-16/**1946**	114	20,400
Del Rio, TX	6/23-24/**1948**	24	10,000
Yankeetown, FL	9/3-7/**1950**	96	43,500
Council Grove, KS	7/9-13/**1951**	108	57,000
Ritter, IA	6/7/53	20	10,000
Vic Pierce, TX	6/23-28/**1954**	120	27,900
Boltan, Ontario, Canada	10/14-15/**1954**	78	20,000
Westfield, MA	8/17-20/**1955**	72	35,000
St. Pierre Baptiste, Que	8/3-4/**1957**	18	7,000
Sombreretillo, Mexico	9/19-24/**1967**	126	60,000
Tyro, VA	8/19-20/**1969**	48	15,000
Zerbe, PA	6/19-3/**1972**	96	130,000
		72.2	**45,094**
		average duration	***average areal extent***

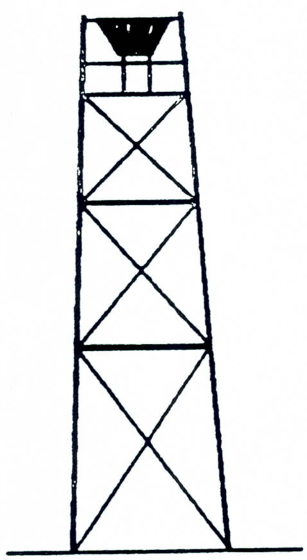

Daily Precipitation - Tropical Storm Alberto
30
25
20
15
10
5
0
inches
3-Jul
4-Jul
5-Jul
6-Jul
7-Jul
Total
1994
Bibb Macon-LARC
Bibb Macon A/P
Sumter Americus



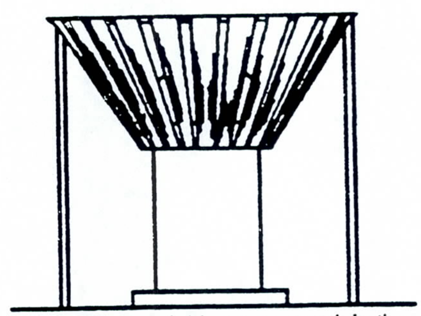
Nonrecording gauge, 8-in. opening (U.S. Weather Bureau standard rain gauge)





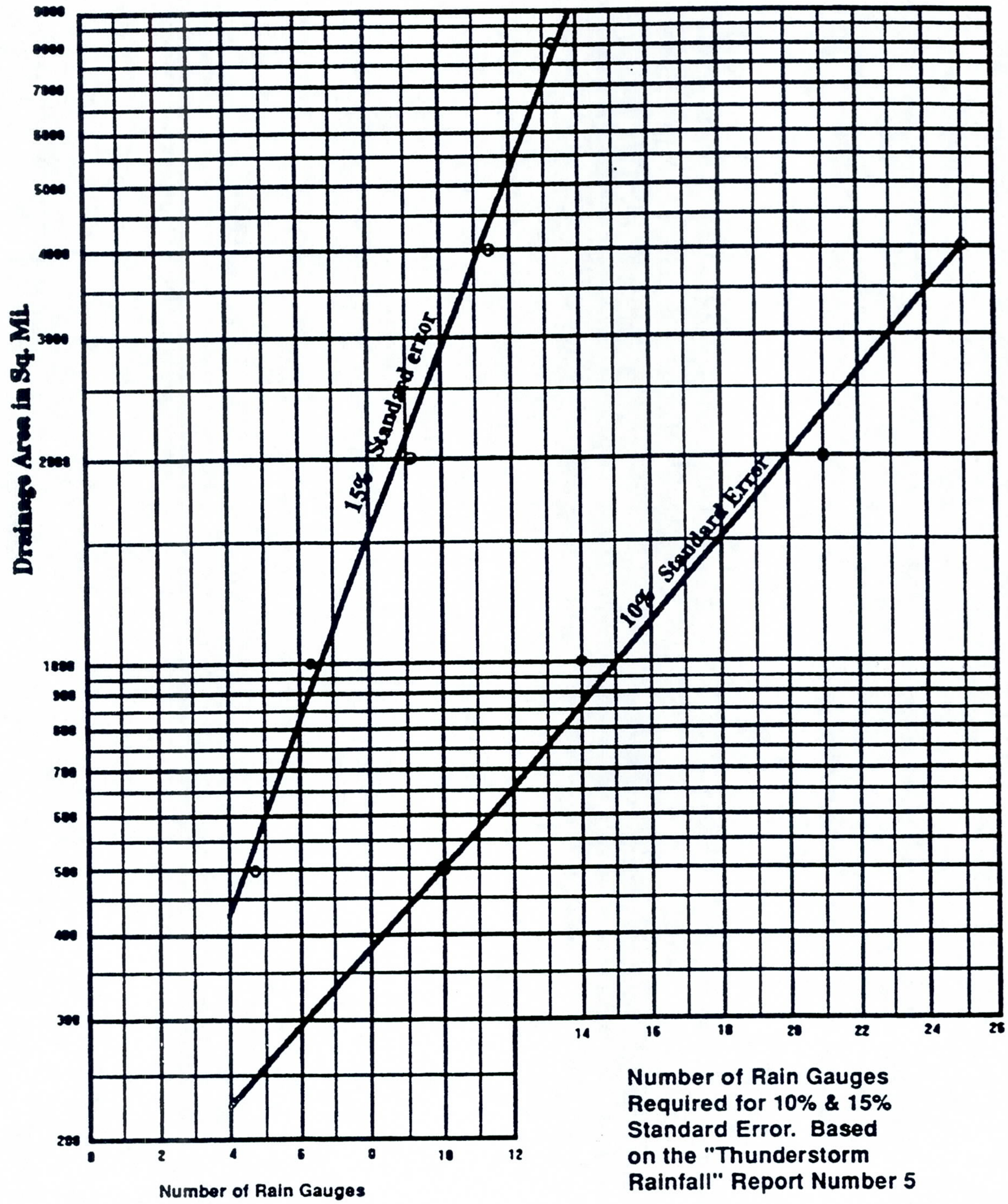


Gauge mounted on snow tower.

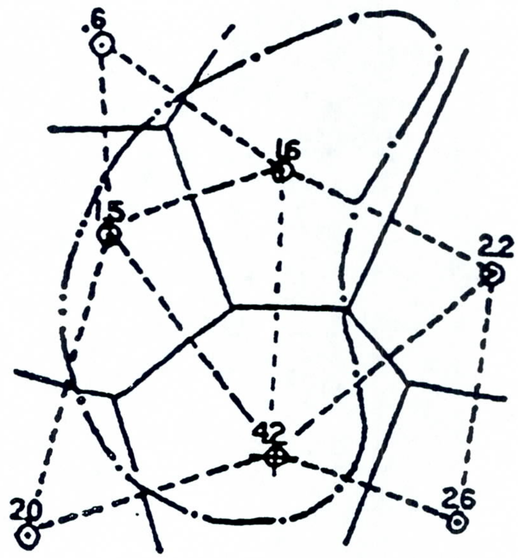


Recording, weighing type precipitation gauge showing ALTER windshield installed.

Weighing type recording rain gauge (from U.S. Weather Bureau source)

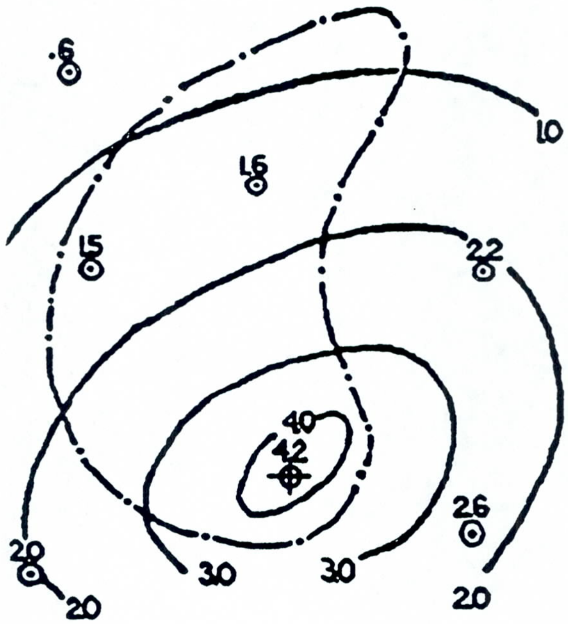


Number of rain gauges required for 10 and 15 percent error (U.S. Department of Commerce 1947)



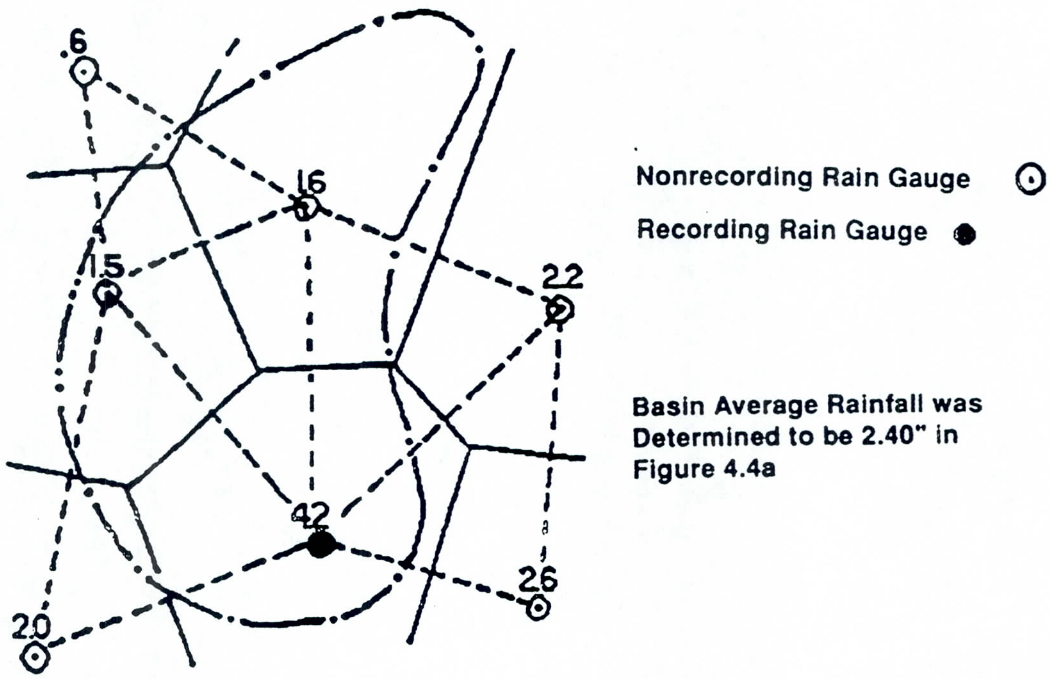
Observed Rainfall (inches)	Polygon (units)	Area (%)	Weighted Rainfall (inches)
.6	2	1	.0
1.5	77	24	.4
1.6	132	40	.6
2.0	4	1	.0
4.2	112	34	1.4
	327	100	2.4

a. THIESSEN POLYGON METHOD



Isohyet Zones	Enclosed (units)	Area (%)	Average Zone Rainfall (inches)	Weighted Rainfall (inches)
>4.0	19	6	4.2	.2
3.0-4.0	60	18	3.5	.6
2.0-3.0	87	27	2.5	.7
1.0-2.0	139	42	1.5	.6
<1.0	22	7	.9	.1
	327	100		2.2

b. ISOHYETAL METHOD



Time (hrs)	Recorded Rainfall (inches)	Incremental Rainfall (%)	Time Distribution of Basin Average Rainfall (2.4")*
0700	0.0	0	.0
0800	0.4	10	0.2
0900	1.0	24	0.6
1000	0.8	19	0.5
1100	1.4	33	0.8
1200	0.6	14	0.3
TOTALS	4.2	100	2.4

* Developed by multiplying the percent of rainfall (divided by 100) occurring at each time period at the recording gauge by the basin average rainfall (i.e., 2.4 in.).

Time distribution of basin average rainfall

PRECIPITATION MEASUREMENTS

rain gage - 8-inch diameter opening
affected by wind, exposure, and height of gage
standard height - 31 inches

one gage for every 250 to 300 square miles

areal coverage -

- gage network
- weather radar
- Doppler
- NEXRAD
- satellite -GOES

areal distribution of rainfall data
Thiessen method
isohyetal method (tropical storm Alberto)

temporal distribution

PUBLISHED RAINFALL DATA

☐ "*Rainfall Frequency Atlas of the United States*," National Weather Service, **Technical Paper No. 40**; 115p, 1961. This reference is to be used for States east of the Rockies, except for durations of 60 minutes or less.

☐ "*Five to 60-Minute Precipitation Frequency for the Eastern and Central United States*," **NOAA Technical Memorandum NWS HYDRO-35**, 36p, 1977.

☐ "*Generalized Estimates of Probable Maximum Precipitation and Rainfall-Frequency Data for Puerto Rico and Virgin Islands*," National Weather Service, **Technical Paper No. 42**, 94p, 1961.

☐ "*Rainfall-Frequency Atlas of the Hawaiian Islands*," National Weather Service, **Technical Paper No. 43**, 60p, 1962.

☐ "*Probable Maximum Precipitation and Rainfall-Frequency Data for Alaska*," National Weather Service, **Technical Paper No. 47**, 69p, 1963.

☐ National Oceanic and Atmospheric Administration Atlas 2. *Precipitation Atlas of the Western United States*, 1973:

Vol. I, **Montana**
Vol. II, **Wyoming**
Vol. III, **Colorado**
Vol. IV, **New Mexico**
Vol. V, **Idaho**
Vol. VI, **Utah**
Vol. VII, **Nevada**
Vol. VIII, **Arizona**
Vol. IX, **Washington**
Vol. X, **Oregon**
Vol. XI, **California**

☐ *Two- to Ten-Day Precipitation for Return Periods of 2 to 100 years in the Contiguous United States*, National Weather Service, **Technical Paper No. 49**, 29p, 1964. Includes the 48 contiguous states. (Use SCS West National Technical Center Technical Note-Hydrology-PO-6, Revised 1973, for States covered by NOAA Atlas 2).

☐ *Two- to Ten-Day Rainfall for Return Periods of 2 to 100 years in the Hawaiian Islands*, National Weather Service, **Technical Paper No. 51**, 34p, 1965.

☐ *Two- to Ten-Day Rainfall for Return Periods of 2 to 100 years in Alaska*, National Weather Service, **Technical Paper No. 52**, 30p, 1965.

☐ *Two- to Ten-Day Rainfall for Return Periods of 2 to 100 years in Puerto Rico and the Virgin Islands*, National Weather Service , **Technical Paper no. 53**, 35p, 1965.

☐ *Probable Maximum Precipitation in California, Interim Report*, National Weather Service, **Hydrometeorological Report No. 36**, 202p, 196l.

☐ *Probable Maximum Precipitation in the Hawaiian Islands*, National Weather Service, **Hydrometeorological Report No. 39**, 98p, 1963.

☐ *Probable Maximum Precipitation, Northwest States*, **United States Weather Bureau Hydrometeorological Report No. 43**, 228p, 1966.

☐ *Probable Maximum Precipitation Estimates, Colorado River and Great Basin Drainages*, **NOAA Hydrometeorological Report No. 49**, 161p, 1977.

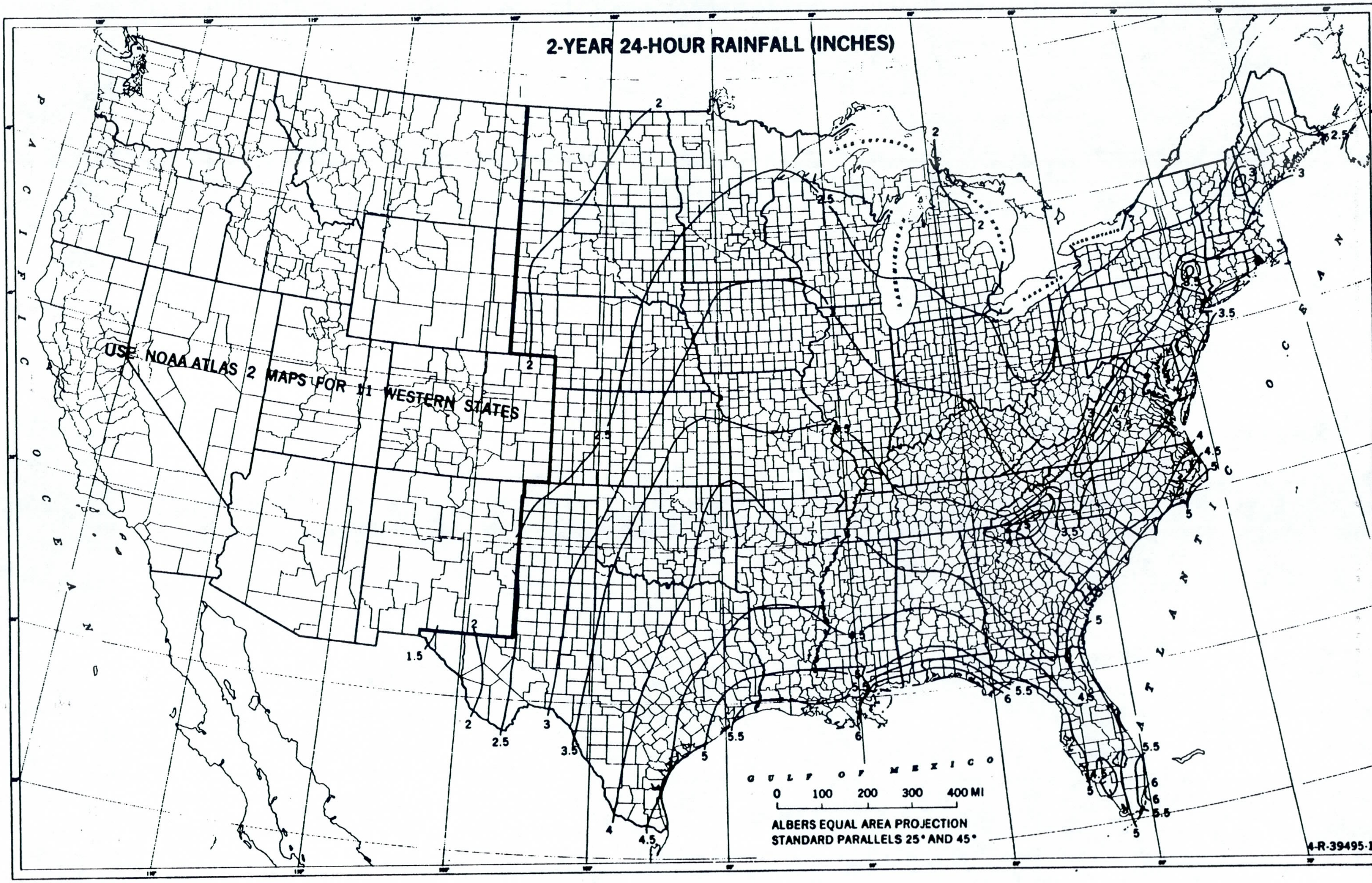
☐ *Probable Maximum Precipitation Estimates, United States East of the 105th Meridian*,
NOAA Hydrometeorology Report No. 51, 87p, 1978.

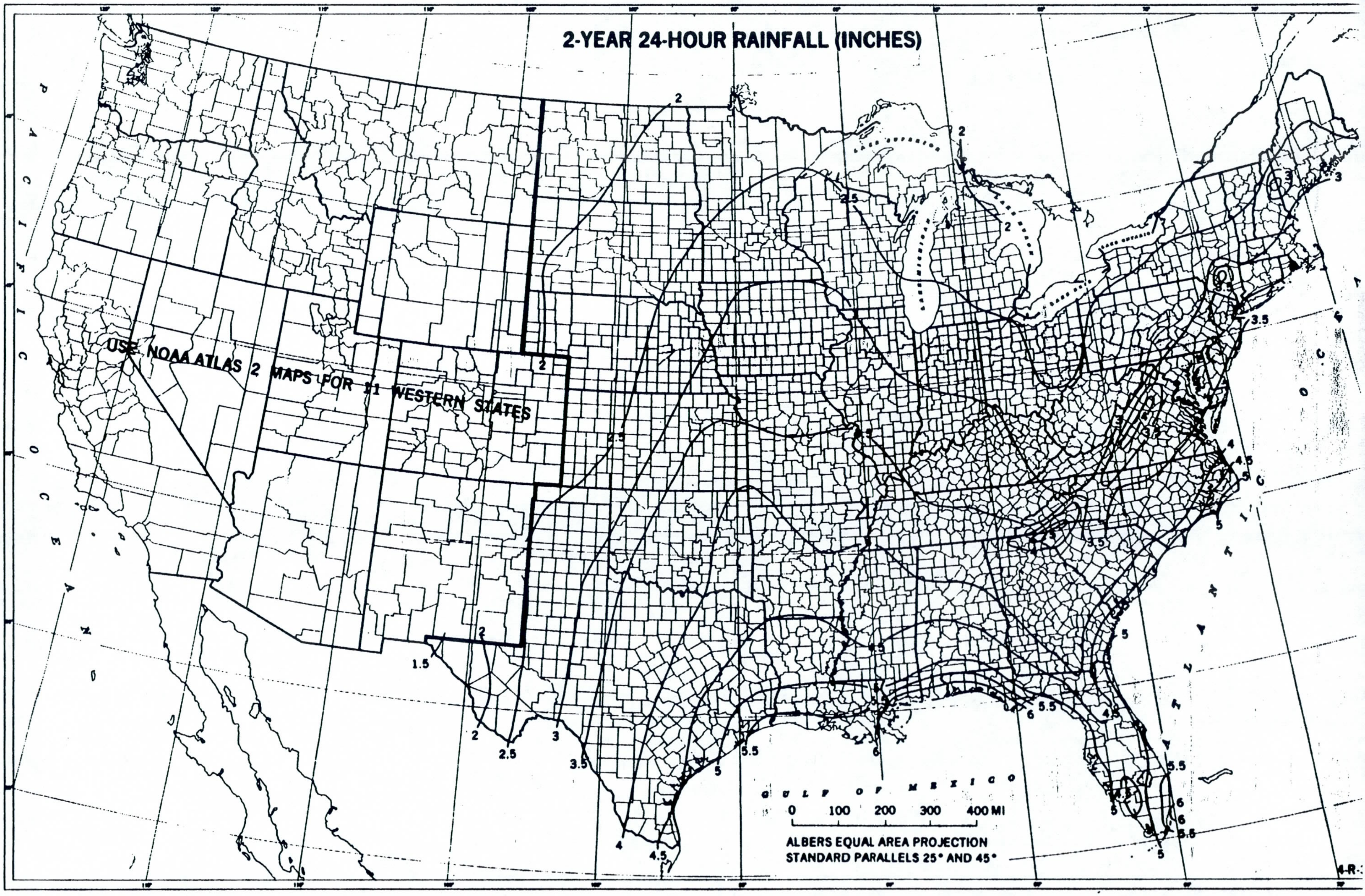
☐ *Application of Probable Maximum Precipita-tion Estimates - United States East of the 105th Meridian,* **NOAA Hydrometeorology Report No. 52**, 168p, 1982.

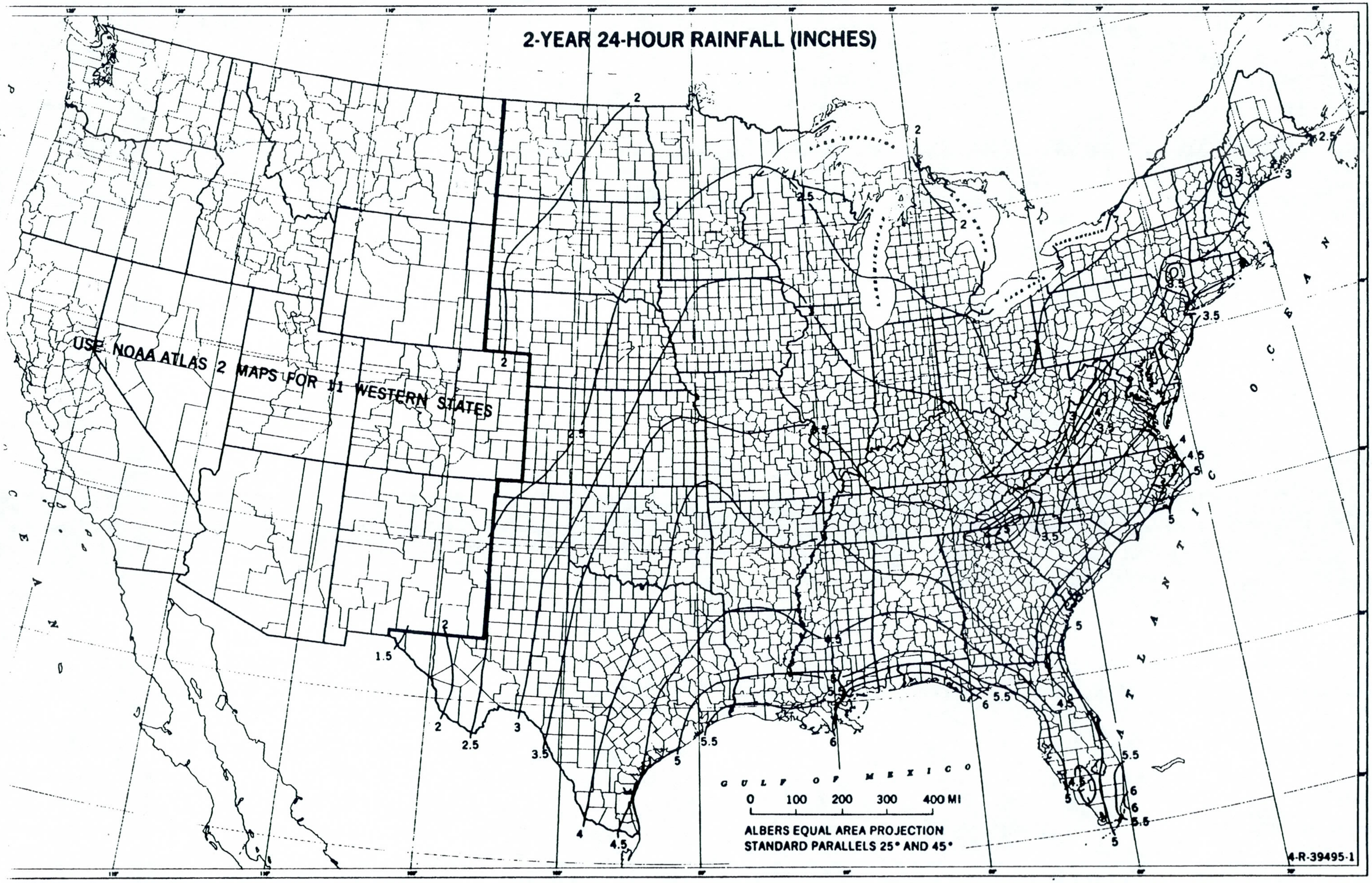
☐ *Probable Maximum Precipitation and Snowmelt Criteria for Southeast Alaska*, **NOAA Hydrometeorological Report No. 54**, 115p, 1983.

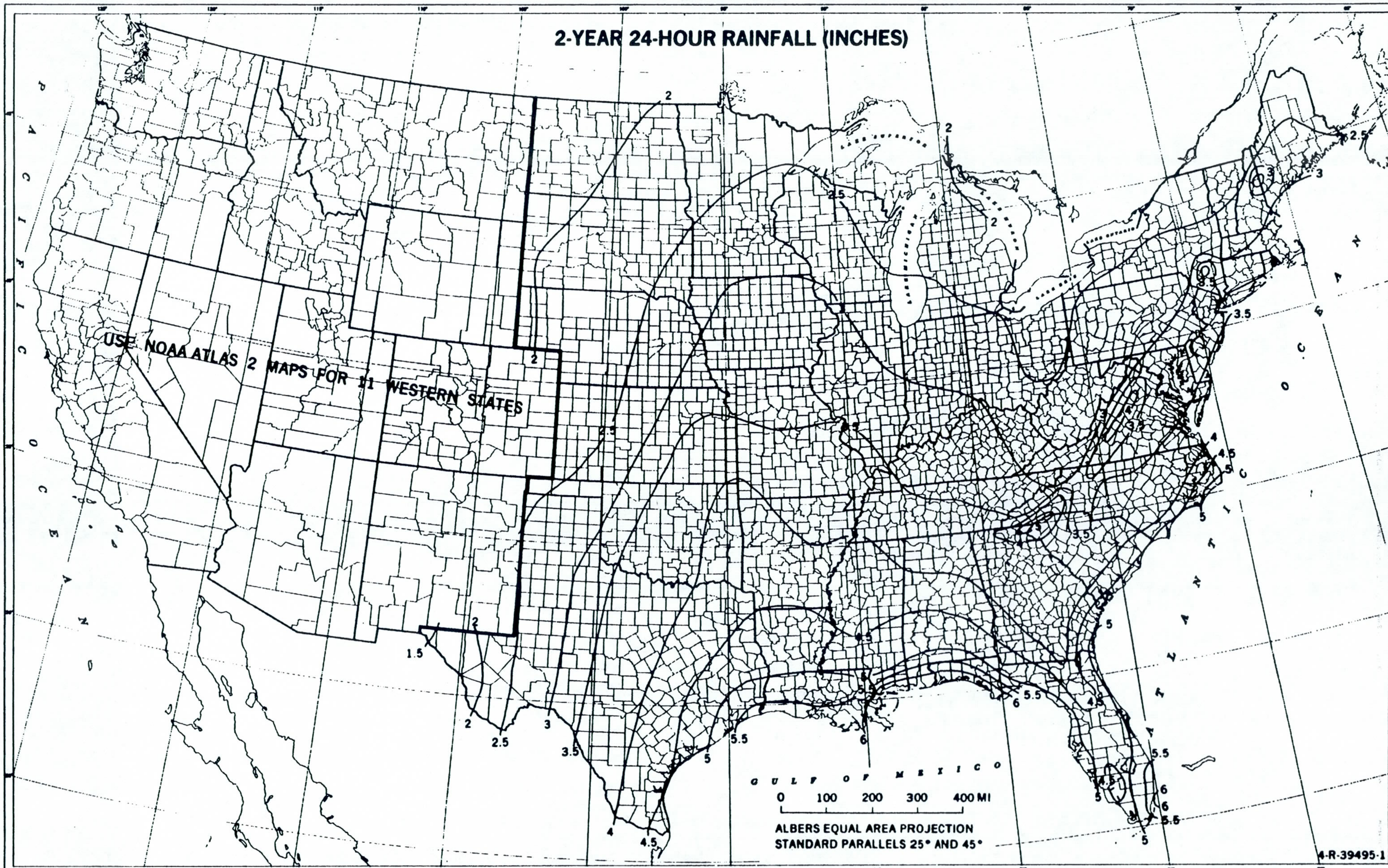
PMP → PMS → PMF

2-YEAR 24-HOUR RAINFALL (INCHES)




2-YEAR 24-HOUR RAINFALL (INCHES)
USE NOAA ATLAS 2 MAPS FOR 11 WESTERN STATES
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
0 100 200 300 400 MI
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 25° AND 45°
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6


2-YEAR 24-HOUR RAINFALL (INCHES)
USE NOAA ATLAS 2 MAPS FOR 11 WESTERN STATES
ATLANTIC OCEAN
GULF OF MEXICO
0 100 200 300 400 MI
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 25° AND 45°
4-R-39495-1


2-YEAR 24-HOUR RAINFALL (INCHES)
USE NOAA ATLAS 2 MAPS FOR 11 WESTERN STATES
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
0 100 200 300 400 MI
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 25° AND 45°
4-R-39495-1
1.5
2
2.5
3
3.5
4
4.5
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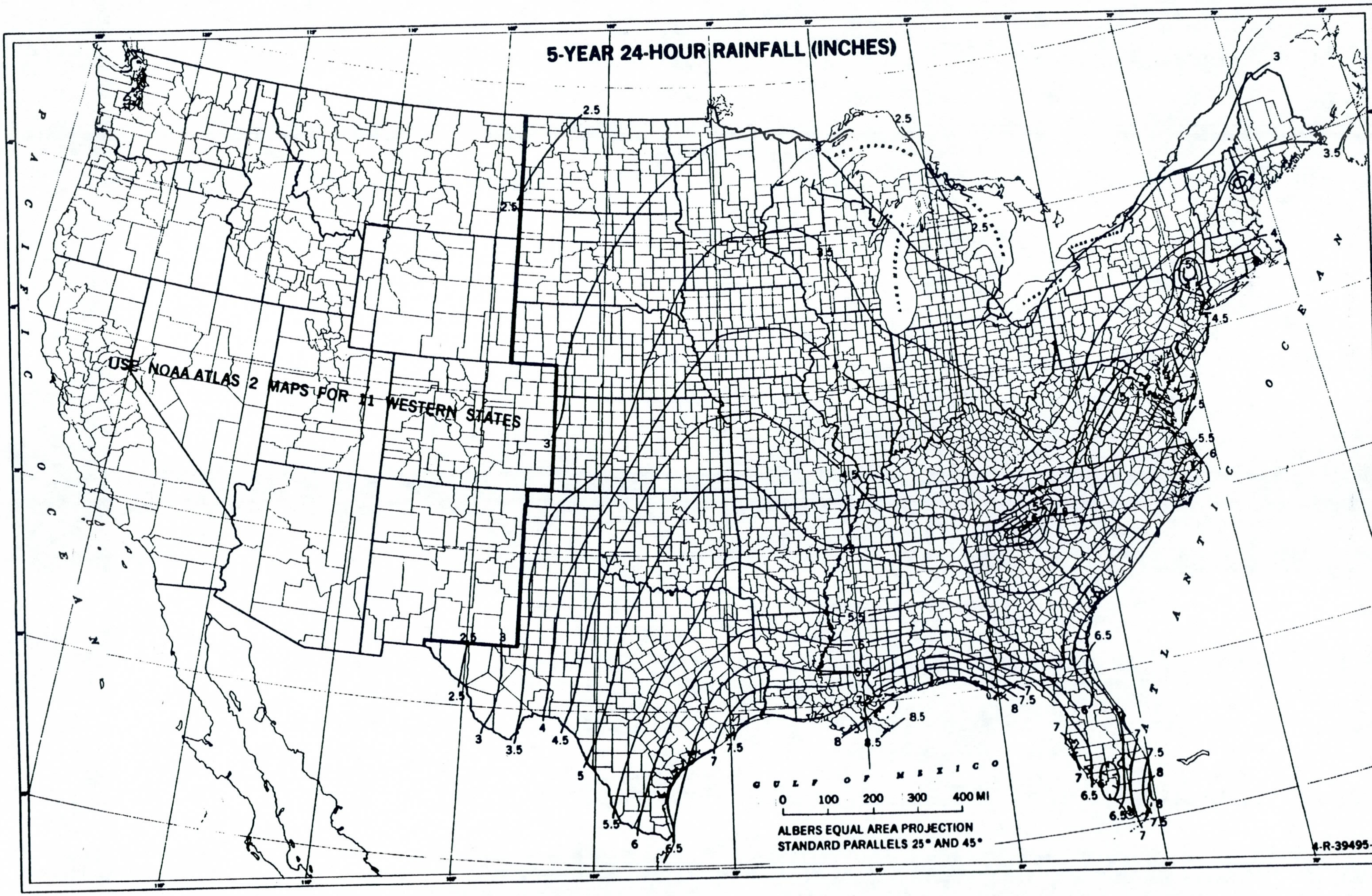
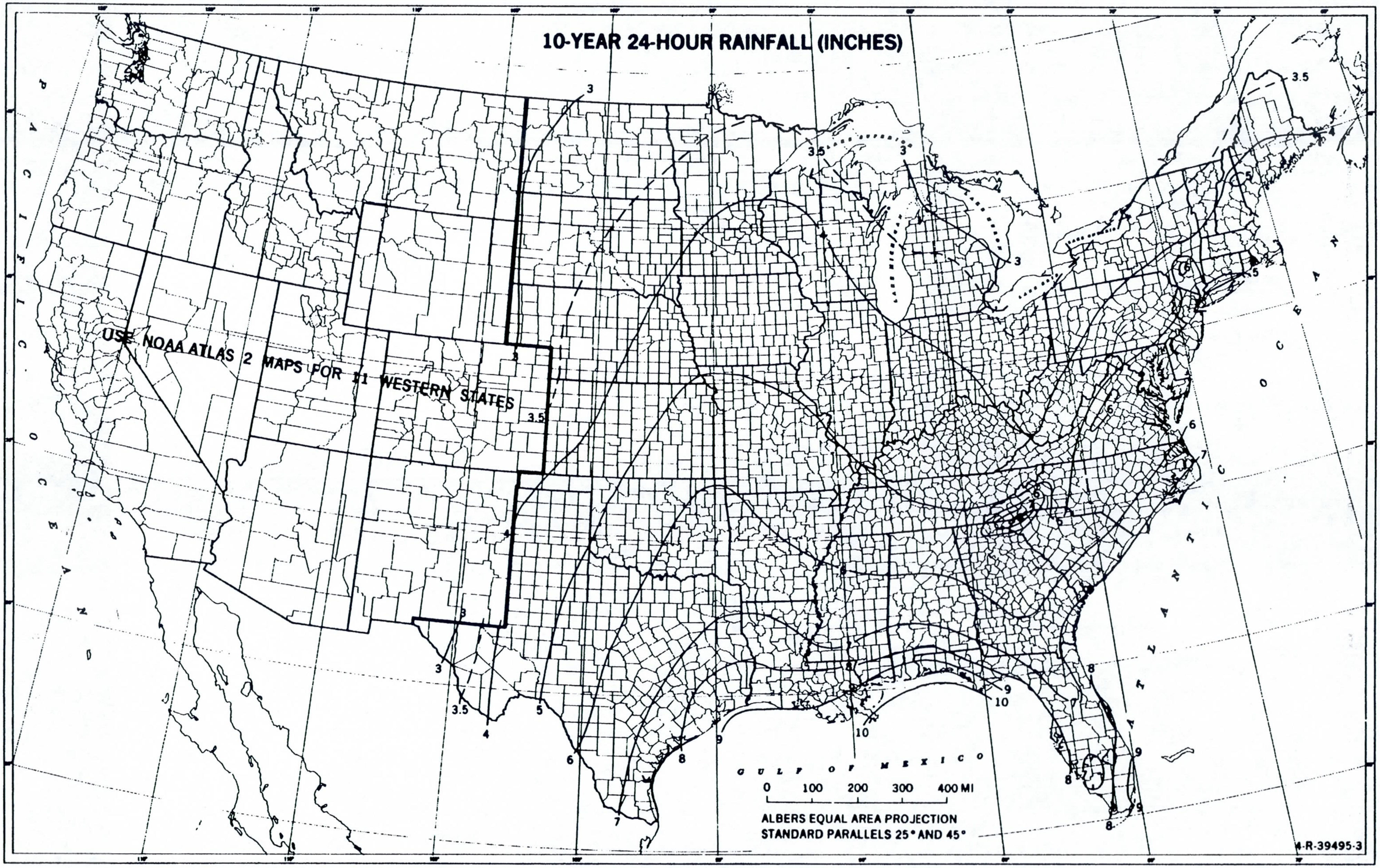
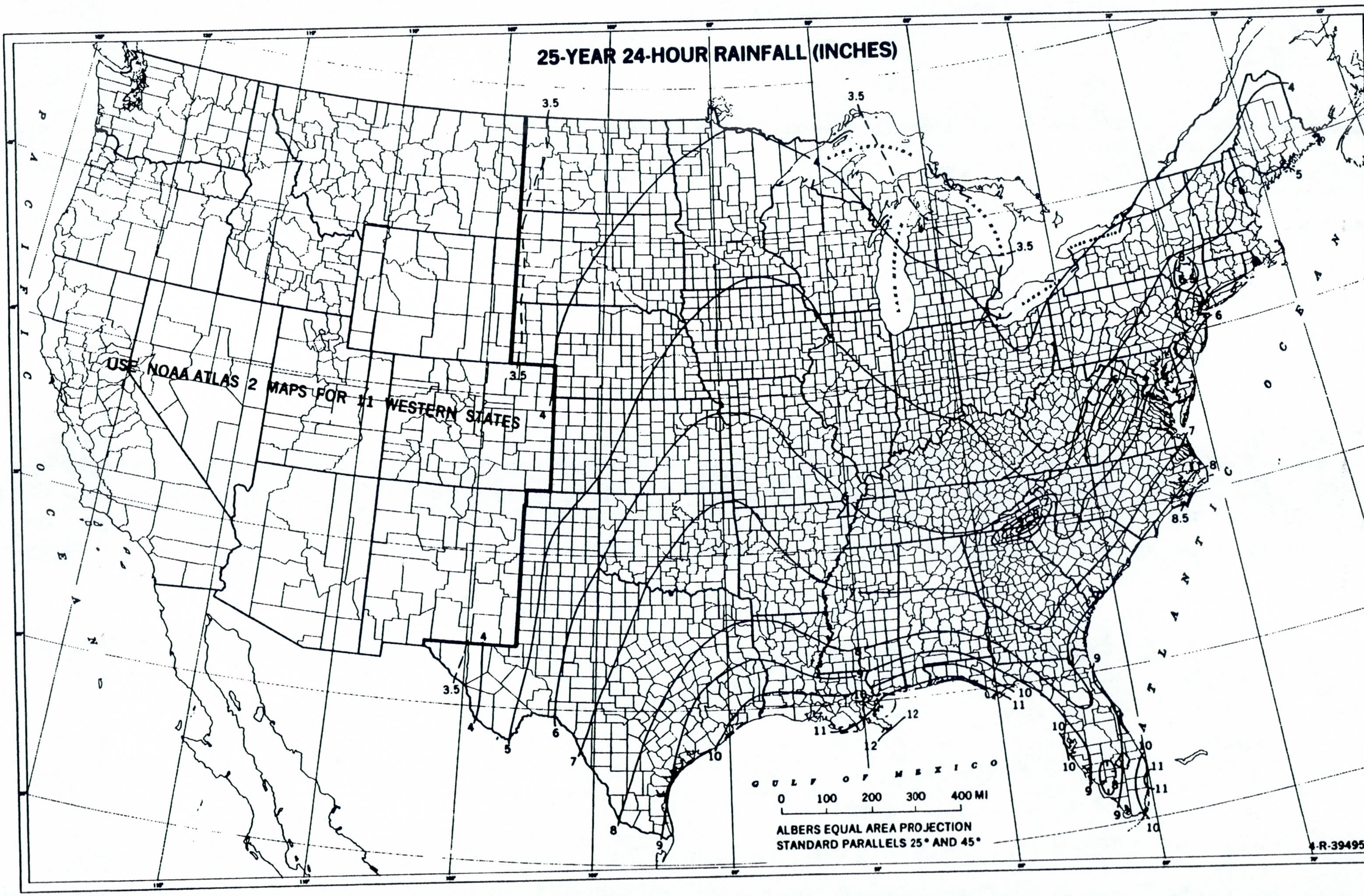
6



5-YEAR 24-HOUR RAINFALL (INCHES)
USE NOAA ATLAS 2 MAPS FOR 11 WESTERN STATES
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
0 100 200 300 400 MI
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 25° AND 45°
4-R-39495-2



10-YEAR 24-HOUR RAINFALL (INCHES)
USE NOAA ATLAS 2 MAPS FOR 11 WESTERN STATES
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
0 100 200 300 400 MI
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 25° AND 45°
4-R-39495-3



25-YEAR 24-HOUR RAINFALL (INCHES)
USE NOAA ATLAS 2 MAPS FOR 11 WESTERN STATES
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
0 100 200 300 400 MI
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 25° AND 45°
3.5
4
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6
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8.5
9
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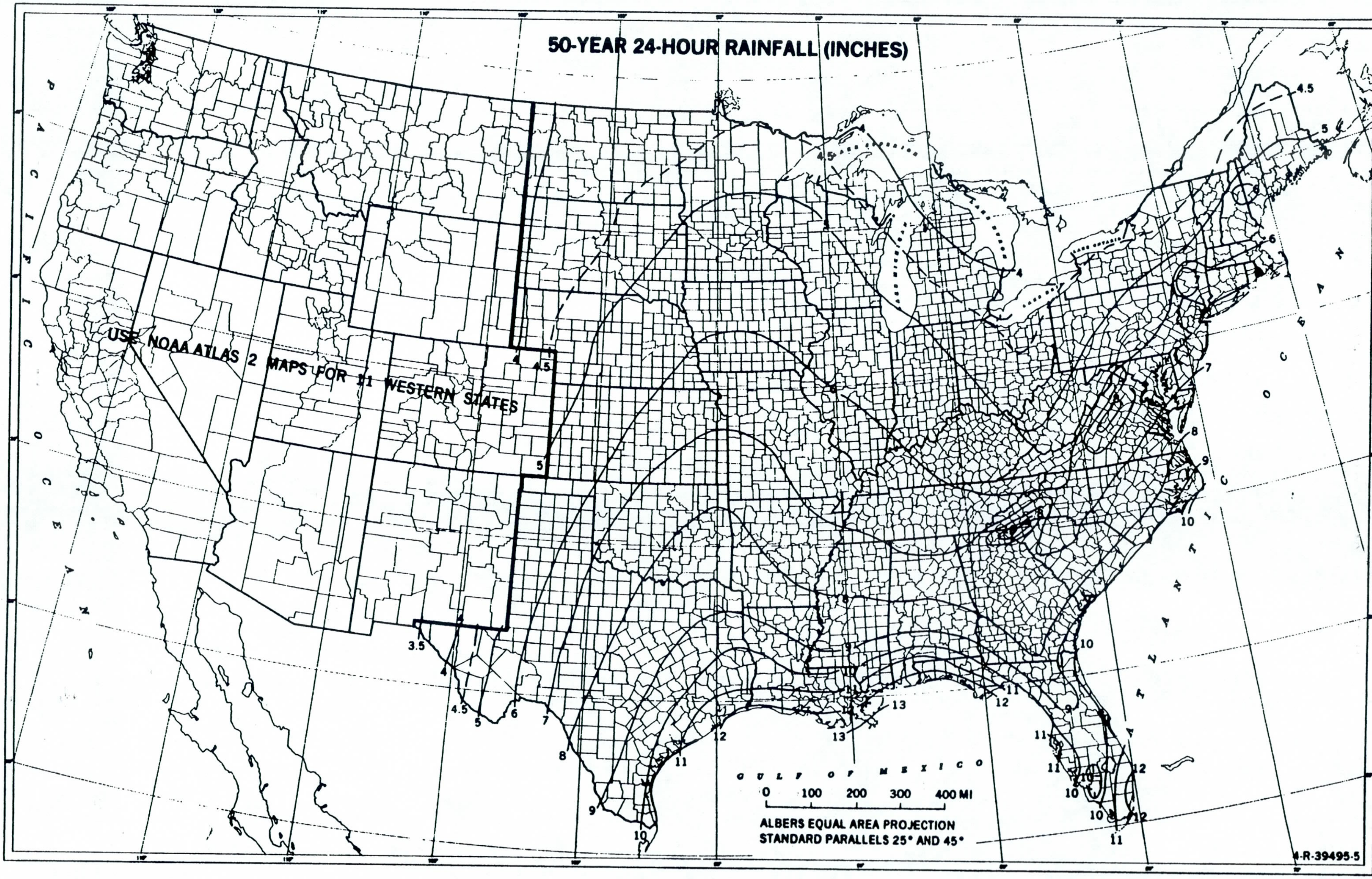
11
12
4-R-39495-4


50-YEAR 24-HOUR RAINFALL (INCHES)
USE NOAA ATLAS 2 MAPS FOR 11 WESTERN STATES
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
0 100 200 300 400 MI
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 25° AND 45°
3.5
4
4.5
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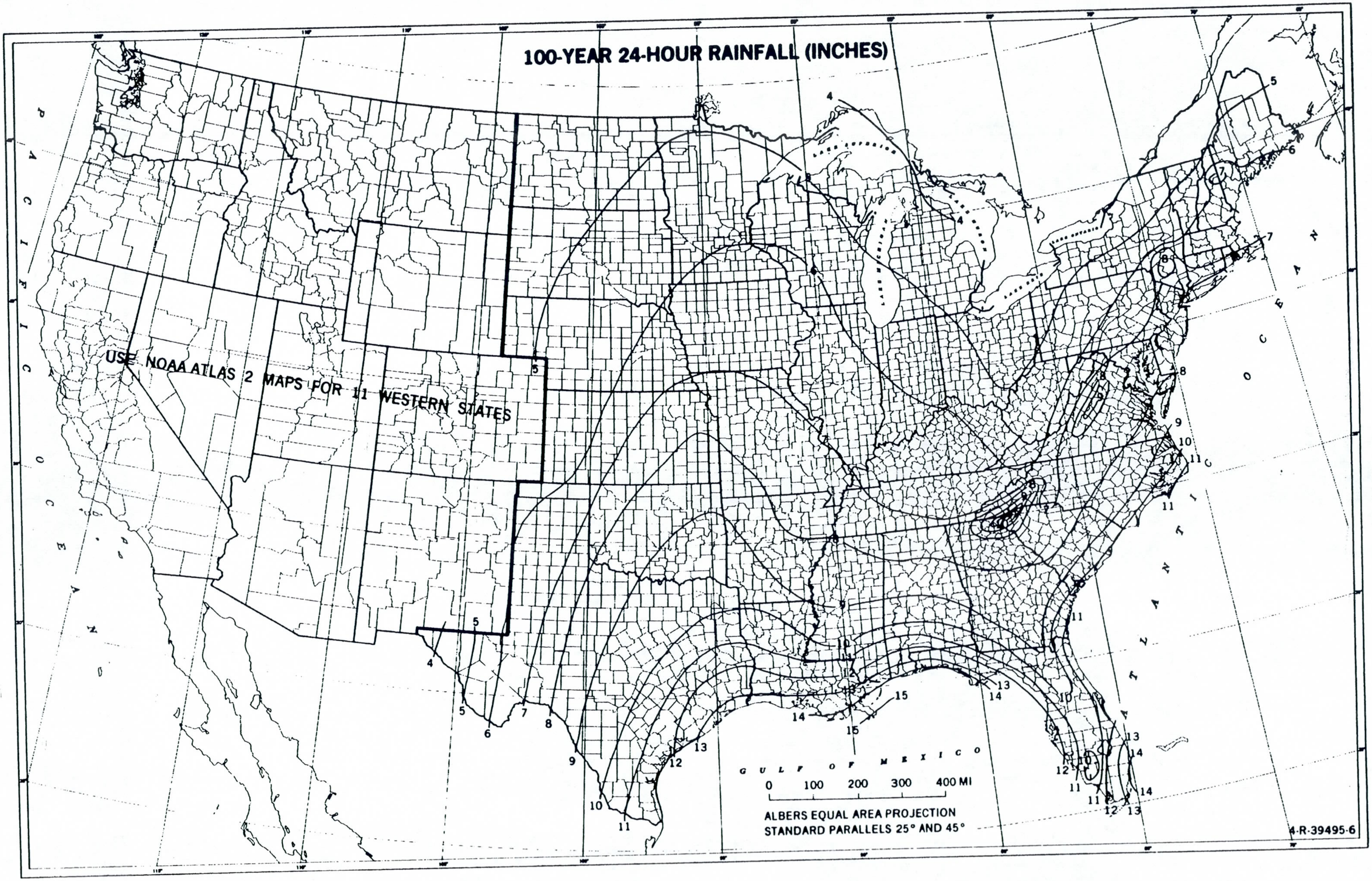
4-R-39495-5



100-YEAR 24-HOUR RAINFALL (INCHES)
USE NOAA ATLAS 2 MAPS FOR 11 WESTERN STATES
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
0 100 200 300 400 MI
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 25° AND 45°
4-R-39495-6

NOAA Technical Memorandum NWS HYDRO-35

FIVE- TO 60-MINUTE PRECIPITATION FREQUENCY FOR THE EASTERN AND CENTRAL UNITED STATES

Ralph H. Frederick
Vance A. Myers
Eugene P. Auciello

Office of Hydrology
Silver Spring, Md.
June 1977

Prepared for Engineering Division,
Soil Conservation Service,
U.S. Department of Agriculture

UNITED STATES
DEPARTMENT OF COMMERCE
Juanita M. Kreps, Secretary

NATIONAL OCEANIC AND
ATMOSPHERIC ADMINISTRATION
Robert M. White, Administrator

National Weather
Service
George P. Cressman, Director

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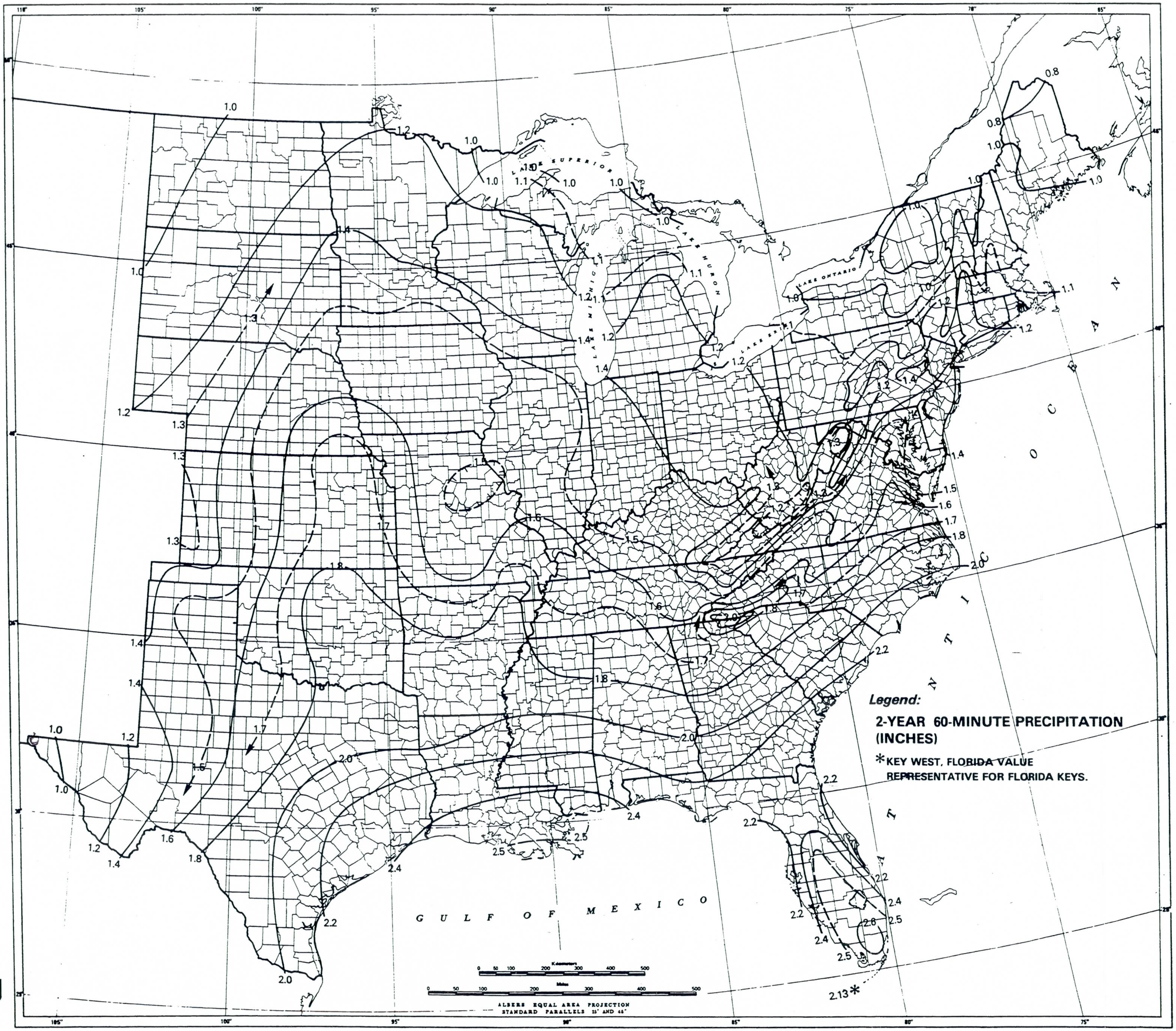


Figure 4.--2-year 60-min precipitation (inches)--adjusted to partial duration series.

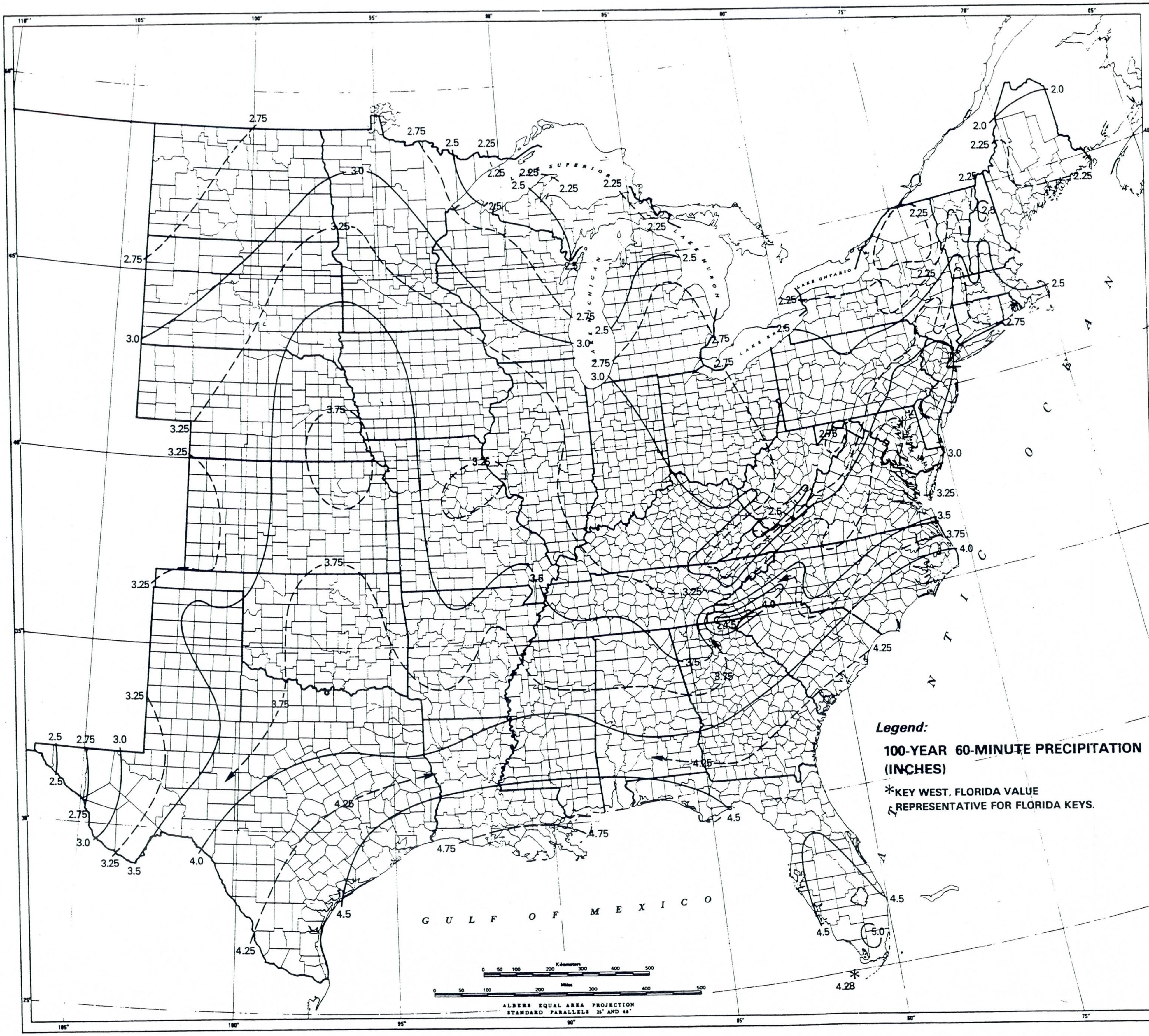


Figure 5.--100-year 60-minute precipitation (inches)--adjusted to partial duration series.

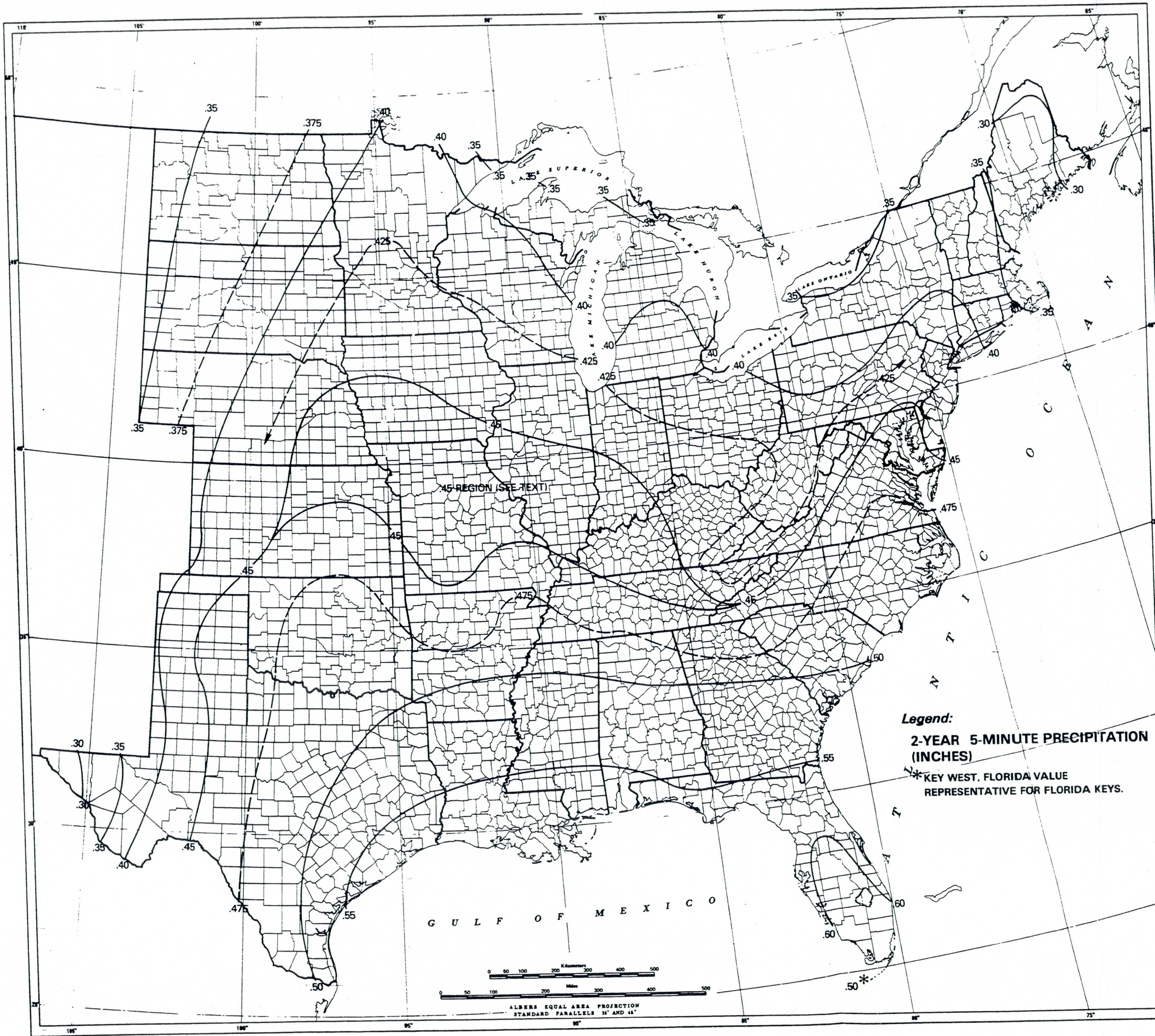


Figure 6.--2-year 5-minute precipitation (inches)--adjusted to partial-duration series.

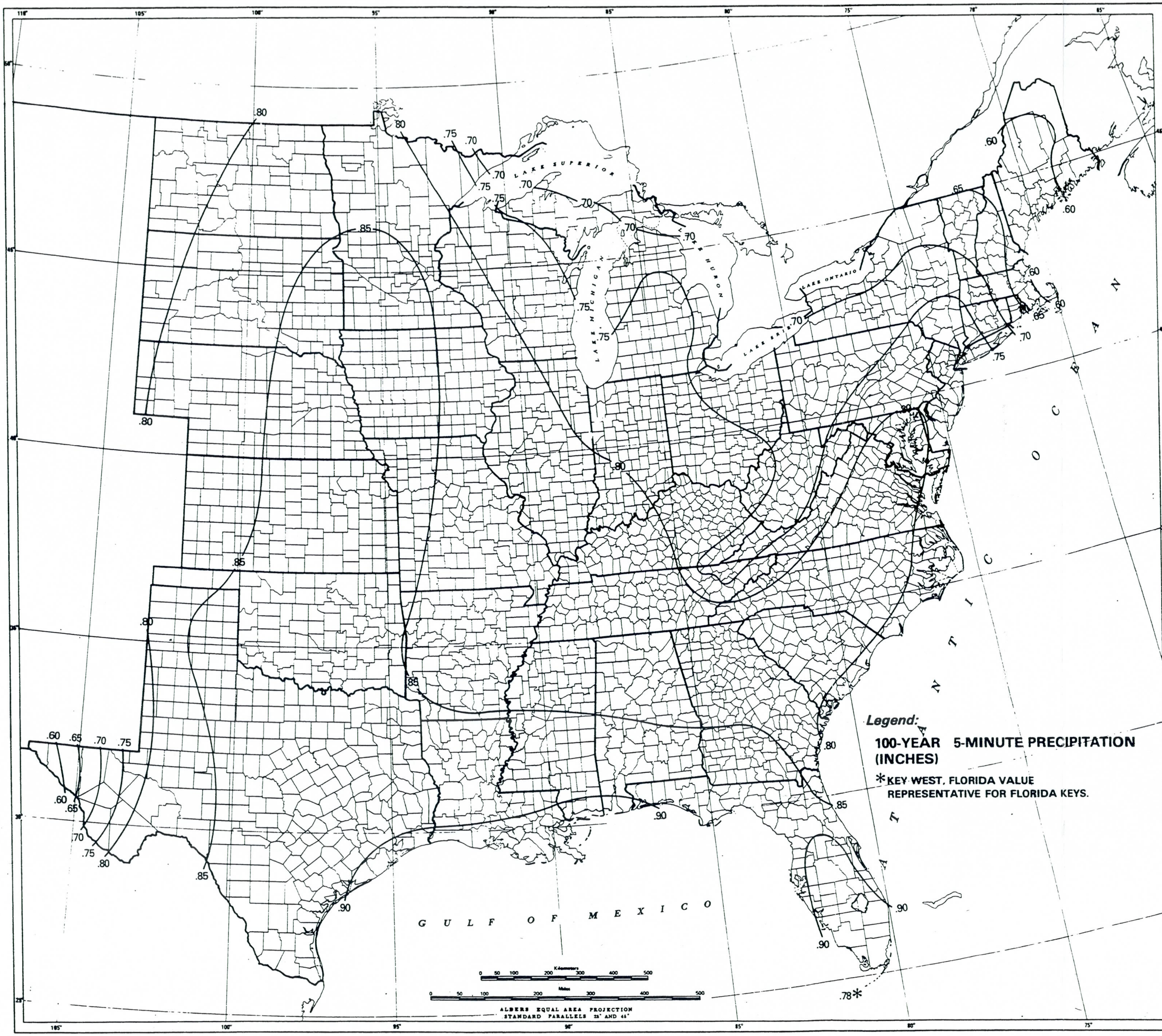


Figure 7.--100-year 5-minute precipitation (inches)--adjusted to partial-duration series.

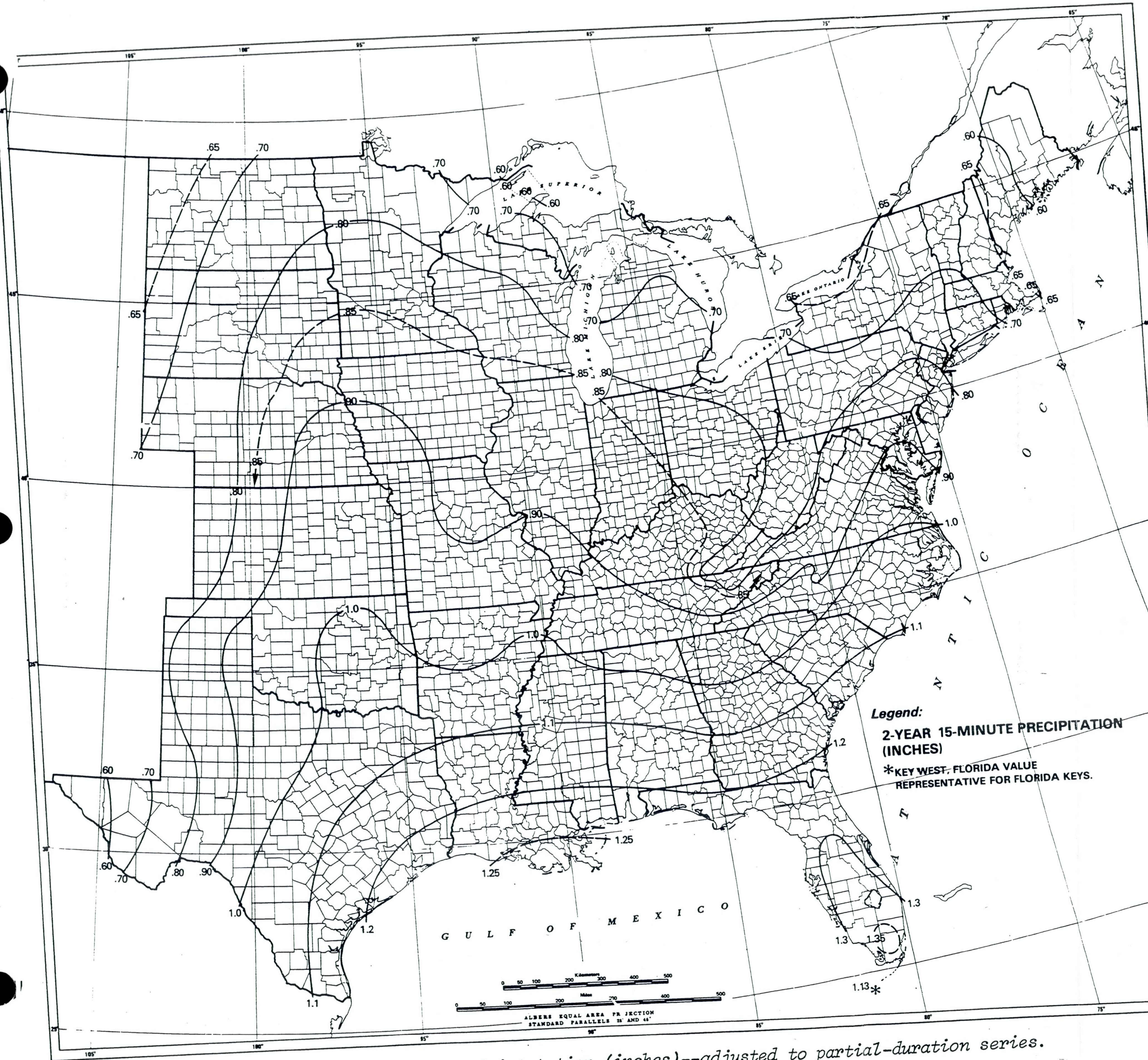


Figure 8.--2-year 15-min precipiatatation (inches)--adjusted to partial-duration series.

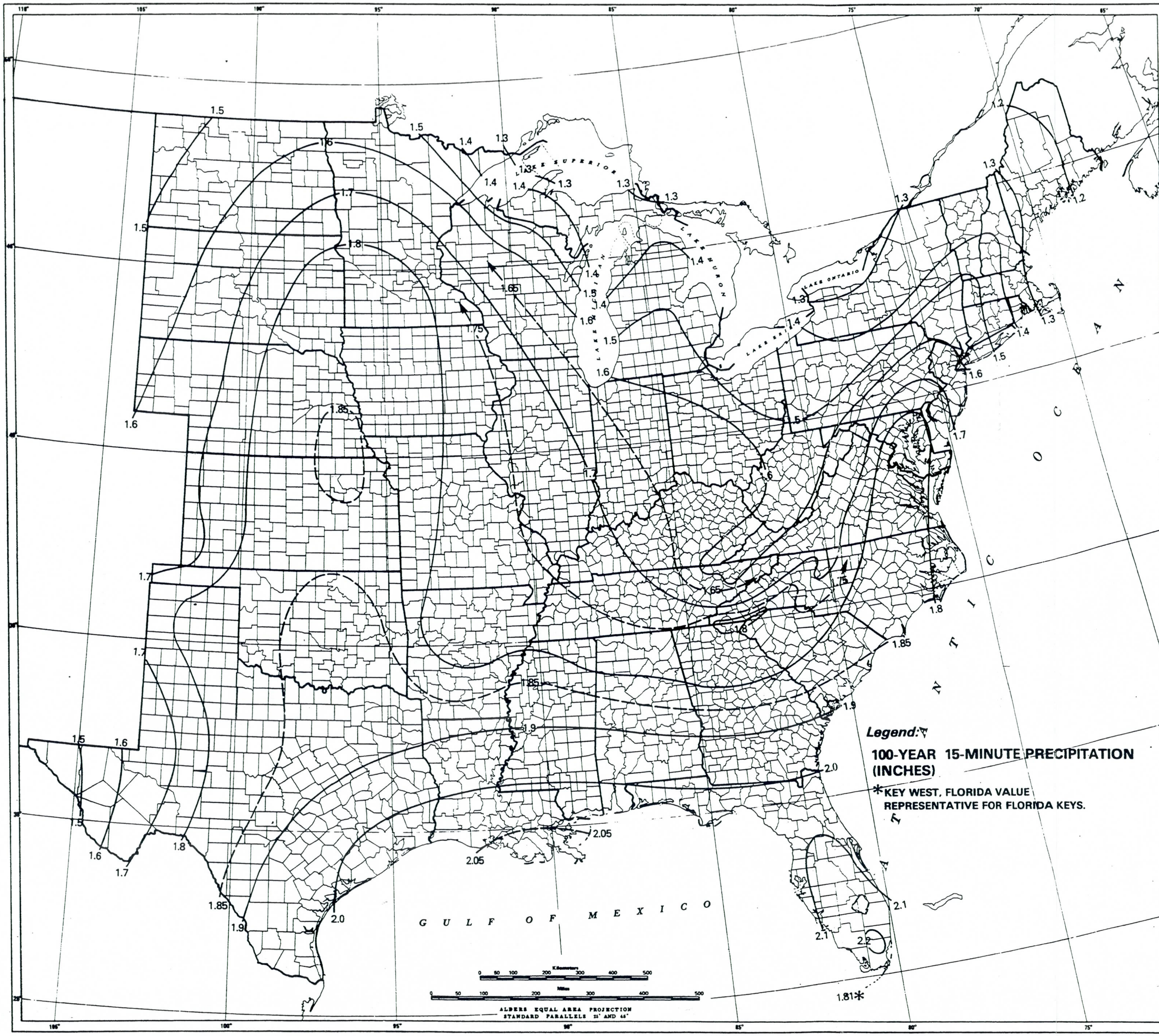


Figure 9.--100-year 15-minute precipitation (inches)--adjusted to partial-duration series.

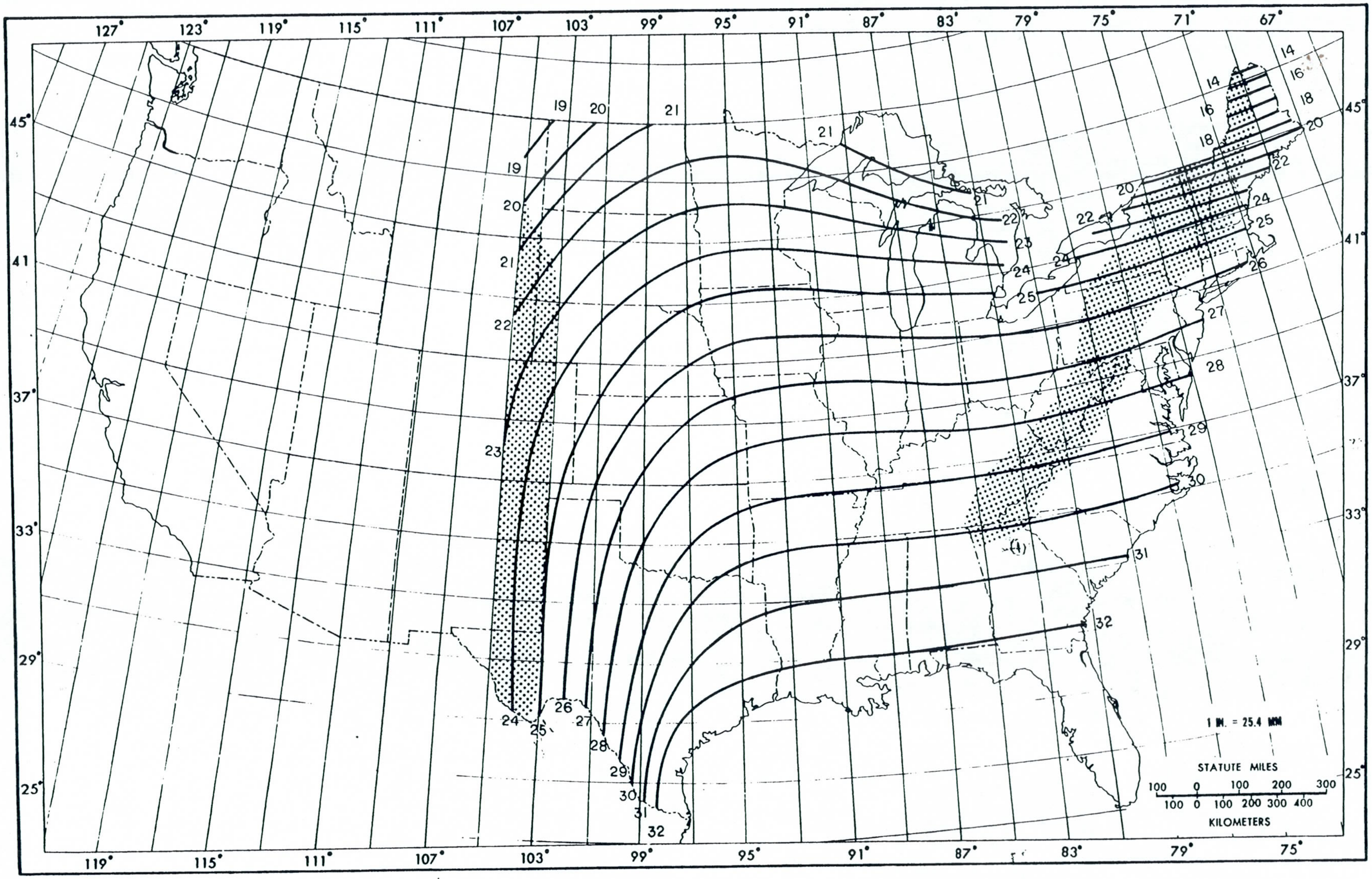


Figure 18.--All-season PMP (in.) for 6 hr 10 mi^2 (26 km^2).

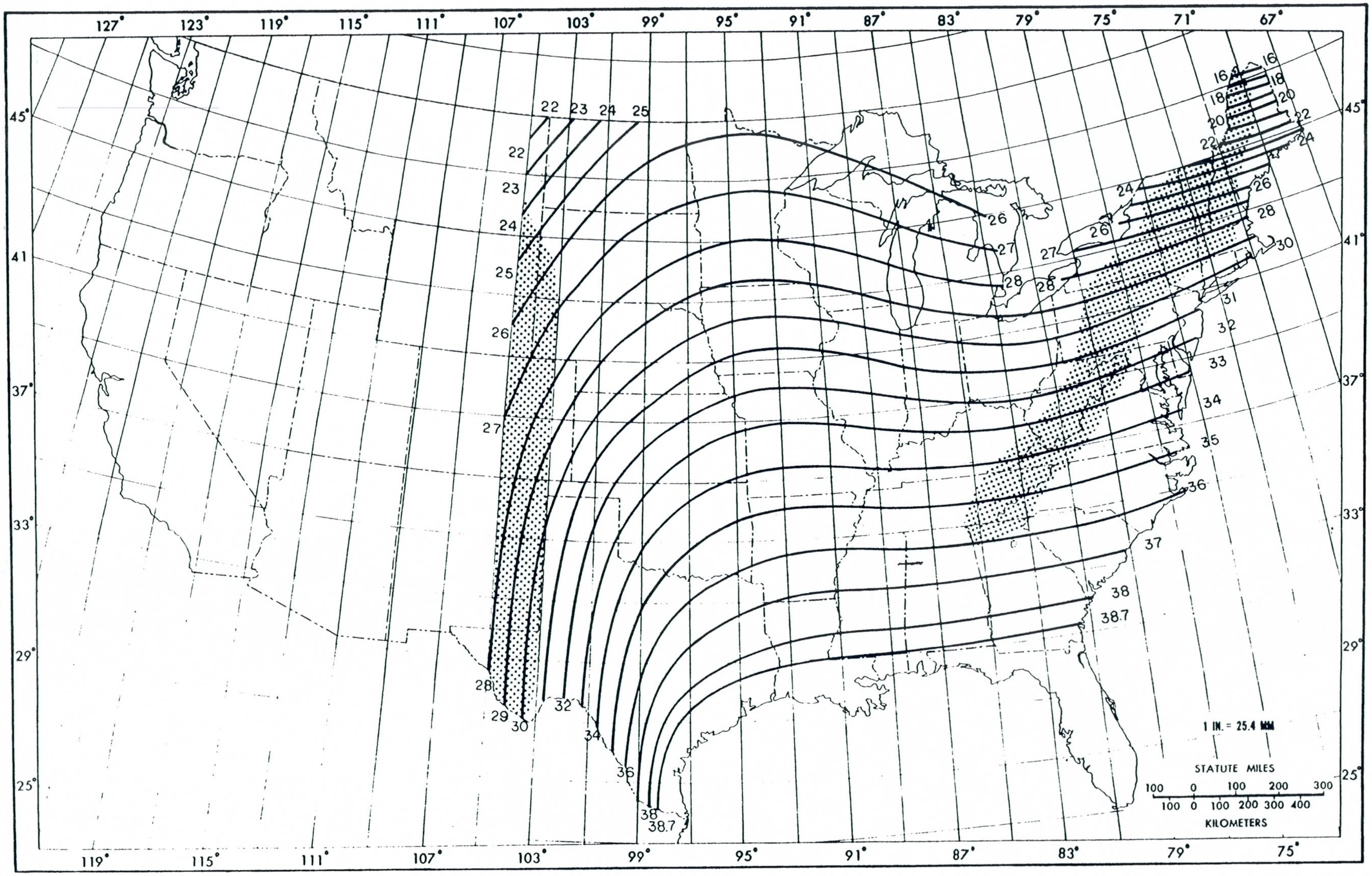


Figure 19.--All-season PMP (in.) for 12 hr 10 mi^2 (26 km^2).

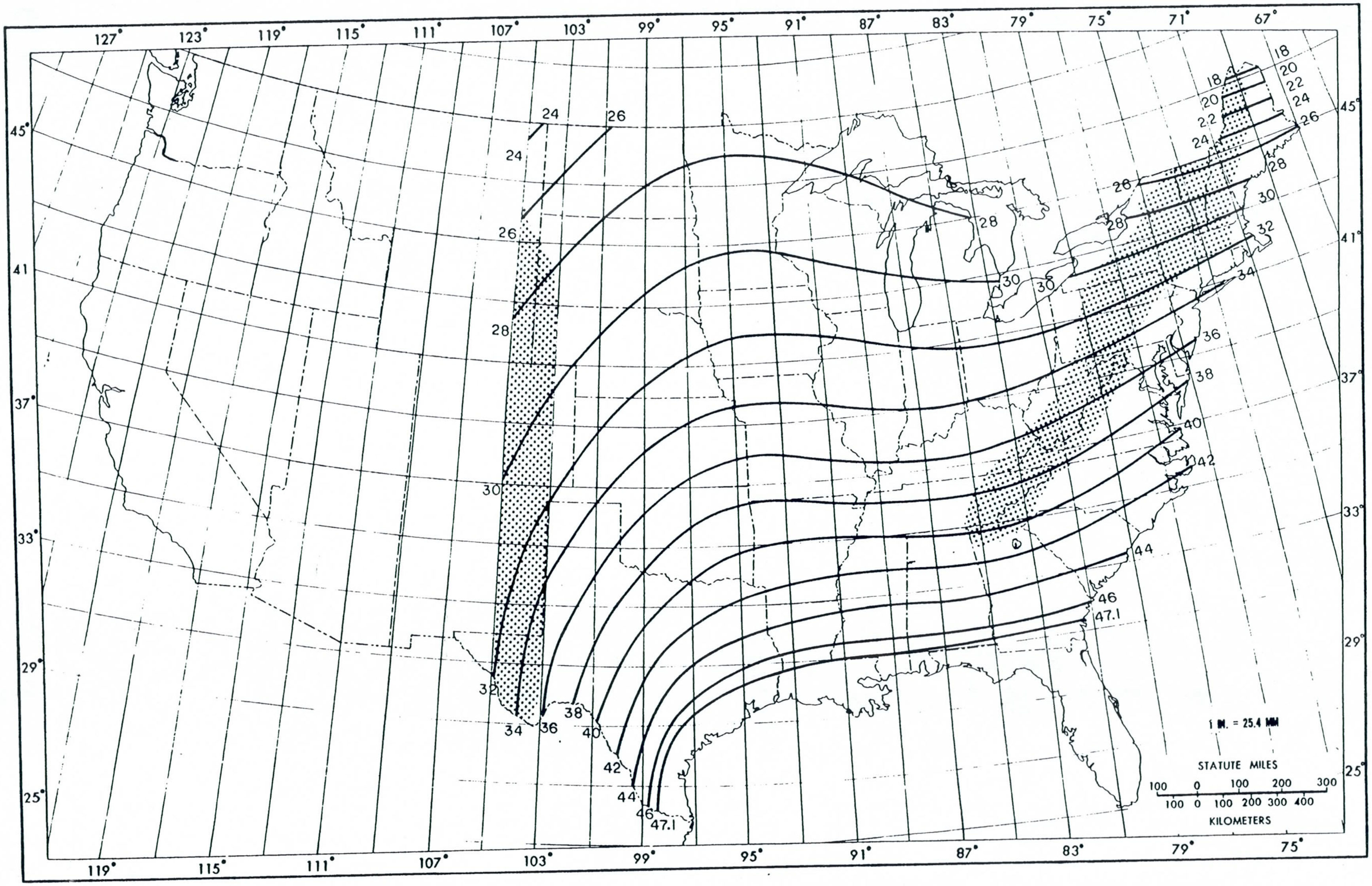


Figure 20.--All-season PMP (in.) for 24 hr 10 mi^2 (26 km^2).

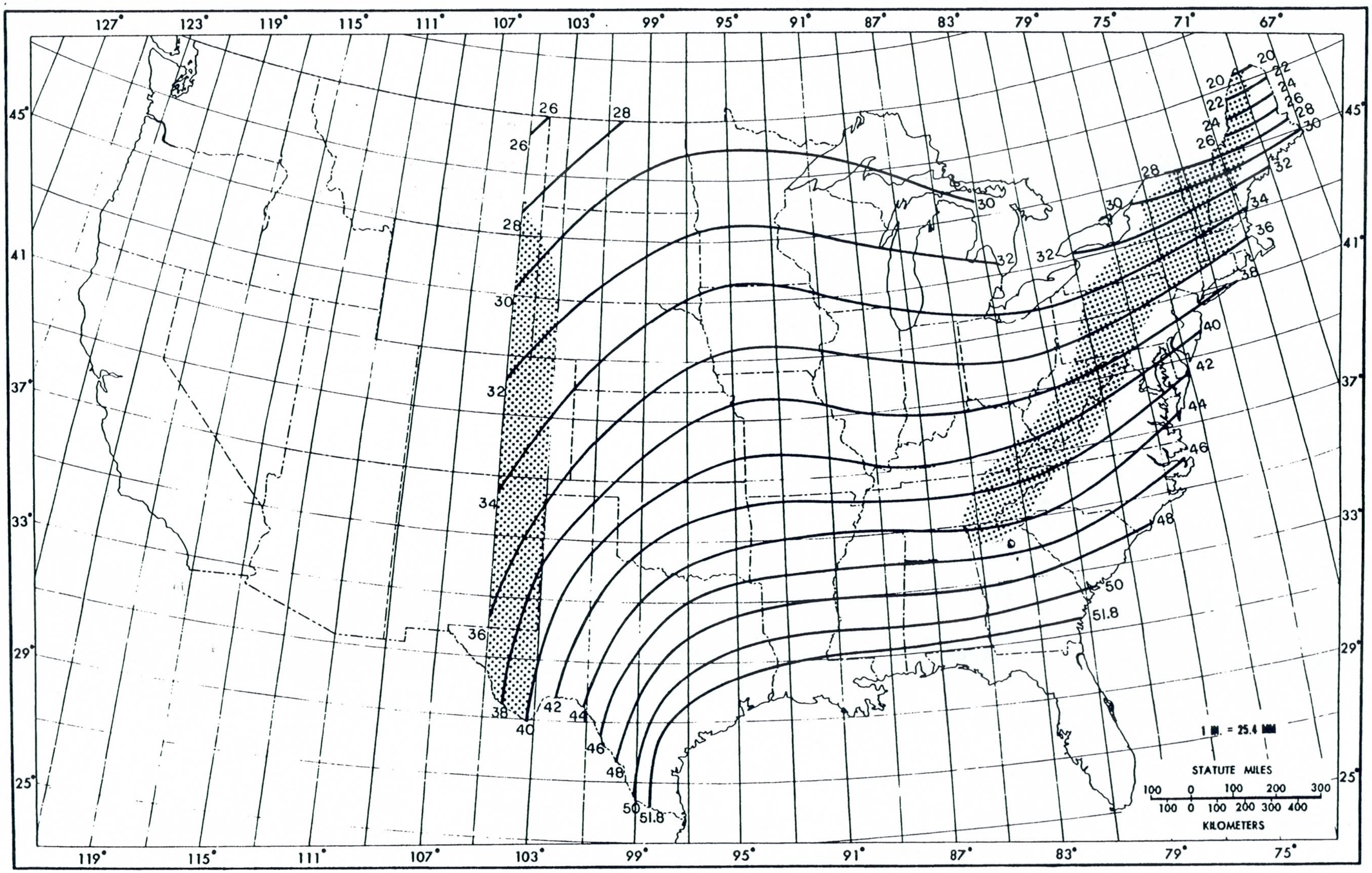


Figure 21.--All-season PMP (in.) for 48 hr 10 mi^2 (26 km^2).

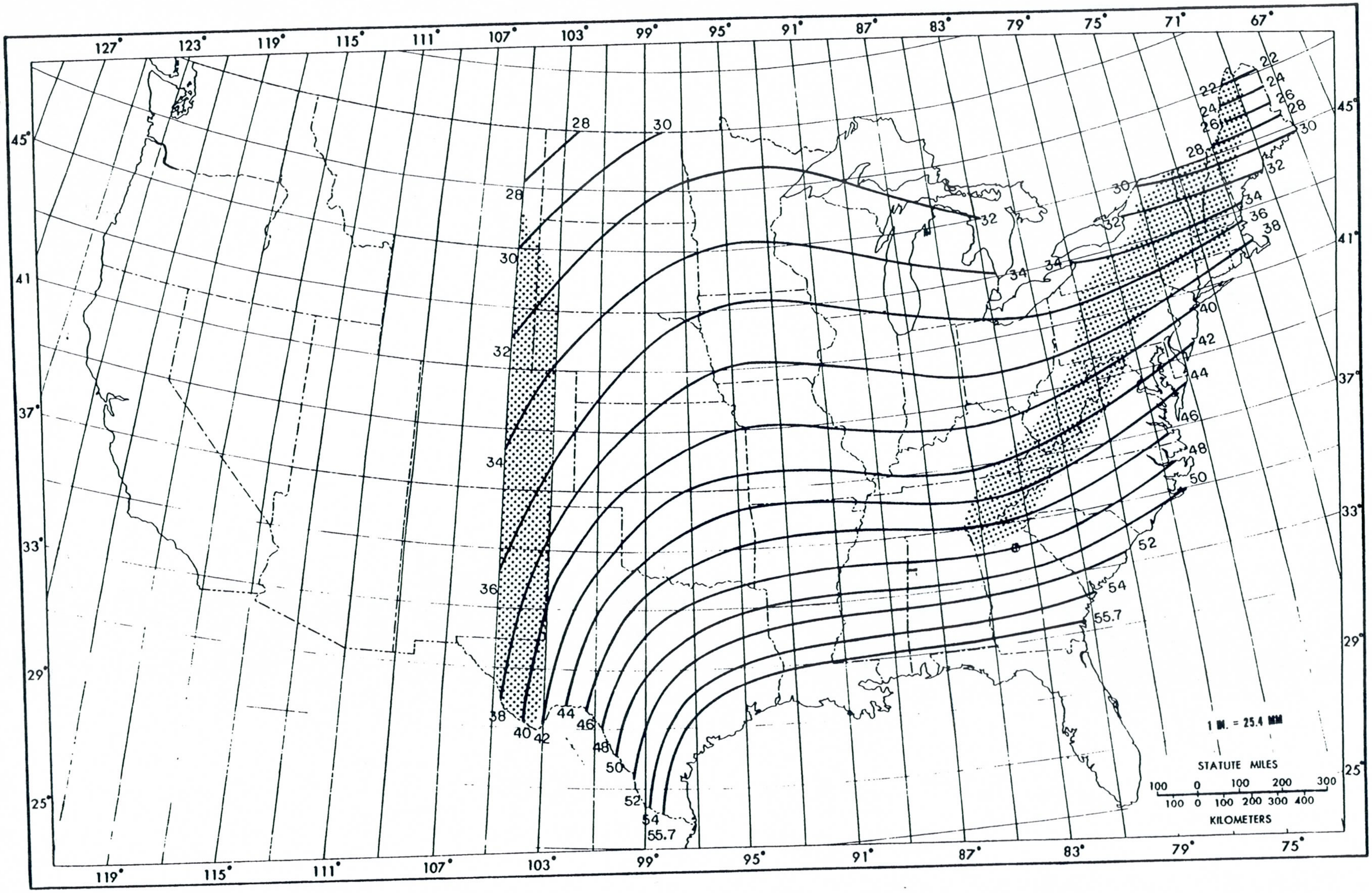


Figure 22.--All-season PMP (in.) for 72 hr 10 mi^2 (26 km^2).

Defining the drainage area

- Square miles
- Sub basins
- Topography
- Cover
- Length
- Soil


Ud
Pine Lake
Ca
PuE
AuC
CuC
Snapfinger
Creek
PfC
CeB
PfD
MdB
MdC
MfC2
Tf
HsB
GeB
MdD
GeE
MfD2
Indian
GwC2
GwD2
GwE2
MdE
PgC2
CeC
AkA
w

SOIL AND WATER FEATURES

[See text for definitions of terms such as "occasional," "brief," "apparent," and "perched." The symbol > means more than. Absence of an entry indicates that the feature is not a concern]

Map symbol and soil name	Hydro-logic group	Flooding			High water table			Bedrock		Risk of corrosio	
		Frequency	Duration	Months	Depth	Kind	Months	Depth	Hard-ness	Uncoated steel	Concret
					Ft			In			
AkA---------------- Altavista	C	Occasional	Very brief	Mar-Jul	1.5-2.5	Apparent	Dec-Mar	>60	---	Moderate	Moderat
AkB---------------- Altavista	C	None---------	---	---	1.5-2.5	Apparent	Dec-Mar	>60	---	Moderate	Moderat
AmB, AmC----------- Appling	B	None---------	---	---	>6.0	---	---	>60	---	Moderate	Moderat
AuC:* Appling-----------	B	None---------	---	---	>6.0	---	---	>60	---	Moderate	Moderat
Urban land.											
AvD, AvF----------- Ashlar	B	None---------	---	---	>6.0	---	---	22-40	Hard	Low-------	High.
AwC,* AwE:* Ashlar------------	B	None---------	---	---	>6.0	---	---	22-40	Hard	Low-------	High.
Wedowee-----------	B	None---------	---	---	>6.0	---	---	>60	---	Moderate	High.
Ca----------------- Cartecay	C	Frequent----	Brief------	Dec-Mar	0.5-1.5	Apparent	Jan-Apr	>60	---	Low-------	Moderat
CeB, CeC, CeD, CfC2-------------- Cecil	B	None---------	---	---	>6.0	---	---	>60	---	Moderate	Moderat
CuC:* Cecil-------------	B	None---------	---	---	>6.0	---	---	>60	---	Moderate	Moderat
Urban land.											
CvF---------------- Chestatee	B	None---------	---	---	>6.0	---	---	>60	---	High------	High.
GeB, GeC, GeD, GeE, GwC2, GwD2, GwE2-------------- Gwinnett	B	None---------	---	---	>6.0	---	---	>60	---	High------	Modera
HsB, HsC, HtC2----- Hiwassee	B	None---------	---	---	>6.0	---	---	>60	---	Moderate	Modera
IrC---------------- Iredell	D	None---------	---	---	1.0-2.0	Perched	Nov-Mar	40-60	Soft	High------	Low.
MdB, MdC, MdD, MdE, MfC2, MfD2, MfE2-------------- Madison	B	None---------	---	---	>6.0	---	---	>60	---	High------	Modera
MvD2, MvE2, MwD, MwF--------------- Musella	B	None---------	---	---	>6.0	---	---	14-20	Soft	Moderate	Modera
PfC, PfD, PfE, PgC2, PgD2-------- Pacolet	B	None---------	---	---	>6.0	---	---	>60	---	High------	High.
PuE:* Pacolet-----------	B	None---------	---	---	>6.0	---	---	>60	---	High------	High.
Urban land.											

HYDROLOGIC SOIL GROUPS (**HSG**)

(indicates the minimum rate of infiltration obtained for bare soil after prolonged wetting)

Group A - *sand, loamy sand, sandy loam*

- low runoff potential
- high infiltration rates
- sands or gravels
- water transmission > 0.30 in/hr

Group B - *silt loam, loam*
moderate infiltration rates
0.15 - 0.30 in/hr

Group C - *sandy clay loam*
low infiltration rates
have a layer that impedes downward movement of water and soils
0.05 - 0.15 in/hr

Group D - *clay loam, silty clay loam, sandy clay, silty clay, clay*
high runoff potential - swelling, water table, clay pan
0 - 0.05 in/hr

Drainage basin soils may be identified from a soil survey report (SCS office or soil and water conservation district office) *travel time (T_t)* - time for water to travel from one location in a watershed to another downstream location

- determined primarily by:
  - slope
  - length of the flow path
  - depth of flow
  - channel surface roughness

$$T_t = \frac{l}{3600\ v}$$

time of concentration (Tc) time it takes for water to travel from the hydraulically most distant location to the location of interest

the time from the end of excessive rainfall to the point on the falling limb of the hydrograph (point of inflection) where the recession curve begins

lag (L) - the delay in time, after a brief, heavy rainfall over a watershed, before the runoff reaches its maximum peak

estimating T_c, T_t, and L

- field observations - soil, roughness, stability, debris
- purpose for estimate - guide to the amount of work
- stream hydraulics method
- upland method
- curve number method (for areas of less than 2000 acres)

$$L = \frac{l^{0.8}\ (S + 1)^{0.7}}{1900\ Y^{0.5}}$$

l = hydraulic length of watershed in feet

Y = average watershed land slope in percent

SCS CURVE NUMBER METHODOLOGY

runoff- determined primarily by rainfall amount and infiltration characteristics related to:

- soil type
- soil moisture
- antecedent rainfall
- cover type
- impervious surfaces
- surface retention

runoff curve number (CN) based on:

- soil
- plant cover
- amount of impervious area interception
- surface storage

Estimating Runoff by the SCS Runoff Curve Number Method

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S}$$

Q = runoff in inches
P = rainfall in inches
S = potential maximum retention after runoff begins (inches)
I_a = initial abstraction (inches)
all losses before runoff begins
= **0.2 S** (studies of many *small agricultural* watersheds)

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

S is a function of soil, and cover conditions (CN)   CN has a range of 0 - 100

$$S = \frac{1000}{CN'} - 10$$

CN' is the *complex number* and is approximately the same as **CN**

What factors determine a drainage basin curve number (CN)?

- the hydrologic soil group (**HSG**)
- cover type
  vegetation, bare soil, impervious surfaces
- treatment
  cultivated agricultural lands
- hydrologic conditions
  the effects of cover type and treatment on infiltration and runoff
- antecedent runoff conditions (**ARC**)
  attempt to account for the variation in CN from storm to storm
- unconnected impervious areas

Limitations of SCS Runoff Curve Number Method

- curve numbers describe *average* conditions
- does not account for rainfall intensity or duration
- 0.2 S is an *approximation* for *agricultural* areas
- does not account for snowmelt or runoff from frozen ground
- less accurate if runoff is less than 0.5 inches
- does not account for subsurface flow or high water tables
- not applicable for weighted CN less than 40

TYPES OF FLOW

- surface flow
  - -overland flow
  - -channel flow
- surface flow with transmission losses
  when infiltration takes place in a channel , it is called a transmission loss
- quick return flow
  springs and seeps
- base flow

STREAM FLOW HYDROGRAPHS

factors affecting runoff

- spatial and temporal distribution of rainfall
- rate of snowmelt
- hydraulics of streams
- watershed and channel storage
- others

types of hydrographs

- natural
- synthetic
- unit
- dimensionless

UNIT HYDROGRAPH

1932 - L. K. Sherman

assumptions

- discharge at any time is proportional to the volume of runoff
- time factors affecting hydrograph shape are constant

principles

- the hydrograph of surface runoff from a watershed due to a given pattern of rainfall is invariable
- the hydrograph resulting from a given pattern of rainfall excess can be built up by superimposing the unit hydrograph due to the separate amounts of rainfall excess occurring in each unit period
- the ordinates of the hydrograph are proportional to the volume of rainfall excess

DIMENSIONLESS UNIT GRAPH (SCS)

ordinate $\mathbf{q/q_p}$ or $\mathbf{Q_a/Q}$
abscissa $\mathbf{t/T_p}$

point of inflection approximately 1.7 times the time to peak
time to peak 0.2 of the time of base
37.5 % of the total runoff volume in the rising side - one unit of time, one unit of discharge

FLOOD HYDROGRAPH ANALYSES AND COMPUTATIONS

-deriving fundamental hydrologic factors by analyzing observed hydrographs of stream flow and related meteorological events

-methods for utilizing deduced factors in computing hypothetical hydrographs of runoff for different conditions

Analysis of a flood hydrograph-

- estimates of the intensity, depth and areal distribution of precipitation causing the runoff (and rate of snowmelt, where this is significant)

- computation of difference between precipitation and direct runoff, expressed as initial loss and infiltration

- determination of the combined effect of drainage area and channel characteristics on the regimen of runoff, expressed herein in terms of "unit hydrographs"

*computation of **hypothetical hydrographs**, based on data derived from natural hydrograph analysis and supplementary studies:*

- determining the ***design storm*** rainfall values, the areal distribution and sequence of occurrence of unit increments that would produce critical rates of runoff , or rates corresponding to specified lesser magnitudes according to the purpose for the estimate

- selecting ***infiltration indices*** and initial loss values to correspond with the given drainage area and assumptions regarding season of the year, antecedent rainfall and other considerations affecting volume of rainfall

- selection of ***unit hydrographs*** to represent the probable order of runoff from adopted design storm rainfall excess

- computation of hypothetical hydrographs by combining factors

transformation of precipitation excess to stormwater runoff

- unit hydrograph
- kinematic wave approximation

Unit hydrograph

-represents direct runoff at the outlet of a basin resulting from one unit (e.g. 1 inch) of precipitation excess over the basin

assumptions

- precipitation excess and losses can be treated as basin average (lumped) quantities (divide the basin into sub basins)

- the ordinates of a direct runoff hydrograph corresponding to precipitation excess of a given duration are directly proportional to the volume of excess (assumption of linearity)

- the direct runoff hydrograph resulting from a given increment of precipitation excess is independent of the time occurrence of the excess (assumption of time invariance)

UNIT HYDROGRAPHS FOR UNGAGED BASINS

Ungaged - there is no stream gage at the basin outlet for which measurements during historical storms are available and data from precipitation gages are not available with which hyetographs of basin average precipitation can be developed for the storms

Synthetic unit hydrographs

SCS dimensionless unit hydrograph

based on data from a large number of small rural basins
37.5 % of the area under the hydrograph occurs from the origin to peak

$$Q_p = 484\, A / t_p$$

where: Q_p = peak discharge of unit hydrograph in cfs
A = basin area, in square miles
t_p = time to peak of unit hydrograph, in hours, which can be expressed as:

$$D/2 + t_l$$

where: D = duration of unit excess for unit hydrograph
t_l = lag, defined as the time from the centroid of precipitation excess to the time of the peak of the unit hydrograph

$$t_l = 0.6\, t_C$$

where t_C is the time of concentration

the constant **484** actually varies from about **600** for basins with steep slopes to **300** for flat swampy basins

Single-linear reservoir method

for small basins with short response times
requires single parameter "K"

Nash model

requires two parameters - "n" and "K"

Clark model

- effects of basin shape (and other factors) on time of travel can be taken into account
- a translation hydrograph at the basin outlet is developed by translating (lagging) the excess based on travel time to the outlet
- requires two parameters - T_c *and R*

Snyder method

provides equations that define characteristics of the unit hydrographs directly without the use of a conceptual model

$$t_t = C_t (LL_{ca})^{0.3}$$

$$Q_p = 640 C_p A / t_l$$

where: t_l = lag of the "standard" unit hydrograph in hours
C_t and C_p = empirical coefficient; use regional values
L = length of main water course from basin outlet to upstream boundary of basin, in miles
L_{ca} = length of main watercourse from basin outlet to point opposite centroid of basin area, in miles
Q_p = peak discharge of "standard" unit hydrograph in cubic feet per second
A = basin area, in square miles

The standard unit hydrograph is one for which the following relationship holds:

$$t_r = t_l / 5.5$$

where: t_r = duration of rainfall excess
t_l = time from center of mass of the unit excess to the time of the peak of the unit hydrograph

UNIT HYDROGRAPHS FOR GAUGED BASINS

- "isolated storm" method
- S - graph method
- matrix method

optimization techniques - obtain parameter values that enable a "best fit" of the observed hydrograph

Procedure

- obtain precipitation and discharge data for actual events
- determine initial streamflow conditions for each event and appropriate values for parameters with which to define flows
- perform an optimization of values for loss and unit hydrograph parameters for each storm
- adopt a single set of values

KINEMATIC WAVE APPROACH

- often used in urban watershed modeling
- very good for modeling overland flow at shallow depths or channel flow in moderately steep channels
- takes a distributed view of a subbasin rather than a lumped view
- captures the different responses from both pervious and impervious areas in a single subbasin
- produces a non linear response to rainfall excess

The kinematic wave equations are based on :

the conservation of mass:

inflow - outflow = the rate of change of channel storage

and *the conservation of momentum*:

gravity + pressure + friction = mass * fluid acceleration

kinematic wave conservation of momentum: $\mathbf{S_f = S_o}$

the momentum of the flow can be approximated by a uniform flow assumption, such as:

$$\mathbf{Q = alpha\ A^m}$$

where **alpha** is related to surface roughness and ^{m} is related flow geometry and **A** is the cross sectional flow area *data needed for each overland flow plane*:

- average overland flow length
- representative slope
- average roughness coefficient (table 7-1)
- the percentage of the subbasin area which the overland flow plane represents
- infiltration and loss rate parameters

data needed to describe collector and sub-collector channels as well as the main channel

- representative channel length
- Mannings n
- average slope
- channel shape
- channel dimensions
- amount of area serviced by the channel element

LOSSES

- interception
- surface storage
- soil infiltration

Surface loss estimation

interception

forested	greatest (10-20% of total precipitation) (up to 2.0 inches)
agricultural	for a storm depth of 1.0 inch, 3-16 % interception
urban	

	detention storage
forested	
agricultural	0.5 inch after tillage
urban	

(see Table 6-1)

soil infiltration affected by-

- chemistry of the water
- biologic activity
- soil heterogeneity
- surface cover

initial water content

Saturated hydraulic capacity - proportionality constant between hydraulic gradient and flow in Darcy's law

effect of surface on rainfall (pg. 6-3,(6))

forested areas - greatest surface losses, no overland flow
range land - grazing
agricultural areas - crusted surfaces
urban area - impervious area

Horton process - overland flow results when all surface storages are filled and rainfall rate exceeds the infiltration rate

Hillslope process - direct runoff is the sum of surface and subsurface flow modeling -

- physically based - solutions to the Richards equation
- conceptual - Holtan
- empirical - SCS curve number (includes surface losses 6-4a)

Antecedent Moisture Conditions (before beginning of rainfall)
antecedent precipitation index (API)

Infiltration Methods

Green and Ampt - as the water content at the soil surface increases, the method models the movement of the infiltrated water by approximating the wetting front with a piston type displacement *(Figure 6-5)*

LG card HEC-1 (pg. A-39) - initial loss in inches (mm)
volumetric moisture deficit
wetting front suction inches (mm) *(table 6-2)*
hydraulic conductivity at natural saturation inches per hour (mm/hr) *(table 6-2)*
percent of subbasin which is impervious

Holtan loss rate method -

$$\mathbf{f = [GI * A * SA^{BEXP}] + FC}$$

f is the infiltration potential in inches per hour
GI is a "growth index " representing the relative maturity of ground cover (range 0 to 1)
A is the infiltration capacity in inches per hour
SA is equivalent depth in inches of pore space in the surface layer of the soil which is available for storage of infiltrated water decreased by the amount of infiltrated water and increased by the percolation rate
FC is the constant rate of percolation of water through the soil profile below the surface layer (SCS hydrologic soil group)
BEXP is an empirical coefficient usually assumed to be **1.4**

Soil Conservation Service curve number method

FLOOD ROUTING

- the procedure by which a flood discharge hydrograph at any point on a stream is determined from a known discharge hydrograph at some point upstream
- a process used to predict the temporal and spatial variations of a flood as it moves through a river reach or reservoir
- strict math treatment of the factors not adaptable to a practical solution
- use approximate flood routing methods that either ignore some of the factors affecting flood wave movement or are based upon simplistic assumptions

two basic types of approximate methods

- storage routing methods (e.g. Muskingum)
- flood wave approximation methods

routing techniques

hydraulic routing based on the solution of partial differential equations of unsteady open channel flow St. Venant or dynamic wave equations

hydrologic routing the continuity equation and an analytical or an empirical relationship between storage within the reach and discharge at the outlet

HYDRAULIC ROUTING TECHNIQUES

the equations of motion

- continuity equation and momentum equation solved together with the proper boundary conditions they become the ***dynamic wave equations***

dynamic wave equations

- considered to be the most accurate and comprehensive solution to one dimensional unsteady flow problems in open channel flow
- they can be applied to a wide range of one dimensional flow problems:
  - ⇒ dam break flood wave routing
  - ⇒ flood stage and velocity forecasting
  - ⇒ evaluating flow conditions due to tidal fluctuations
  - ⇒ routing flows through irrigation and canal systems

assumptions:

- velocity is constant
- water surface is horizontal across any cross section
- flow is gradually varied with hydrostatic pressure prevailing at all points in the flow (vertical accelerations can be neglected)
- no lateral secondary circulation occurs
- channel boundaries are assumed to fixed; therefore no erosion or deposition occurs
- water is of uniform density and resistance to flow can be described by empirical formulas, such as the Mannings equation.

KINEMATIC WAVE APPROXIMATION

occurs when gravitational and frictional forces achieve a balance (this never occurs)

flow situations where gravitational and frictional forces *approach* an equilibrium: changes in depth and velocity with respect to time are small in magnitude when compared to the bed slope of the channel.

Momentum equation reduces to:

$$S_f = S_0$$

Kinematic wave equations:

- do not allow for hydrograph diffusion
- equations usually solved by finite difference techniques
- application of the equations limited to flow conditions that do not demonstrate appreciable hydrograph attenuation
- best applied to well defined, steep channels (10 ft/mi or greater) where the floodwave is gradually varied

diffusion wave approximation

- a significant improvement over the kinematic wave model because of the addition of a pressure differential term
- allows the diffusion model to describe the attenuation (diffusion) effect of the floodwave
- allows the specification of a boundary condition at the downstream extremity of the routing reach to account for backwater effects
- limited to slow to moderately rising flood waves
- most natural flood waves can be described with the diffusion form of the equation

quasi-steady dynamic wave approximation

- the third expansion of the dynamic wave equations
- not used in flood routing
- used for steady flood water surface profile computations

DATA REQUIREMENTS

The data requirements of the various hydraulic routing techniques are virtually the same

- flow data (hydrographs)
- channel cross sections and reach lengths
- roughness coefficients
- initial conditions
- boundary conditions

Channel cross sections

surveyed sections perpendicular to flow
accuracy
spacing
HEC report - accuracy of computed water surface profiles

HYDROLOGIC ROUTING TECHNIQUES

-the continuity equation and either an analytical or an empirical relationship between storage within the reach and discharge at the outlet.

modified puls reservoir routing

applied in *one* routing step

modified puls channel routing - storage in a river is not a function of outflow alone

determining the storage-outflow relationship for a river:

- steady flow profile determinations
- observed water surface profiles
- normal-depth calculations
- optimization techniques applied to observed inflow and outflow hydrographs

determining the number of routing steps (NSTSP):

initial estimate - $\mathbf{K} = \mathbf{L \backslash V_w}$

NSTPS = K / delta t

delta t should be less than 1/5 of the time of rise (t_r) of the inflow hydrograph

K = *floodway travel time through a reach*
L = *channel reach length*
$\mathbf{V_w}$ = *velocity of flood wave (not average velocity)*

Muskingum method defines the storage (S) in the reach as a linear function of weighted inflow and outflow

$$S = \text{prism storage} + \text{wedge storage}$$

prism storage - the water stored under the steady flow water surface profile
wedge storage - the additional storage under the actual water surface profile

$$S = KO + KX(I-O)$$

$$S = K[XI + (1-X)O]$$

O = rate of outflow from routing reach
I = rate of inflow to the routing reach
K = travel time of the flood wave through the reach
X = 0.0 (maximum attenuation) to 0.5 (no attenuation)

determining K and X

observed inflow and outflow hydrographs

- estimated as the travel time of the floodwave through the routing reach
- estimate the average flow velocity and multiply it by a factor (for a natural channel, multiply by 1.5)
- for channels with mild slopes and flows that do go out of bank X will be closer 0
- for steep streams, with well defined channels that do have flows going out of banks X will be close to 0.5
- most natural channels X lies between the two limits - "engineering judgment"

estimating Muskingum X coefficient in ungaged areas - Cunge method

selecting the number of sub reaches
(delta t) should not be less than 2KX to avoid negative coefficients and routing computation instabilities
a long routing reach should be subdivided so that the travel time through each subreach is approximately equal to the routing interval (delta t)

floodwave movement in natural channels.
Muskingum with a variable K or modified puls with wedge storage

Muskingum-Cunge channel routing

- a nonlinear coefficient method that accounts for hydrograph diffusion based on the physical channel properties and the inflowing hydroraph
- the parameters of the model are more physically based
- cannot account for backwater

data needed:

- representative cross sections
- reach length, L
- manning roughness coefficients, n
- friction slope, S_f or channel bed slope S_o

Applicability of Routing Techniques

hydrologic routing methods - utilized on a reach by reach basis from upstream to downstream

advantages

- simplicity
- ease of use
- computational efficiency
- accurate

hydraulic routing methods

- can simulate the widest range of flow situations and channel characteristics
- more physically based since they have one parameter (roughness coefficient) to estimate or calibrate

MAJOR FACTORS THAT SHOULD BE CONSIDERED IN THE METHOD SELECTION PROCESS

1. **backwater effects**

produced by tidal fluctuations, significant tributary inflows, dams, bridges, culverts, and channel constrictions

-for the *hydrologic methods*, only the *modified puls* method is capable of incorporating the effects of backwater into the solution

-for the *hydraulic methods*, all are applicable except the *kinematic wave* technique

2. **floodplains** - water flows out of the channel and into the overbank area

-all of the routing methods except for Muskingum

-when modeling floods through extremely flat and wide floodplains, the assumption of one dimensional flow may be invalid

3. **channel slope and hydrograph characteristics**

-for the *hydraulic methods*, only the *complete unsteady flow* equations are capable of routing flood waves through channels that range from steep to extremely flat

-for the *hydrologic methods*, the *Muskingum-Cunge* method is applicable to the widest range of channel slopes and inflowing hydrographs. Without gage data for calibration, the hydrologic methods should not be applies to channels with slopes less than 2 ft/mile

4. **flow networks**

-tributary flows
-stream confluences
-flow division
-changes in flow direction

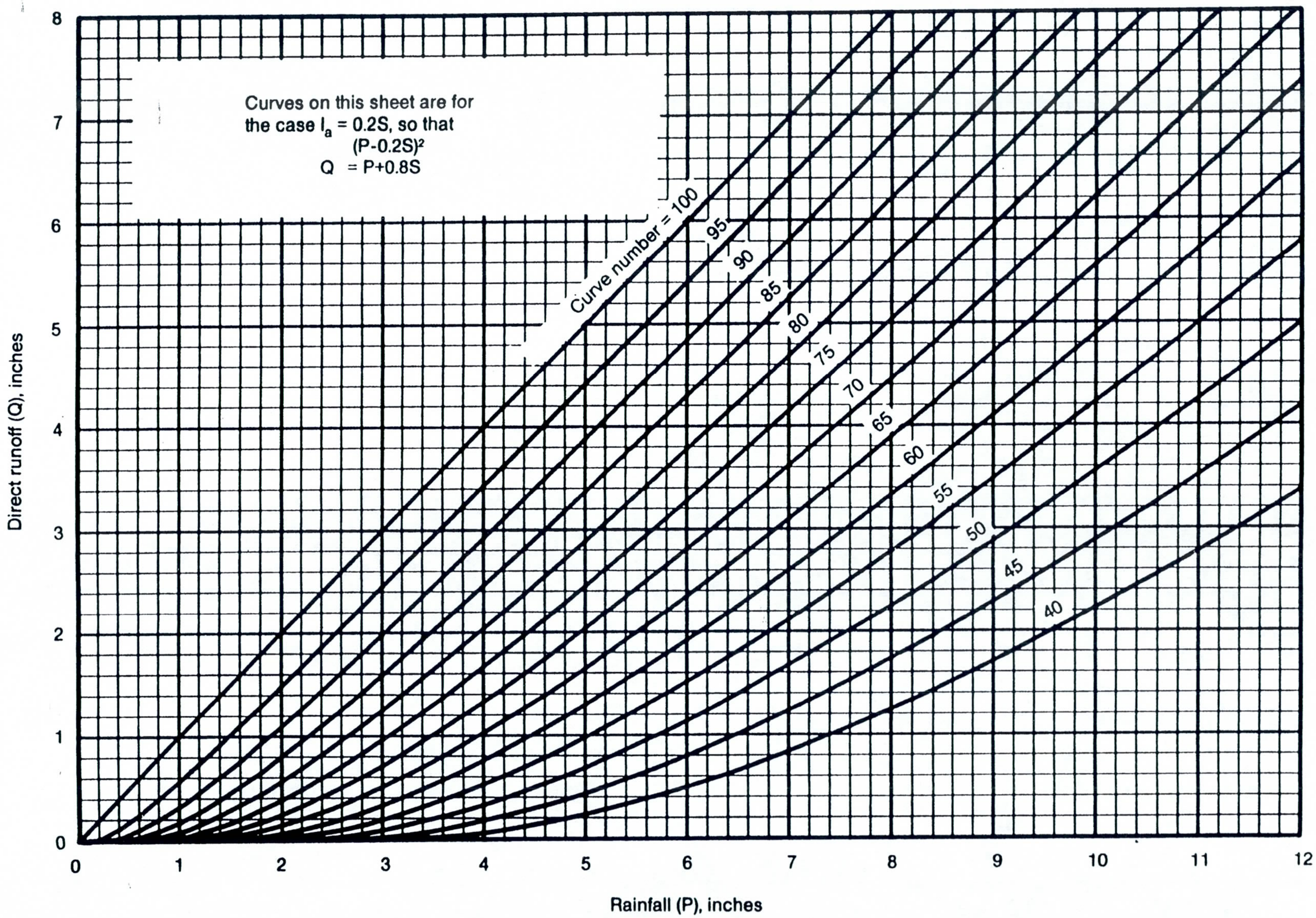
5. **flow regime**

6. **observed data**

7. **required accuracy**

8. **type of information desired - hydrographs, stages, velocities)**

9. **the familiarity and experience of the user with a given method**


Curves on this sheet are for the case $I_a = 0.2S$, so that
$Q = \frac{(P-0.2S)^2}{P+0.8S}$
Curve number = 100
95
90
85
80
75
70
65
60
55
50
45
40
Direct runoff (Q), inches
Rainfall (P), inches
0
1
2
3
4
5
6
7
8
9
10
11
12

USGS TR55

Runoff depth for selected CN's and rainfall amounts[1]

Rainfall	Runoff depth for curve number of—												
	40	45	50	55	60	65	70	75	80	85	90	95	98
	inches												
1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.08	0.17	0.32	0.56	0.79
1.2	.00	.00	.00	.00	.00	.00	.03	.07	.15	.27	.46	.74	.99
1.4	.00	.00	.00	.00	.00	.02	.06	.13	.24	.39	.61	.92	1.18
1.6	.00	.00	.00	.00	.01	.05	.11	.20	.34	.52	.76	1.11	1.38
1.8	.00	.00	.00	.00	.03	.09	.17	.29	.44	.65	.93	1.29	1.58
2.0	.00	.00	.00	.02	.06	.14	.24	.38	.56	.80	1.09	1.48	1.77
2.5	.00	.00	.02	.08	.17	.30	.46	.65	.89	1.18	1.53	1.96	2.27
3.0	.00	.02	.09	.19	.33	.51	.71	.96	1.25	1.59	1.98	2.45	2.77
3.5	.02	.08	.20	.35	.53	.75	1.01	1.30	1.64	2.02	2.45	2.94	3.27
4.0	.06	.18	.33	.53	.76	1.03	1.33	1.67	2.04	2.46	2.92	3.43	3.77
4.5	.14	.30	.50	.74	1.02	1.33	1.67	2.05	2.46	2.91	3.40	3.92	4.26
5.0	.24	.44	.69	.98	1.30	1.65	2.04	2.45	2.89	3.37	3.88	4.42	4.76
6.0	.50	.80	1.14	1.52	1.92	2.35	2.81	3.28	3.78	4.30	4.85	5.41	5.76
7.0	.84	1.24	1.68	2.12	2.60	3.10	3.62	4.15	4.69	5.25	5.82	6.41	6.76
8.0	1.25	1.74	2.25	2.78	3.33	3.89	4.46	5.04	5.63	6.21	6.81	7.40	7.76
9.0	1.71	2.29	2.88	3.49	4.10	4.72	5.33	5.95	6.57	7.18	7.79	8.40	8.76
10.0	2.23	2.89	3.56	4.23	4.90	5.56	6.22	6.88	7.52	8.16	8.78	9.40	9.76
11.0	2.78	3.52	4.26	5.00	5.72	6.43	7.13	7.81	8.48	9.13	9.77	10.39	10.76
12.0	3.38	4.19	5.00	5.79	6.56	7.32	8.05	8.76	9.45	10.11	10.76	11.39	11.76
13.0	4.00	4.89	5.76	6.61	7.42	8.21	8.98	9.71	10.42	11.10	11.76	12.39	12.76
14.0	4.65	5.62	6.55	7.44	8.30	9.12	9.91	10.67	11.39	12.08	12.75	13.39	13.76
15.0	5.33	6.36	7.35	8.29	9.19	10.04	10.85	11.63	12.37	13.07	13.74	14.39	14.76

[1]Interpolate the values shown to obtain runoff depths for CN's or rainfall amounts not shown.

Runoff curve numbers for urban areas[1]

Cover description		Curve numbers for hydrologic soil group—			
Cover type and hydrologic condition	Average percent impervious area[2]	A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.)[3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only)[4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation)[5]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2c).					

[1]Average runoff condition, and $I_a = 0.2S$.
[2]The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.
[3]CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.
[4]Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.
[5]Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4, based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

Runoff curve numbers for cultivated agricultural lands[1]

Cover description			Curve numbers for hydrologic soil group—			
Cover type	Treatment[2]	Hydrologic condition[3]	A	B	C	D
Fallow	Bare soil	—	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	C&T + CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
	C&T + CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded or broadcast legumes or rotation meadow	SR	Poor	66	77	85	89
		Good	58	72	81	85
	C	Poor	64	75	83	85
		Good	55	69	78	83
	C&T	Poor	63	73	80	83
		Good	51	67	76	80

[1]Average runoff condition, and $I_a = 0.2S$.
[2]*Crop residue cover* applies only if residue is on at least 5% of the surface throughout the year.
[3]Hydrologic condition is based on combination of factors that affect infiltration and runoff, including (a) density and canopy of vegetative areas, (b) amount of year-round cover, (c) amount of grass or close-seeded legumes in rotations, (d) percent of residue cover on the land surface (good ≥ 20%), and (e) degree of surface roughness.
Poor: Factors impair infiltration and tend to increase runoff.
Good: Factors encourage average and better than average infiltration and tend to decrease runoff.

NRCS

~~USGS~~ TR55

Runoff curve numbers for other agricultural lands[1]

Cover description		Curve numbers for hydrologic soil group—			
Cover type	Hydrologic condition	A	B	C	D
Pasture, grassland, or range—continuous forage for grazing.[2]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow—continuous grass, protected from grazing and generally mowed for hay.	—	30	58	71	78
Brush—brush-weed-grass mixture with brush the major element.[3]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	[4]30	48	65	73
Woods—grass combination (orchard or tree farm).[5]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods.[6]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	[4]30	55	70	77
Farmsteads—buildings, lanes, driveways, and surrounding lots.	—	59	74	82	86

[1] Average runoff condition, and $I_a = 0.2S$.

[2] *Poor:* <50% ground cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: >75% ground cover and lightly or only occasionally grazed.

[3] *Poor:* <50% ground cover.
Fair: 50 to 75% ground cover.
Good: >75% ground cover.

[4] Actual curve number is less than 30; use CN = 30 for runoff computations.

[5] CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.

[6] *Poor:* Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

USGS TR55

Runoff curve numbers for arid and semiarid rangelands[1]

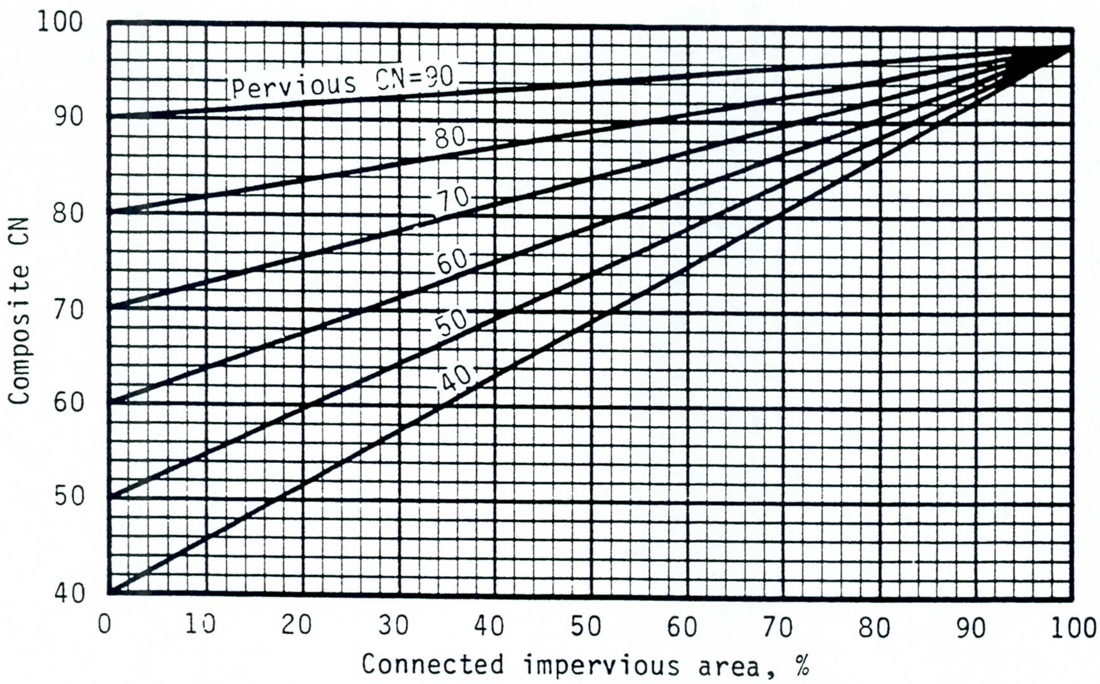
Cover description		Curve numbers for hydrologic soil group—			
Cover type	Hydrologic condition[2]	A[3]	B	C	D
Herbaceous—mixture of grass, weeds, and low-growing brush, with brush the minor element.	Poor		80	87	93
	Fair		71	81	89
	Good		62	74	85
Oak-aspen—mountain brush mixture of oak brush, aspen, mountain mahogany, bitter brush, maple, and other brush.	Poor		66	74	79
	Fair		48	57	63
	Good		30	41	48
Pinyon-juniper—pinyon, juniper, or both; grass understory.	Poor		75	85	89
	Fair		58	73	80
	Good		41	61	71
Sagebrush with grass understory.	Poor		67	80	85
	Fair		51	63	70
	Good		35	47	55
Desert shrub—major plants include saltbush, greasewood, creosotebush, blackbrush, bursage, palo verde, mesquite, and cactus.	Poor	63	77	85	88
	Fair	55	72	81	86
	Good	49	68	79	84

[1]Average runoff condition, and $I_a = 0.2S$. For range in humid regions, use table 2-2c.

[2]*Poor:* <30% ground cover (litter, grass, and brush overstory).
Fair: 30 to 70% ground cover.
Good: >70% ground cover.

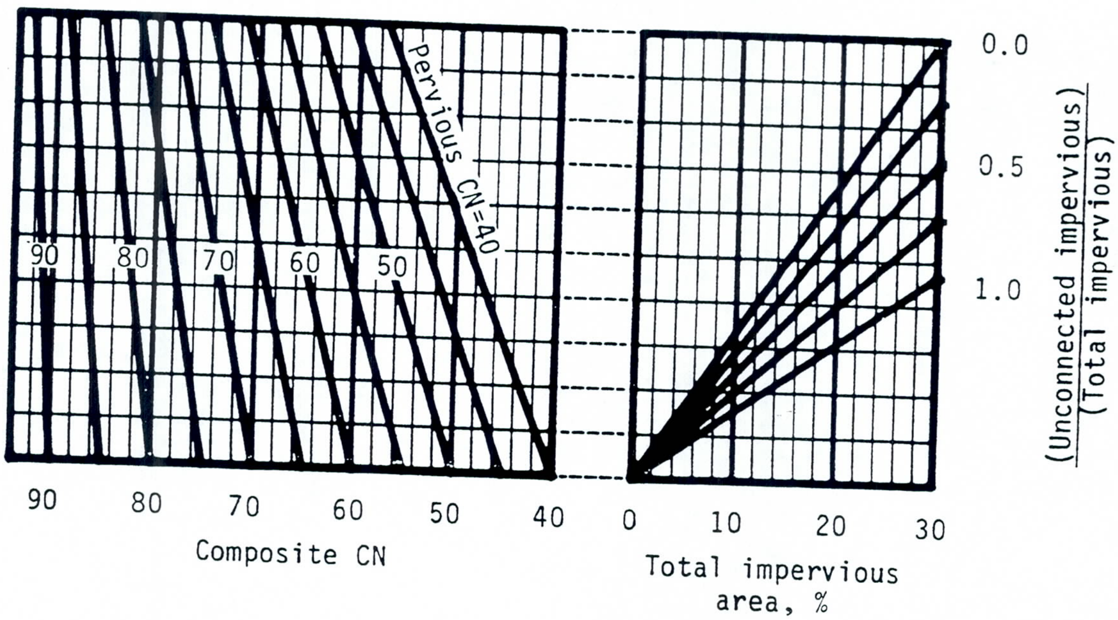
[3]Curve numbers for group A have been developed only for desert shrub.

USGS TR55

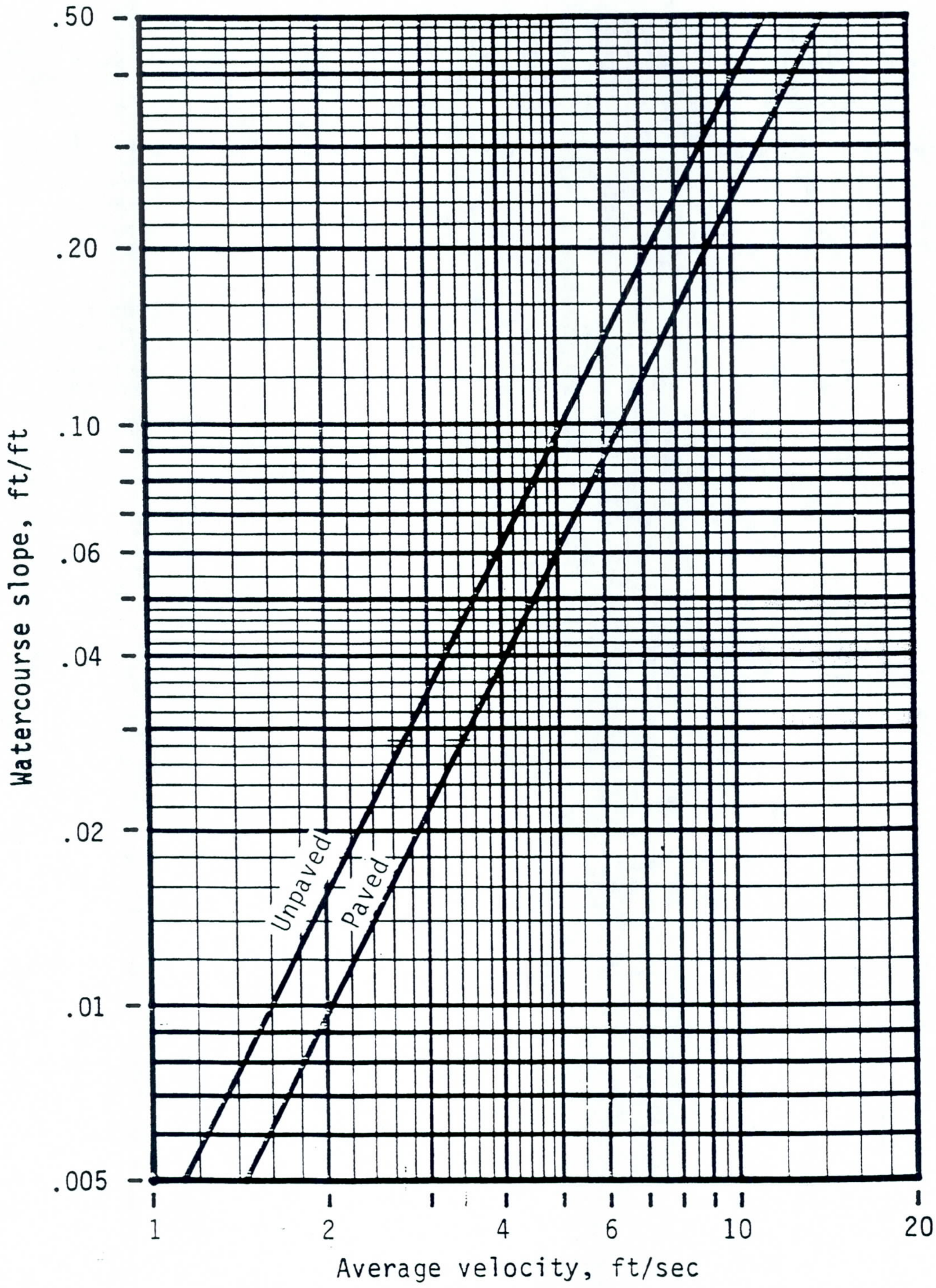


Composite CN with connected impervious area.

~~USGS~~ TR55



Composite CN with unconnected impervious areas and total impervious area less than 30%.



Average velocities for estimating travel time for shallow concentrated flow.

USGS TR55

Roughness coefficients (Manning's n) for sheet flow < 1.2"

Surface description	n[1]
Smooth surfaces (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated soils:	
Residue cover ≤20%	0.06
Residue cover >20%	0.17
Grass:	
Short grass prairie	0.15
Dense grasses[2]	0.24
Bermudagrass	0.41
Range (natural)	0.13
Woods:[3]	
Light underbrush	0.40
Dense underbrush	0.80

[1]The n values are a composite of information compiled by Engman (1986).
[2]Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.
[3]When selecting n, consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

Defining the drainage area

- Square miles
- Sub basins
- Topography
- Cover
- Length
- Soil


Pine Lake
Snapfinger
Creek
Indian
Ud
AmC
PuE
PfE
Ca
AuC
CuC
10
PfC
CeC
CeB
PfD
MdB
MdC
MfC2
Tf
MfD2
w
GeC
HsB
GeB
PgC2
MdD
GeE
AkB
AkA
GwC2
GwD2
GwE2
MdE

SOIL AND WATER FEATURES

[See text for definitions of terms such as "occasional," "brief," "apparent," and "perched." The symbol > means more than. Absence of an entry indicates that the feature is not a concern]

Map symbol and soil name	Hydro-logic group	Flooding			High water table			Bedrock		Risk of corrosio	
		Frequency	Duration	Months	Depth	Kind	Months	Depth	Hard-ness	Uncoated steel	Concret
					Ft			In			
AkA---------------- Altavista	C	Occasional	Very brief	Mar-Jul	1.5-2.5	Apparent	Dec-Mar	>60	---	Moderate	Moderat
AkB---------------- Altavista	C	None---------	---	---	1.5-2.5	Apparent	Dec-Mar	>60	---	Moderate	Moderat
AmB, AmC----------- Appling	B	None---------	---	---	>6.0	---	---	>60	---	Moderate	Moderat
AuC:* Appling-----------	B	None---------	---	---	>6.0	---	---	>60	---	Moderate	Moderat
Urban land.											
AvD, AvF----------- Ashlar	B	None---------	---	---	>6.0	---	---	22-40	Hard	Low-------	High.
AwC,* AwE:* Ashlar------------	B	None---------	---	---	>6.0	---	---	22-40	Hard	Low-------	High.
Wedowee-----------	B	None---------	---	---	>6.0	---	---	>60	---	Moderate	High.
Ca----------------- Cartecay	C	Frequent----	Brief------	Dec-Mar	0.5-1.5	Apparent	Jan-Apr	>60	---	Low-------	Moderat
CeB, CeC, CeD, CfC2-------------- Cecil	B	None---------	---	---	>6.0	---	---	>60	---	Moderate	Moderat
CuC:* Cecil-------------	B	None---------	---	---	>6.0	---	---	>60	---	Moderate	Moderat
Urban land.											
CvF---------------- Chestatee	B	None---------	---	---	>6.0	---	---	>60	---	High------	High.
GeB, GeC, GeD, GeE, GwC2, GwD2, GwE2-------------- Gwinnett	B	None---------	---	---	>6.0	---	---	>60	---	High------	Moderat
HsB, HsC, HtC2---- Hiwassee	B	None---------	---	---	>6.0	---	---	>60	---	Moderate	Moderat
IrC---------------- Iredell	D	None---------	---	---	1.0-2.0	Perched	Nov-Mar	40-60	Soft	High------	Low.
MdB, MdC, MdD, MdE, MfC2, MfD2, MfE2-------------- Madison	B	None---------	---	---	>6.0	---	---	>60	---	High------	Modera
MvD2, MvE2, MwD, MwF--------------- Musella	B	None---------	---	---	>6.0	---	---	14-20	Soft	Moderate	Modera
PfC, PfD, PfE, PgC2, PgD2-------- Pacolet	B	None---------	---	---	>6.0	---	---	>60	---	High------	High.
PuE:* Pacolet-----------	B	None---------	---	---	>6.0	---	---	>60	---	High------	High.
Urban land.											

HYDROLOGIC SOIL GROUPS (**HSG**)

(indicates the minimum rate of infiltration obtained for bare soil after prolonged wetting)

Group A - *sand, loamy sand, sandy loam*

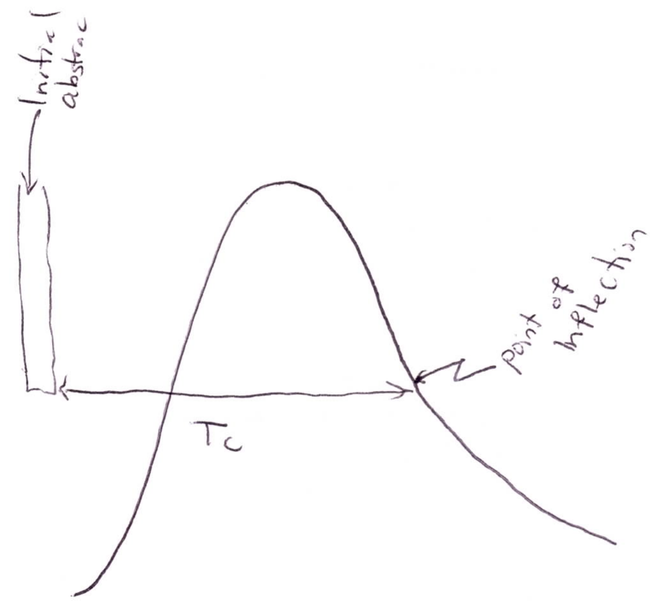
- low runoff potential
- high infiltration rates
- sands or gravels
- water transmission > 0.30 in/hr

Group B - *silt loam, loam*
moderate infiltration rates
0.15 - 0.30 in/hr

Group C - *sandy clay loam*
low infiltration rates
have a layer that impedes downward movement of water and soils
0.05 - 0.15 in/hr

Group D - *clay loam, silty clay loam, sandy clay, silty clay, clay*
high runoff potential - swelling, water table, clay pan
0 - 0.05 in/hr

Drainage basin soils may be identified from a soil survey report (SCS office or soil and water conservation district office)


Initial abstrac
point of inflection
Tc

travel time (T_t) - time for water to travel from one location in a watershed to another downstream location

- determined primarily by:
  - slope
  - length of the flow path
  - depth of flow
  - channel surface roughness

$$T_t = \frac{l}{3600\ v}$$

time of concentration (Tc) time it takes for water to travel from the hydraulically most distant location to the location of interest

the time from the end of excessive rainfall to the point on the falling limb of the hydrograph (point of inflection) where the recession curve begins

lag (L) - the delay in time, after a brief, heavy rainfall over a watershed, before the runoff reaches its maximum peak

estimating T_c, T_t, and L

- field observations - soil, roughness, stability, debris
- purpose for estimate - guide to the amount of work
- stream hydraulics method
- upland method
- curve number method (for areas of less than 2000 acres)

-
$$L = \frac{l^{0.8}\ (S + 1)^{0.7}}{1900\ Y^{0.5}}$$

l = hydraulic length of watershed in feet

Y = average watershed land slope in percent

SCS CURVE NUMBER METHODOLOGY

runoff- determined primarily by rainfall amount and infiltration characteristics related to:

- soil type
- soil moisture
- antecedent rainfall
- cover type
- impervious surfaces
- surface retention

runoff curve number (CN) based on:

- soil
- plant cover
- amount of impervious area interception
- surface storage

Estimating Runoff by the SCS Runoff Curve Number Method

$$\mathbf{Q} = \frac{(P - I_a)^2}{(P - I_a) + S}$$

Q = runoff in inches
P = rainfall in inches
S = potential maximum retention after runoff begins (inches)
I_a = initial abstraction (inches)
all losses before runoff begins
= **0.2 S** (studies of many *small agricultural* watersheds)

$$\mathbf{Q} = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

S is a function of soil, and cover conditions (CN) CN has a range of 0 - 100

$$S = \frac{1000}{CN'} - 10$$

CN' is the *complex number* and is approximately the same as **CN**

What factors determine a drainage basin curve number (CN)?

- the hydrologic soil group **(HSG)**
- cover type
  - vegetation, bare soil, impervious surfaces
- treatment
  - cultivated agricultural lands
- hydrologic conditions
  - the effects of cover type and treatment on infiltration and runoff
- antecedent runoff conditions **(ARC)**
  - attempt to account for the variation in CN from storm to storm
- unconnected impervious areas

Limitations of SCS Runoff Curve Number Method

- curve numbers describe *average* conditions
- does not account for rainfall intensity or duration
- 0.2 S is an *approximation* for *agricultural* areas
- does not account for snowmelt or runoff from frozen ground
- less accurate if runoff is less than 0.5 inches
- does not account for subsurface flow or high water tables
- not applicable for weighted CN less than 40

TYPES OF FLOW

- surface flow
  - -overland flow
  - -channel flow
- surface flow with transmission losses
  when infiltration takes place in a channel , it is called a transmission loss
- quick return flow
  springs and seeps
- base flow

STREAM FLOW HYDROGRAPHS

factors affecting runoff

- spatial and temporal distribution of rainfall
- rate of snowmelt
- hydraulics of streams
- watershed and channel storage
- others

types of hydrographs

- natural
- synthetic
- unit
- dimensionless

UNIT HYDROGRAPH

1932 - L. K. Sherman

assumptions

- discharge at any time is proportional to the volume of runoff
- time factors affecting hydrograph shape are constant

principles

- the hydrograph of surface runoff from a watershed due to a given pattern of rainfall is invariable
- the hydrograph resulting from a given pattern of rainfall excess can be built up by superimposing the unit hydrograph due to the separate amounts of rainfall excess occurring in each unit period
- the ordinates of the hydrograph are proportional to the volume of rainfall excess

DIMENSIONLESS UNIT GRAPH (SCS)

ordinate $\mathbf{q/q_p}$ or $\mathbf{Q_a/Q}$
abscissa $\mathbf{t/T_p}$

point of inflection approximately 1.7 times the time to peak
time to peak 0.2 of the time of base
37.5 % of the total runoff volume in the rising side - one unit of time, one unit of discharge

FLOOD HYDROGRAPH ANALYSES AND COMPUTATIONS

-deriving fundamental hydrologic factors by analyzing observed hydrographs of stream flow and related meteorological events

-methods for utilizing deduced factors in computing hypothetical hydrographs of runoff for different conditions

Analysis of a flood hydrograph-

- estimates of the intensity, depth and areal distribution of precipitation causing the runoff (and rate of snowmelt, where this is significant)
- computation of difference between precipitation and direct runoff, expressed as initial loss and infiltration
- determination of the combined effect of drainage area and channel characteristics on the regimen of runoff, expressed herein in terms of "unit hydrographs"

*computation of **hypothetical hydrographs**, based on data derived from natural hydrograph analysis and supplementary studies:*

- determining the ***design storm*** rainfall values, the areal distribution and sequence of occurrence of unit increments that would produce critical rates of runoff , or rates corresponding to specified lesser magnitudes according to the purpose for the estimate
- selecting ***infiltration indices*** and initial loss values to correspond with the given drainage area and assumptions regarding season of the year, antecedent rainfall and other considerations affecting volume of rainfall
- selection of ***unit hydrographs*** to represent the probable order of runoff from adopted design storm rainfall excess
- computation of hypothetical hydrographs by combining factors

transformation of precipitation excess to stormwater runoff

- unit hydrograph
- kinematic wave approximation

Unit hydrograph

-represents direct runoff at the outlet of a basin resulting from one unit (e.g. 1 inch) of precipitation excess over the basin

assumptions

- precipitation excess and losses can be treated as basin average (lumped) quantities (divide the basin into sub basins)

- the ordinates of a direct runoff hydrograph corresponding to precipitation excess of a given duration are directly proportional to the volume of excess (assumption of linearity)

- the direct runoff hydrograph resulting from a given increment of precipitation excess is independent of the time occurrence of the excess (assumption of time invariance)

UNIT HYDROGRAPHS FOR UNGAGED BASINS

Ungaged - there is no stream gage at the basin outlet for which measurements during historical storms are available and data from precipitation gages are not available with which hyetographs of basin average precipitation can be developed for the storms

<u>*Synthetic unit hydrographs*</u>

SCS dimensionless unit hydrograph

based on data from a large number of small rural basins
37.5 % of the area under the hydrograph occurs from the origin to peak

$$\mathbf{Q_p = 484\ A / t_p}$$

where: $\mathbf{Q_p}$ = peak discharge of unit hydrograph in cfs
$\mathbf{A}$ = basin area, in square miles
$\mathbf{t_p}$ = time to peak of unit hydrograph, in hours, which can be expressed as:

$$\mathbf{D/2 + t_l}$$

where: $\mathbf{D}$ = duration of unit excess for unit hydrograph
$\mathbf{t_l}$ = lag, defined as the time from the centroid of precipitation excess to the time of the peak of the unit hydrograph

$$\mathbf{t_l = 0.6\ t_C}$$

where $\mathbf{t_C}$ is the time of concentration

the constant **484** actually varies from about **600** for basins with steep slopes to **300** for flat swampy basins

Single-linear reservoir method

for small basins with short response times
requires single parameter "K"

Nash model

requires two parameters - "n" and "K"

Clark model

- effects of basin shape (and other factors) on time of travel can be taken into account
- a translation hydrograph at the basin outlet is developed by translating (lagging) the excess based on travel time to the outlet
- requires two parameters - T_c *and R*

Snyder method

provides equations that define characteristics of the unit hydrographs directly without the use of a conceptual model

$$\mathbf{t_t = C_t\,(LL_{ca})^{0.3}}$$

$$\mathbf{Q_p = 640C_pA/t_l}$$

where: $\mathbf{t_l}$ = lag of the "standard" unit hydrograph in hours
$\mathbf{C_t}$ and $\mathbf{C_p}$ = empirical coefficient; use regional values
$\mathbf{L}$ = length of main water course from basin outlet to upstream boundary of basin, in miles
$\mathbf{L_{ca}}$ = length of main watercourse from basin outlet to point opposite centroid of basin area, in miles
$\mathbf{Q_p}$ = peak discharge of "standard" unit hydrograph in cubic feet per second
$\mathbf{A}$ = basin area, in square miles

The standard unit hydrograph is one for which the following relationship holds:

$$\mathbf{t_r = t_l / 5.5}$$

where: $\mathbf{t_r}$ = duration of rainfall excess
$\mathbf{t_l}$ = time from center of mass of the unit excess to the time of the peak of the unit hydrograph

UNIT HYDROGRAPHS FOR GAUGED BASINS

- "isolated storm" method
- S - graph method
- matrix method

optimization techniques - obtain parameter values that enable a "best fit" of the observed hydrograph

Procedure

- obtain precipitation and discharge data for actual events
- determine initial streamflow conditions for each event and appropriate values for parameters with which to define flows
- perform an optimization of values for loss and unit hydrograph parameters for each storm
- adopt a single set of values

KINEMATIC WAVE APPROACH

- often used in urban watershed modeling
- very good for modeling overland flow at shallow depths or channel flow in moderately steep channels
- takes a distributed view of a subbasin rather than a lumped view
- captures the different responses from both pervious and impervious areas in a single subbasin
- produces a non linear response to rainfall excess

The kinematic wave equations are based on :

the conservation of mass:

inflow - outflow = the rate of change of channel storage

and *the conservation of momentum*:

gravity + pressure + friction = mass * fluid acceleration

kinematic wave conservation of momentum: $\mathbf{S_f = S_o}$

the momentum of the flow can be approximated by a uniform flow assumption, such as:

$$\mathbf{Q = alpha\ A^m}$$

where **alpha** is related to surface roughness and ^{m} is related flow geometry and **A** is the cross sectional flow area *data needed for each overland flow plane*:

- average overland flow length
- representative slope
- average roughness coefficient (table 7-1)
- the percentage of the subbasin area which the overland flow plane represents
- infiltration and loss rate parameters

data needed to describe collector and sub-collector channels as well as the main channel

- representative channel length
- Mannings n
- average slope
- channel shape
- channel dimensions
- amount of area serviced by the channel element

LOSSES

- interception
- surface storage
- soil infiltration

Surface loss estimation

interception

forested greatest (10-20% of total precipitation) (up to 2.0 inches)
agricultural for a storm depth of 1.0 inch, 3-16 % interception
urban

detention storage

forested
agricultural 0.5 inch after tillage
urban

(see Table 6-1)

soil infiltration affected by-

- chemistry of the water
- biologic activity
- soil heterogeneity
- surface cover

initial water content

Saturated hydraulic capacity - proportionality constant between hydraulic gradient and flow in Darcy's law

effect of surface on rainfall (pg. 6-3,(6))

forested areas - greatest surface losses, no overland flow
range land - grazing
agricultural areas - crusted surfaces
urban area - impervious area

Horton process - overland flow results when all surface storages are filled and rainfall rate exceeds the infiltration rate

Hillslope process - direct runoff is the sum of surface and subsurface flow

modeling -
- physically based - solutions to the Richards equation
- conceptual - Holtan
- empirical - SCS curve number (includes surface losses 6-4a)

Antecedent Moisture Conditions (before beginning of rainfall)
antecedent precipitation index (API)

Infiltration Methods

Green and Ampt - as the water content at the soil surface increases, the method models the movement of the infiltrated water by approximating the wetting front with a piston type displacement (*Figure 6-5)*

LG card HEC-1 (pg. A-39) - initial loss in inches (mm)
volumetric moisture deficit
wetting front suction inches (mm) *(table 6-2)*
hydraulic conductivity at natural saturation inches per hour (mm/hr) *(table 6-2)*
percent of subbasin which is impervious

Holtan loss rate method -

$$\mathbf{f = [GI * A * SA^{BEXP}] + FC}$$

f is the infiltration potential in inches per hour
GI is a "growth index " representing the relative maturity of ground cover (range 0 to 1)
A is the infiltration capacity in inches per hour
SA is equivalent depth in inches of pore space in the surface layer of the soil which is available for storage of infiltrated water decreased by the amount of infiltrated water and increased by the percolation rate
FC is the constant rate of percolation of water through the soil profile below the surface layer (SCS hydrologic soil group)
BEXP is an empirical coefficient usually assumed to be **1.4**

Soil Conservation Service curve number method

FLOOD ROUTING

- the procedure by which a flood discharge hydrograph at any point on a stream is determined from a known discharge hydrograph at some point upstream
- a process used to predict the temporal and spatial variations of a flood as it moves through a river reach or reservoir
- strict math treatment of the factors not adaptable to a practical solution
- use approximate flood routing methods that either ignore some of the factors affecting flood wave movement or are based upon simplistic assumptions

two basic types of approximate methods

- storage routing methods (e.g. Muskingum)
- flood wave approximation methods

routing techniques

hydraulic routing based on the solution of partial differential equations of unsteady open channel flow St. Venant or dynamic wave equations

hydrologic routing the continuity equation and an analytical or an empirical relationship between storage within the reach and discharge at the outlet

HYDRAULIC ROUTING TECHNIQUES

the equations of motion

- continuity equation and momentum equation solved together with the proper boundary conditions they become the ***dynamic wave equations***

dynamic wave equations

- considered to be the most accurate and comprehensive solution to one dimensional unsteady flow problems in open channel flow
- they can be applied to a wide range of one dimensional flow problems:

  ⇒ dam break flood wave routing
  ⇒ flood stage and velocity forecasting
  ⇒ evaluating flow conditions due to tidal fluctuations
  ⇒ routing flows through irrigation and canal systems

assumptions:

- velocity is constant
- water surface is horizontal across any cross section
- flow is gradually varied with hydrostatic pressure prevailing at all points in the flow (vertical accelerations can be neglected)
- no lateral secondary circulation occurs
- channel boundaries are assumed to fixed; therefore no erosion or deposition occurs
- water is of uniform density and resistance to flow can be described by empirical formulas, such as the Mannings equation.

KINEMATIC WAVE APPROXIMATION

occurs when gravitational and frictional forces achieve a balance (this never occurs)

flow situations where gravitational and frictional forces *approach* an equilibrium: changes in depth and velocity with respect to time are small in magnitude when compared to the bed slope of the channel.

Momentum equation reduces to:

$$S_f = S_0$$

Kinematic wave equations:

- do not allow for hydrograph diffusion
- equations usually solved by finite difference techniques
- application of the equations limited to flow conditions that do not demonstrate appreciable hydrograph attenuation
- best applied to well defined, steep channels (10 ft/mi or greater) where the floodwave is gradually varied

diffusion wave approximation

- a significant improvement over the kinematic wave model because of the addition of a pressure differential term
- allows the diffusion model to describe the attenuation (diffusion) effect of the floodwave
- allows the specification of a boundary condition at the downstream extremity of the routing reach to account for backwater effects
- limited to slow to moderately rising flood waves
- most natural flood waves can be described with the diffusion form of the equation

quasi-steady dynamic wave approximation

- the third expansion of the dynamic wave equations
- not used in flood routing
- used for steady flood water surface profile computations

DATA REQUIREMENTS

The data requirements of the various hydraulic routing techniques are virtually the same

- flow data (hydrographs)
- channel cross sections and reach lengths
- roughness coefficients
- initial conditions
- boundary conditions

Channel cross sections

surveyed sections perpendicular to flow
accuracy
spacing
HEC report - accuracy of computed water surface profiles

HYDROLOGIC ROUTING TECHNIQUES

-the continuity equation and either an analytical or an empirical relationship between storage within the reach and discharge at the outlet.

modified puls reservoir routing

applied in *one* routing step

modified puls channel routing - storage in a river is not a function of outflow alone

determining the storage-outflow relationship for a river:

- steady flow profile determinations
- observed water surface profiles
- normal-depth calculations
- optimization techniques applied to observed inflow and outflow hydrographs

determining the number of routing steps (NSTSP):

initial estimate - $\mathbf{K = L \backslash V_w}$

NSTPS = K / delta t

delta t should be less than 1/5 of the time of rise (t_r) of the inflow hydrograph

K = *floodway travel time through a reach*
L = *channel reach length*
$\mathbf{V_w}$ = *velocity of flood wave (not average velocity)*

<u>Muskingum method</u> defines the storage (S) in the reach as a linear function of weighted inflow and outflow

S = prism storage + wedge storage

prism storage - the water stored under the steady flow water surface profile
wedge storage - the additional storage under the actual water surface profile

$$S = KO + KX(I-O)$$

$$S = K[XI + (1-X)O]$$

O = rate of outflow from routing reach
I = rate of inflow to the routing reach
K = travel time of the flood wave through the reach
X = 0.0 (maximum attenuation) to 0.5 (no attenuation)

determining K and X

<u>observed inflow and outflow hydrographs</u>

- estimated as the travel time of the floodwave through the routing reach
- estimate the average flow velocity and multiply it by a factor (for a natural channel, multiply by 1.5)
- for channels with mild slopes and flows that do go out of bank X will be closer 0
- for steep streams, with well defined channels that do have flows going out of banks X will be close to 0.5
- most natural channels X lies between the two limits - "engineering judgment"

<u>estimating Muskingum X coefficient in ungaged areas - Cunge method</u>

selecting the number of sub reaches
(delta t) should not be less than 2KX to avoid negative coefficients and routing computation instabilities
a long routing reach should be subdivided so that the travel time through each subreach is approximately equal to the routing interval (delta t)

floodwave movement in natural channels.
Muskingum with a variable K or modified puls with wedge storage

Muskingum-Cunge channel routing

- a nonlinear coefficient method that accounts for hydrograph diffusion based on the physical channel properties and the inflowing hydroraph
- the parameters of the model are more physically based
- cannot account for backwater

data needed:

- representative cross sections
- reach length, L
- manning roughness coefficients, n
- friction slope, S_f or channel bed slope S_o

Applicability of Routing Techniques

hydrologic routing methods - utilized on a reach by reach basis from upstream to downstream

advantages

- simplicity
- ease of use
- computational efficiency
- accurate

hydraulic routing methods

- can simulate the widest range of flow situations and channel characteristics
- more physically based since they have one parameter (roughness coefficient) to estimate or calibrate

MAJOR FACTORS THAT SHOULD BE CONSIDERED IN THE METHOD SELECTION PROCESS

1. **backwater effects**

   produced by tidal fluctuations, significant tributary inflows, dams, bridges, culverts, and channel constrictions

   -for the *hydrologic methods*, only the *modified puls* method is capable of incorporating the effects of backwater into the solution

   -for the *hydraulic methods*, all are applicable except the *kinematic wave* technique

2. **floodplains** - water flows out of the channel and into the overbank area

   -all of the routing methods except for Muskingum

   -when modeling floods through extremely flat and wide floodplains, the assumption of one dimensional flow may be invalid

3. **channel slope and hydrograph characteristics**

   -for the *hydraulic methods*, only the *complete unsteady flow* equations are capable of routing flood waves through channels that range from steep to extremely flat

   -for the *hydrologic methods*, the *Muskingum-Cunge* method is applicable to the widest range of channel slopes and inflowing hydrographs. Without gage data for calibration, the hydrologic methods should not be applies to channels with slopes less than 2 ft/mile

4. **flow networks**

   -tributary flows
   -stream confluences
   -flow division
   -changes in flow direction

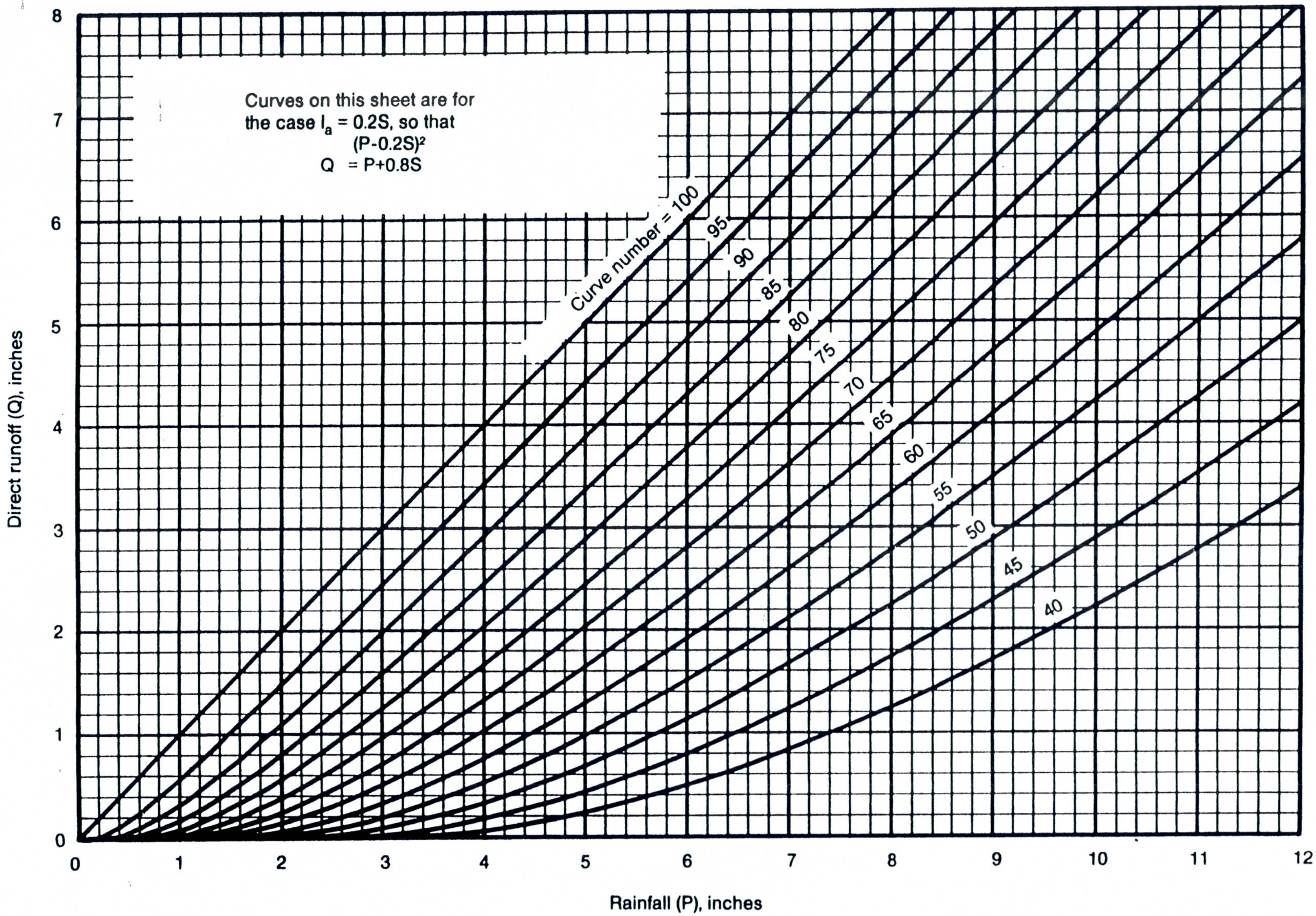
5. **flow regime**

6. **observed data**

7. **required accuracy**

8. **type of information desired - hydrographs, stages, velocities)**

9. **the familiarity and experience of the user with a given method**


Curves on this sheet are for
the case I_a = 0.2S, so that
$Q = \frac{(P-0.2S)^2}{P+0.8S}$
Curve number = 100
95
90
85
80
75
70
65
60
55
50
45
40
Direct runoff (Q), inches
Rainfall (P), inches
0
1
2
3
4
5
6
7
8
9
10
11
12

USGS TR55

Runoff depth for selected CN's and rainfall amounts[1]

Rainfall	Runoff depth for curve number of—												
	40	45	50	55	60	65	70	75	80	85	90	95	98
	inches												
1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.08	0.17	0.32	0.56	0.79
1.2	.00	.00	.00	.00	.00	.00	.03	.07	.15	.27	.46	.74	.99
1.4	.00	.00	.00	.00	.00	.02	.06	.13	.24	.39	.61	.92	1.18
1.6	.00	.00	.00	.00	.01	.05	.11	.20	.34	.52	.76	1.11	1.38
1.8	.00	.00	.00	.00	.03	.09	.17	.29	.44	.65	.93	1.29	1.58
2.0	.00	.00	.00	.02	.06	.14	.24	.38	.56	.80	1.09	1.48	1.77
2.5	.00	.00	.02	.08	.17	.30	.46	.65	.89	1.18	1.53	1.96	2.27
3.0	.00	.02	.09	.19	.33	.51	.71	.96	1.25	1.59	1.98	2.45	2.77
3.5	.02	.08	.20	.35	.53	.75	1.01	1.30	1.64	2.02	2.45	2.94	3.27
4.0	.06	.18	.33	.53	.76	1.03	1.33	1.67	2.04	2.46	2.92	3.43	3.77
4.5	.14	.30	.50	.74	1.02	1.33	1.67	2.05	2.46	2.91	3.40	3.92	4.26
5.0	.24	.44	.69	.98	1.30	1.65	2.04	2.45	2.89	3.37	3.88	4.42	4.76
6.0	.50	.80	1.14	1.52	1.92	2.35	2.81	3.28	3.78	4.30	4.85	5.41	5.76
7.0	.84	1.24	1.68	2.12	2.60	3.10	3.62	4.15	4.69	5.25	5.82	6.41	6.76
8.0	1.25	1.74	2.25	2.78	3.33	3.89	4.46	5.04	5.63	6.21	6.81	7.40	7.76
9.0	1.71	2.29	2.88	3.49	4.10	4.72	5.33	5.95	6.57	7.18	7.79	8.40	8.76
10.0	2.23	2.89	3.56	4.23	4.90	5.56	6.22	6.88	7.52	8.16	8.78	9.40	9.76
11.0	2.78	3.52	4.26	5.00	5.72	6.43	7.13	7.81	8.48	9.13	9.77	10.39	10.76
12.0	3.38	4.19	5.00	5.79	6.56	7.32	8.05	8.76	9.45	10.11	10.76	11.39	11.76
13.0	4.00	4.89	5.76	6.61	7.42	8.21	8.98	9.71	10.42	11.10	11.76	12.39	12.76
14.0	4.65	5.62	6.55	7.44	8.30	9.12	9.91	10.67	11.39	12.08	12.75	13.39	13.76
15.0	5.33	6.36	7.35	8.29	9.19	10.04	10.85	11.63	12.37	13.07	13.74	14.39	14.76

[1]Interpolate the values shown to obtain runoff depths for CN's or rainfall amounts not shown.

Runoff curve numbers for urban areas[1]

Cover description		Curve numbers for hydrologic soil group—			
Cover type and hydrologic condition	Average percent impervious area[2]	A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.)[3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only)[4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation)[5]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2c).					

[1]Average runoff condition, and $I_a = 0.2S$.
[2]The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.
[3]CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.
[4]Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.
[5]Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4, based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

Runoff curve numbers for cultivated agricultural lands[1]

Cover description			Curve numbers for hydrologic soil group—			
Cover type	Treatment[2]	Hydrologic condition[3]	A	B	C	D
Fallow	Bare soil	—	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	C&T + CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
	C&T + CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded or broadcast legumes or rotation meadow	SR	Poor	66	77	85	89
		Good	58	72	81	85
	C	Poor	64	75	83	85
		Good	55	69	78	83
	C&T	Poor	63	73	80	83
		Good	51	67	76	80

[1]Average runoff condition, and $I_a = 0.2S$.
[2]*Crop residue cover* applies only if residue is on at least 5% of the surface throughout the year.
[3]Hydrologic condition is based on combination of factors that affect infiltration and runoff, including (a) density and canopy of vegetative areas, (b) amount of year-round cover, (c) amount of grass or close-seeded legumes in rotations, (d) percent of residue cover on the land surface (good ≥ 20%), and (e) degree of surface roughness.
Poor: Factors impair infiltration and tend to increase runoff.
Good: Factors encourage average and better than average infiltration and tend to decrease runoff.

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Runoff curve numbers for other agricultural lands[1]

Cover description		Curve numbers for hydrologic soil group—			
Cover type	Hydrologic condition	A	B	C	D
Pasture, grassland, or range—continuous forage for grazing.[2]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow—continuous grass, protected from grazing and generally mowed for hay.	—	30	58	71	78
Brush—brush-weed-grass mixture with brush the major element.[3]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	[4]30	48	65	73
Woods—grass combination (orchard or tree farm).[5]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods.[6]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	[4]30	55	70	77
Farmsteads—buildings, lanes, driveways, and surrounding lots.	—	59	74	82	86

[1] Average runoff condition, and $I_a = 0.2S$.

[2] *Poor:* <50% ground cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: >75% ground cover and lightly or only occasionally grazed.

[3] *Poor:* <50% ground cover.
Fair: 50 to 75% ground cover.
Good: >75% ground cover.

[4] Actual curve number is less than 30; use CN = 30 for runoff computations.

[5] CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.

[6] *Poor:* Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

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Runoff curve numbers for arid and semiarid rangelands[1]

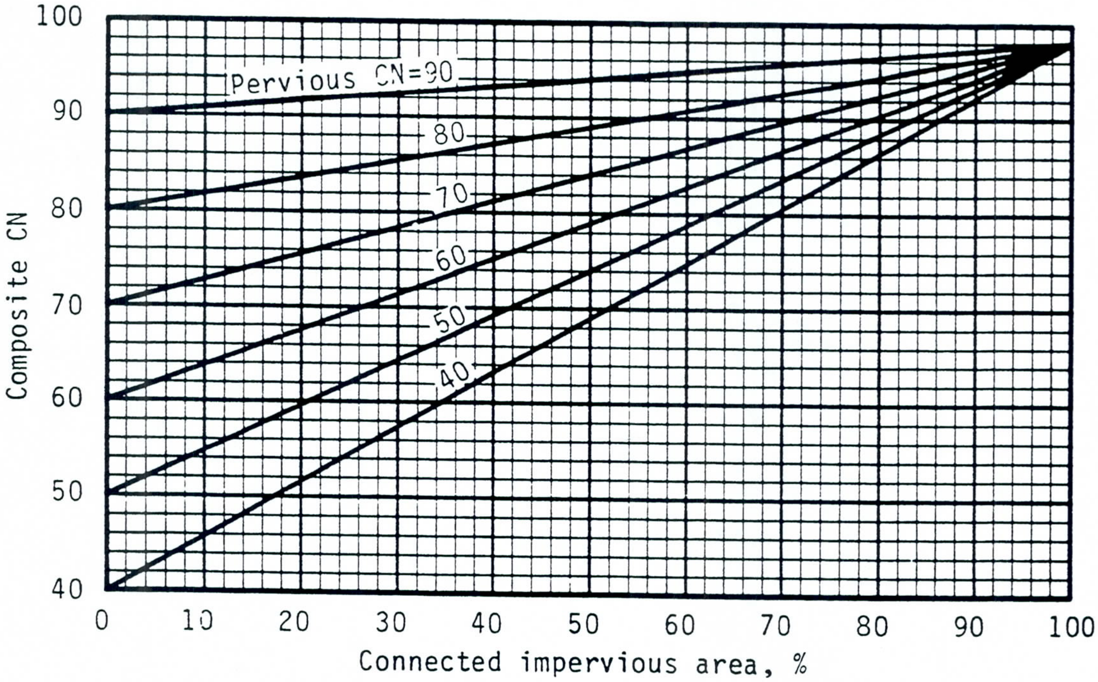
Cover description		Curve numbers for hydrologic soil group—			
Cover type	Hydrologic condition[2]	A[3]	B	C	D
Herbaceous—mixture of grass, weeds, and low-growing brush, with brush the minor element.	Poor		80	87	93
	Fair		71	81	89
	Good		62	74	85
Oak-aspen—mountain brush mixture of oak brush, aspen, mountain mahogany, bitter brush, maple, and other brush.	Poor		66	74	79
	Fair		48	57	63
	Good		30	41	48
Pinyon-juniper—pinyon, juniper, or both; grass understory.	Poor		75	85	89
	Fair		58	73	80
	Good		41	61	71
Sagebrush with grass understory.	Poor		67	80	85
	Fair		51	63	70
	Good		35	47	55
Desert shrub—major plants include saltbush, greasewood, creosotebush, blackbrush, bursage, palo verde, mesquite, and cactus.	Poor	63	77	85	88
	Fair	55	72	81	86
	Good	49	68	79	84

[1]Average runoff condition, and $I_a = 0.2S$. For range in humid regions, use table 2-2c.

[2]*Poor:* <30% ground cover (litter, grass, and brush overstory).
Fair: 30 to 70% ground cover.
Good: >70% ground cover.

[3]Curve numbers for group A have been developed only for desert shrub.

USGS TR55



Composite CN with connected impervious area.

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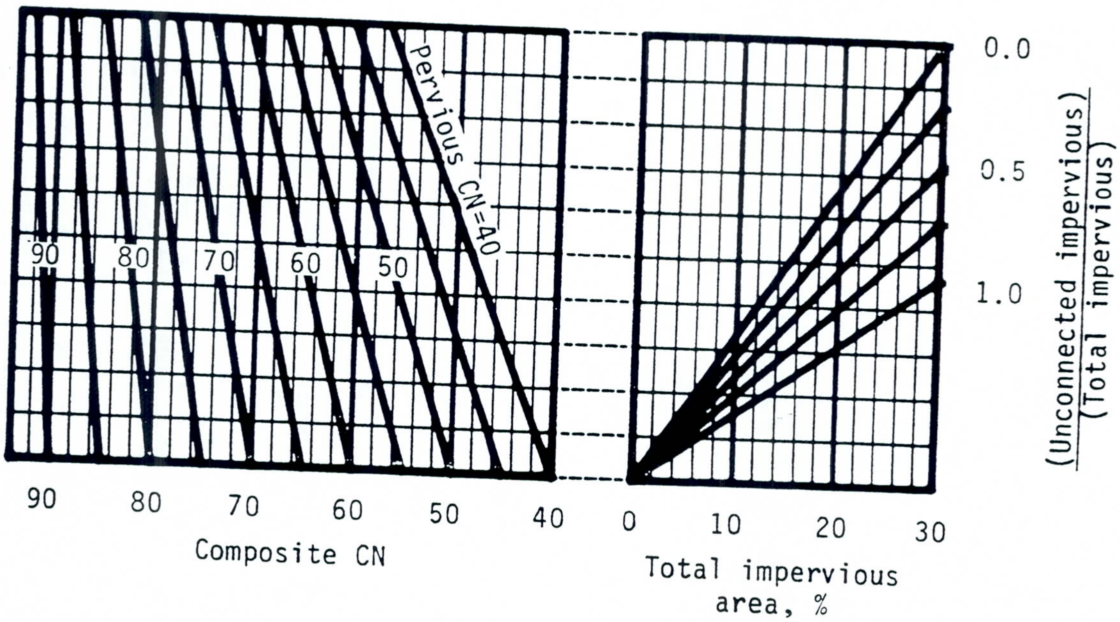
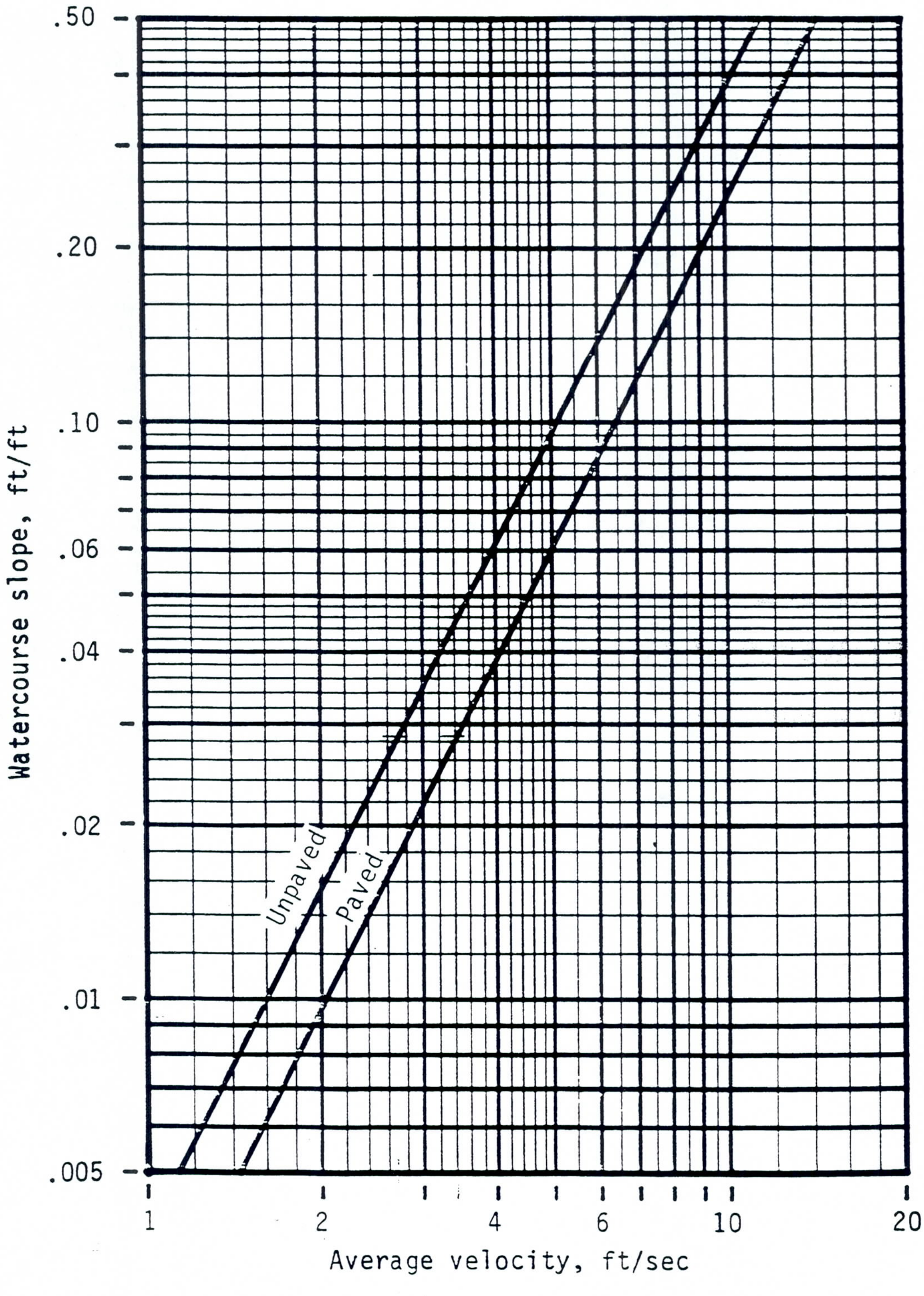


Composite CN with unconnected impervious areas and total impervious area less than 30%.



Average velocities for estimating travel time for shallow concentrated flow.

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Roughness coefficients (Manning's n) for sheet flow < 1.2"

Surface description	n[1]
Smooth surfaces (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated soils:	
Residue cover ≤20%	0.06
Residue cover >20%	0.17
Grass:	
Short grass prairie	0.15
Dense grasses[2]	0.24
Bermudagrass	0.41
Range (natural)	0.13
Woods:[3]	
Light underbrush	0.40
Dense underbrush	0.80

[1]The n values are a composite of information compiled by Engman (1986).

[2]Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.

[3]When selecting n, consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

COMPUTER APPLICATIONS

PROBABLE MAXIMUM PRECIPITATION

HMR52

Probable Maximum Storm (Eastern United States)

User's Manual

March 1984
Revision: April 1987

US Army Corps of Engineers
Hydrologic Engineering Center
609 Second Street
Davis, CA 95616-4687

(916) 756-1104

CPD-46

Section 1

INTRODUCTION

1.1 Program Purpose

Computer program HMR52 computes basin-average precipitation for Probable Maximum Storms (PMS) in accordance with the criteria specified in Hydrometeorological Report No. 52 (National Weather Service, 1982). That Hydrometeorological Report (HMR) describes a procedure for developing a temporal and spatial storm pattern to be associated with the Probable Maximum Precipitation (PMP) estimates provided in Hydrometeorological Report No. 51, "Probable Maximum Precipitation Estimates - United States East of the 105th Meridian." The U.S. National Weather Service (NWS) has determined the application criteria in a cooperative effort with the U.S. Army Corps of Engineers and the U.S. Bureau of Reclamation.

Other reports, HMR Nos. 36, 43, 49 and 55 (NWS, 1961, 1966, 1977, and 1983, respectively) describe the PMP in other regions of the U.S., Fig 1. This program, HMR52, is applicable only to the eastern U.S., and is intended for areas of 10 to 20,000 mi². (HMR No. 52 also contains a 1-mi², 1-hr PMP). A time interval as small as 5 minutes can be used for storm definition. Before using the HMR52 program, one should be thoroughly familiar with the procedures described in Hydrometeorological Report No. 52.

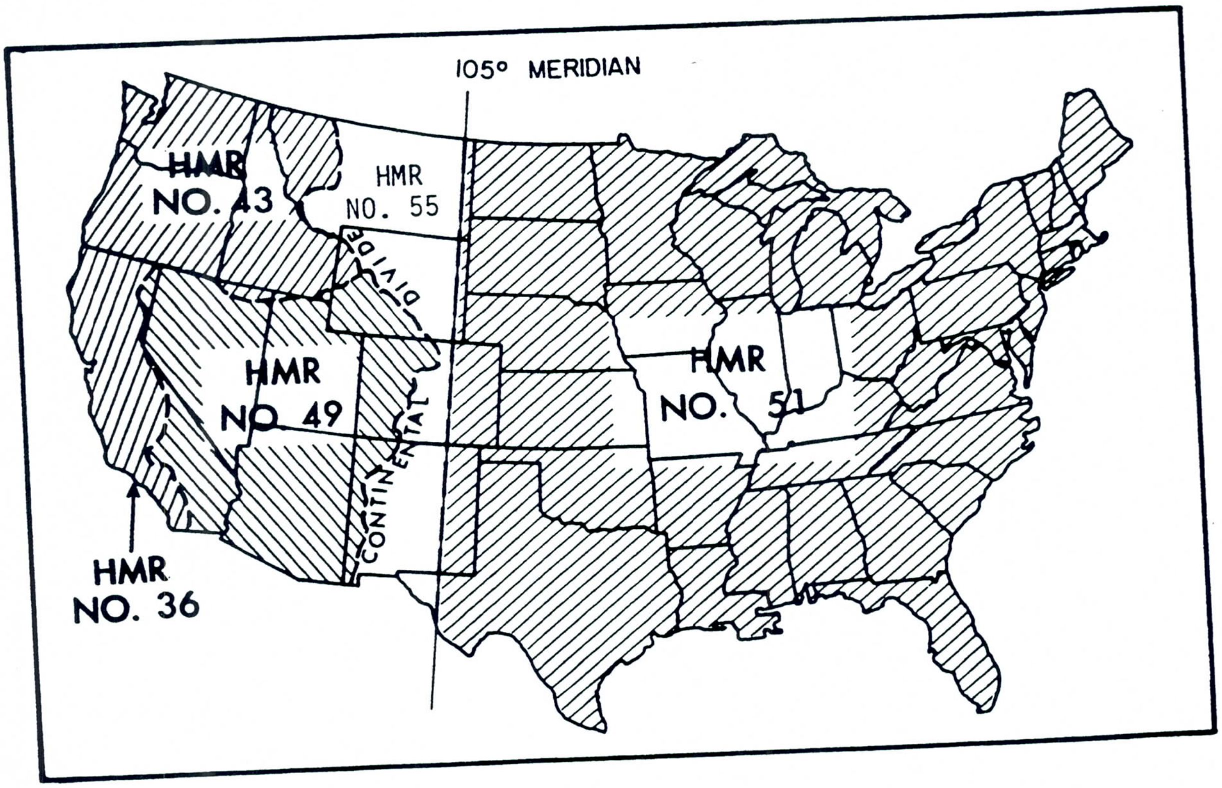


Figure 1. Regions Covered by Generalized PMP Studies (NWS, 1980)

The generalized PMP maps of HMR No. 51 are stippled in two regions, indicating estimates may be deficient because of orographic influences. Major projects within the stippled area should be considered on a case-by-case basis and expert hydrometeorological guidance should be sought.

Data required for application of the HMR52 program are:

- X,Y coordinates describing the river basin and subbasin watershed boundaries;
- PMP from HMR No. 51 (NWS, 1978); and
- Storm orientation, size, centering, and timing.

The program computes the spatially averaged PMP for any of the subbasins or combinations thereof. The Probable Maximum Flood (PMF) can then be computed as the runoff from the PMS, using an appropriate precipitation-runoff program such as HEC-1 (Hydrologic Engineering Center, HEC, 1981). A typical application of HMR52 does not produce a PMS. The PMS is defined by the Corps of Engineers to be that storm which produces the PMF. Thus, the PMS can only be determined by computing (and maximizing) runoff. That is, the runoff characteristics of a watershed must be considered in PMF (and therefore PMS) development.

HMR No. 52 requires that a critical storm-area size, orientation, centering and timing be determined which produces the maximum precipitation. The HMR52 computer program will optimize the storm-area size and orientation in order to produce the maximum basin-average precipitation. The user must provide the desired centering although the centroid of the basin area is provided as a default option.

The user must specify the time distribution for that storm. Using that time distribution information, the HMR52 program will produce a data file containing the incremental basin-average precipitation values for every subbasin requested. That precipitation data file will subsequently be input to a rainfall-runoff model, such as HEC-1, for computation of the resulting flood. The user then analyzes the various storm variables and recomputes the floods in order to determine the storm which produces the maximum runoff. That storm and runoff are defined as the PMS and PMF, respectively.

1.2 Computer Requirements

The HMR52 computer program requires a computer with 45K (decimal) words of core storage and 7 scratch tape/disk files. Plots of the basin geometry and storm patterns can be made on a line printer. Section 10 of this manual specifies detailed computer hardware and software requirements.

1.3 Acknowledgements

The computer program HMR52 was written by Paul B. Ely of the HEC. John C. Peters provided much valuable assistance in the design of the program's capabilities and applications methodology.

Section 2

PROBABLE MAXIMUM STORM ANALYSIS PROCEDURE

2.1 Probable Maximum Precipitation Definition

Probable Maximum Precipitation (PMP) is theoretically the greatest depth of precipitation for a given duration that is physically possible over a given size storm area at a particular geographical location at a certain time of the year. Hydrometeorological Report No. 51 (HMR No. 51) contains generalized (for any storm area) all-season estimates of PMP for the United States, east of the 105th meridian, Fig. 1.

2.2 Probable Maximum Storm Definition

Probable Maximum Storm (PMS) is a hypothetical storm which produces the Probable Maximum Flood from a particular drainage basin. Hydrometeorological Report No. 52 (HMR No. 52) provides criteria and step-by-step instructions for configuring a PMS using PMP estimates from HMR No. 51. Key concepts upon which the procedures in HMR No. 52 are based are as follows.

2.2.1 Spatial Distribution

The spatial distribution of the PMP is governed by principals described under four headings: isohyetal shape, orientation, storm-area size, and spatial variability.

(1) Isohyetal shape. The PMS is represented by elliptical isohyets, each of which has a ratio of major axis to minor axis of 2.5 to 1. Standard ellipses have been established containing areas from 10 to 60,000 mi² (Fig. 2).

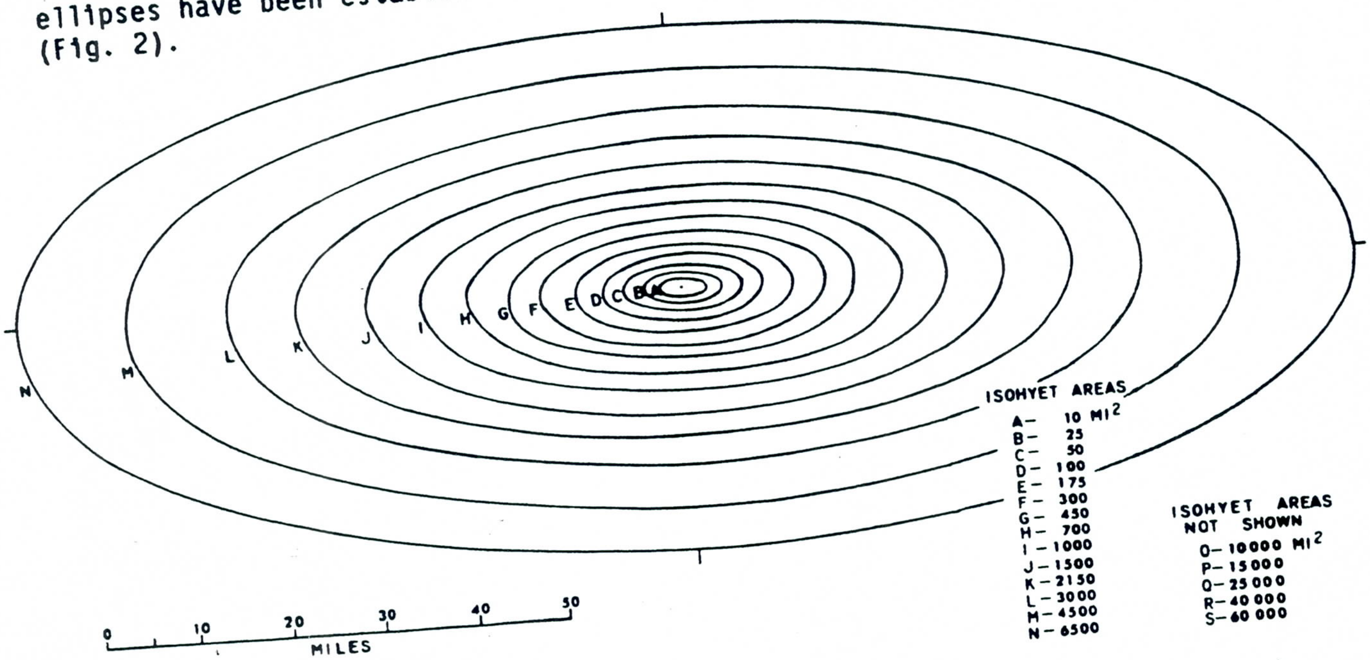


Figure 2. Standard Isohyetal Pattern (NWS, 1982)

(ii) Orientation. There is a preferred orientation for storms at a particular geographic location. That orientation is related to the general movement of storm systems and the direction of moisture-bearing winds. Contours of preferred orientation are shown in Fig. 3. When developing a PMS, it is generally desirable to orient the storm to produce maximum precipitation volume in the watershed. PMP will be reduced by an adjustment factor (shown in Fig. 4) when the storm orientation differs from the preferred orientation by more than ± 40 degrees.

(iii) Storm-Area Size. The average precipitation depth over an area is PMP for one and only one area size. This is the "storm-area size." The average precipitation on areas larger or smaller than the storm-area size is less than PMP for the larger or smaller areas. Fig. 5 illustrates this concept for a storm area of 1000 mi². The storm-area size is chosen to yield the maximum precipitation volume from a given drainage basin.

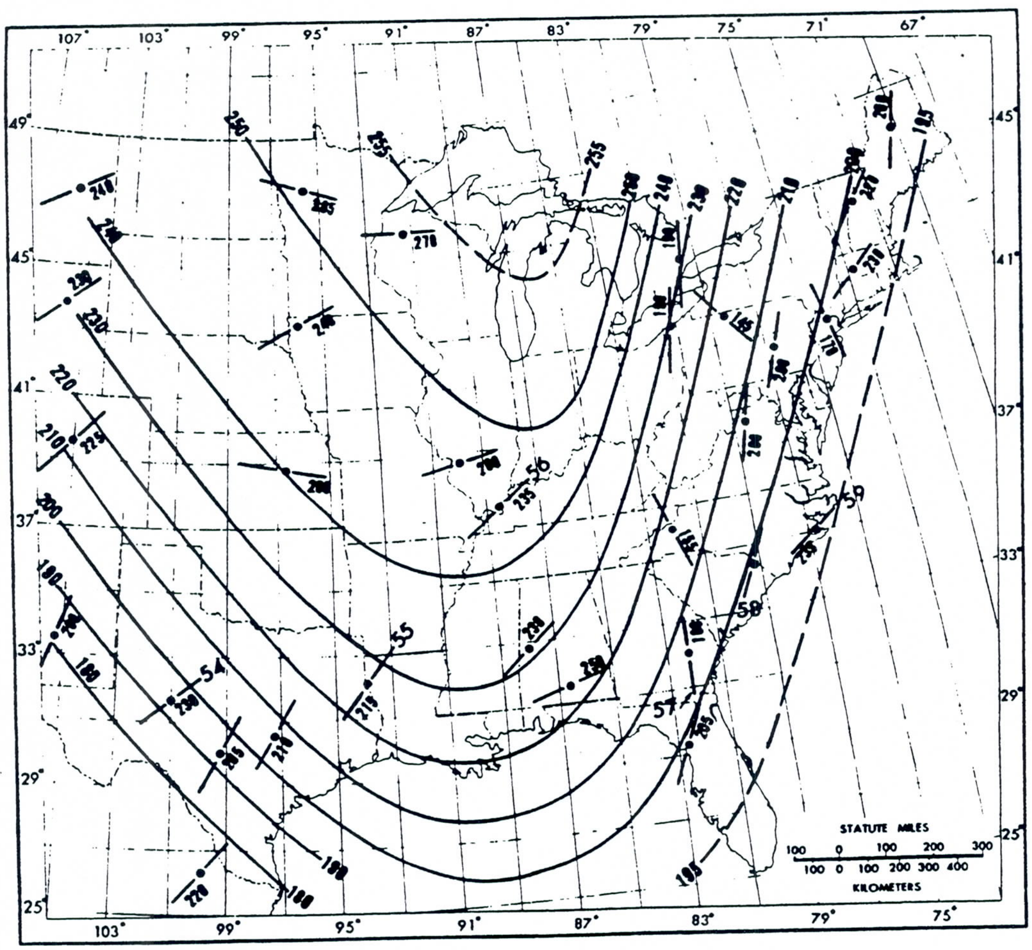


Figure 3. Preferred Orientation for PMS (NWS, 1982)

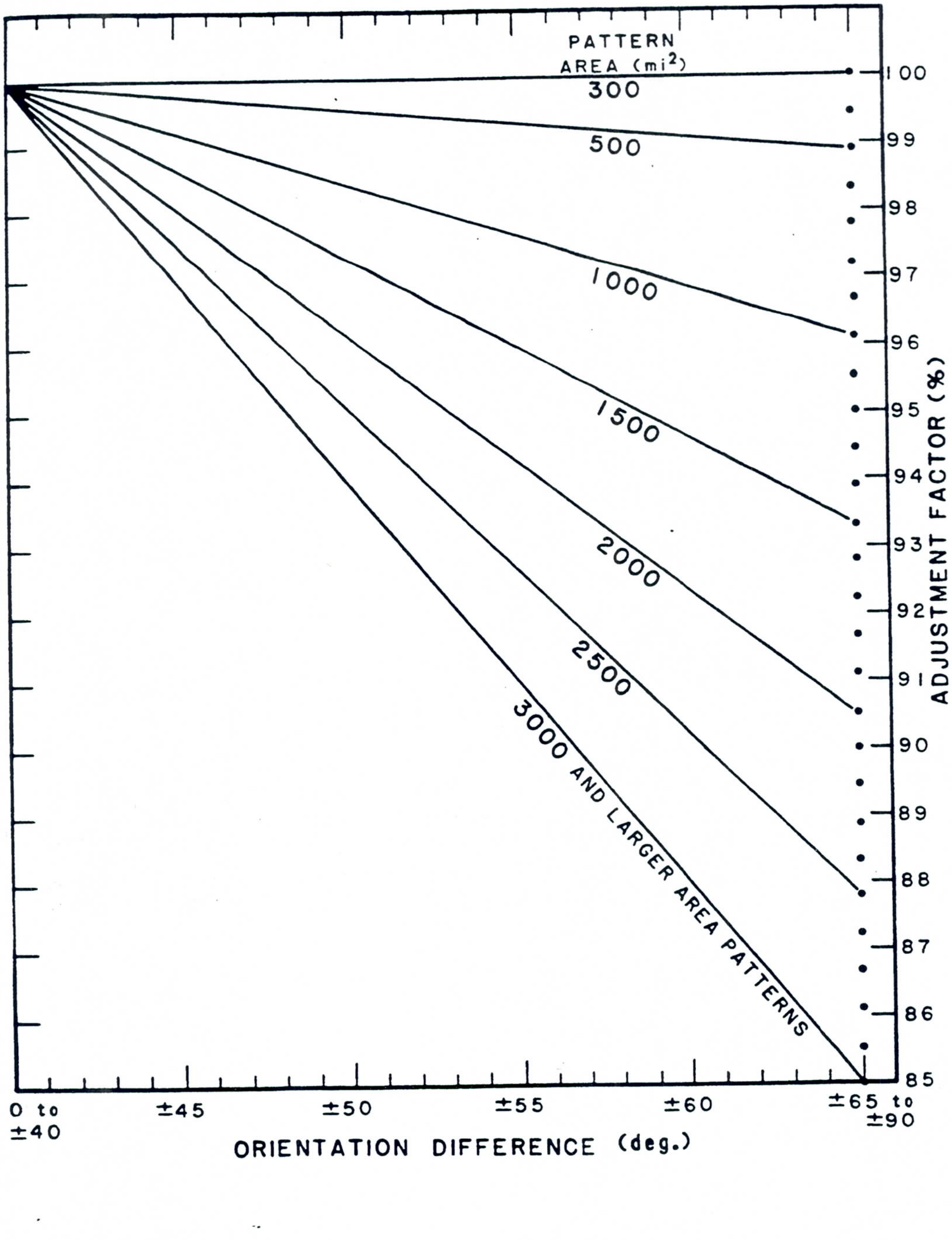


Figure 4. PMP Orientation Adjustment Factors (NWS, 1982)

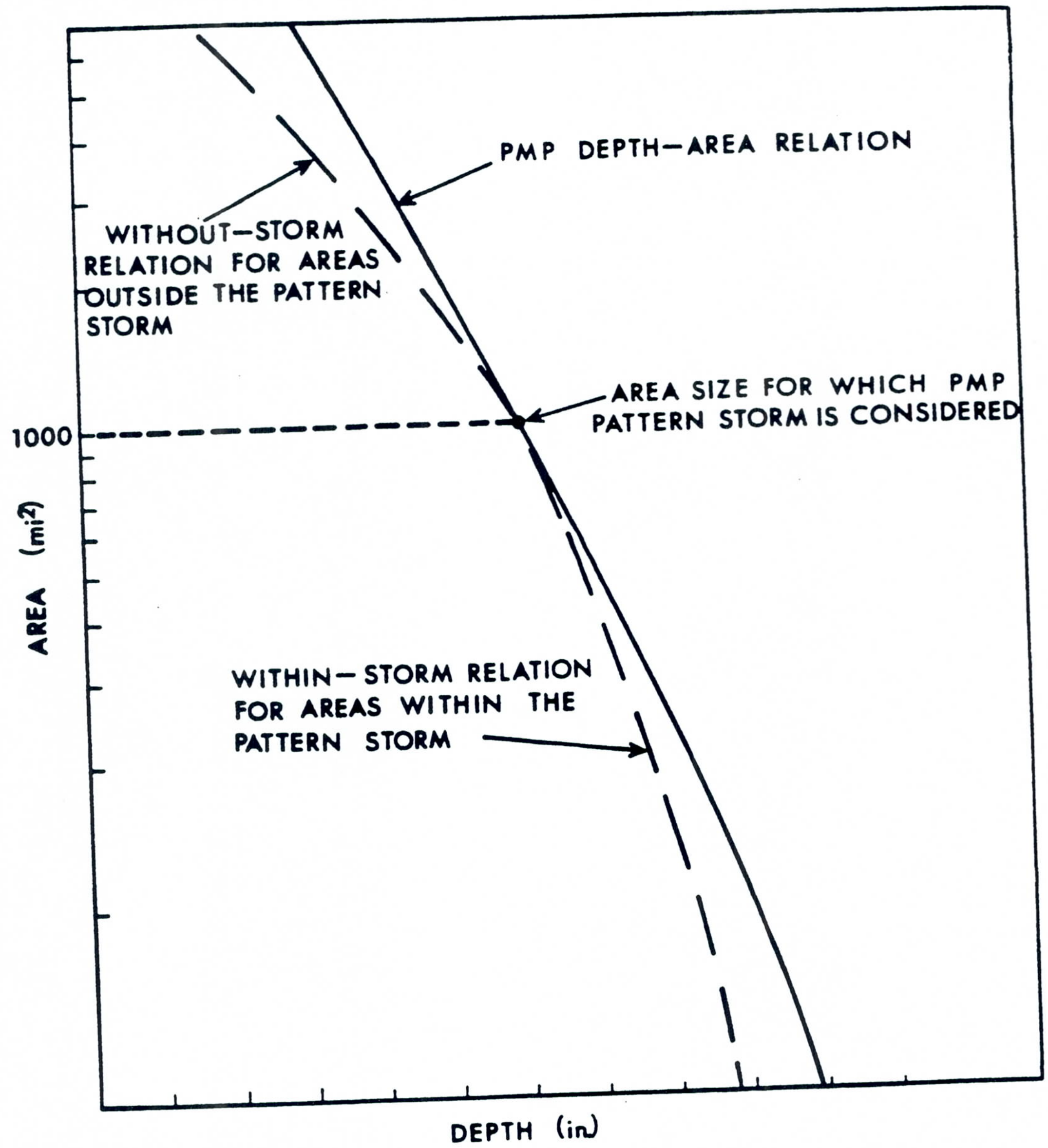


Figure 5. Comparison of PMP Depth-Area Relation with 1,000 mi² PMS (NWS, 1982)

(iv) Spatial Variability. Spatial variation of precipitation is a maximum during the 6-hr period when the maximum precipitation occurs. Spatial variation diminishes for the second and third largest 6-hr amounts. For the remaining 6-hr periods, the within-storm precipitation is uniform, but there is spatial variation in the residual precipitation occurring outside the elliptical boundary that corresponds to the storm-area size. HMR No. 52 contains nomograms which express spatial variation for each 6-hr period as a percent of PMP. Percentages for selected area sizes are tabulated in Tables 1 through 4. For each isohyet, the percent of PMP for the storm area is interpolated from Tables 1-4. Those percentages are multiplied times the PMP to obtain precipitation for each isohyet for each 6-hr interval. A graphical illustration of a typical spatial variation is shown in Fig. 6.

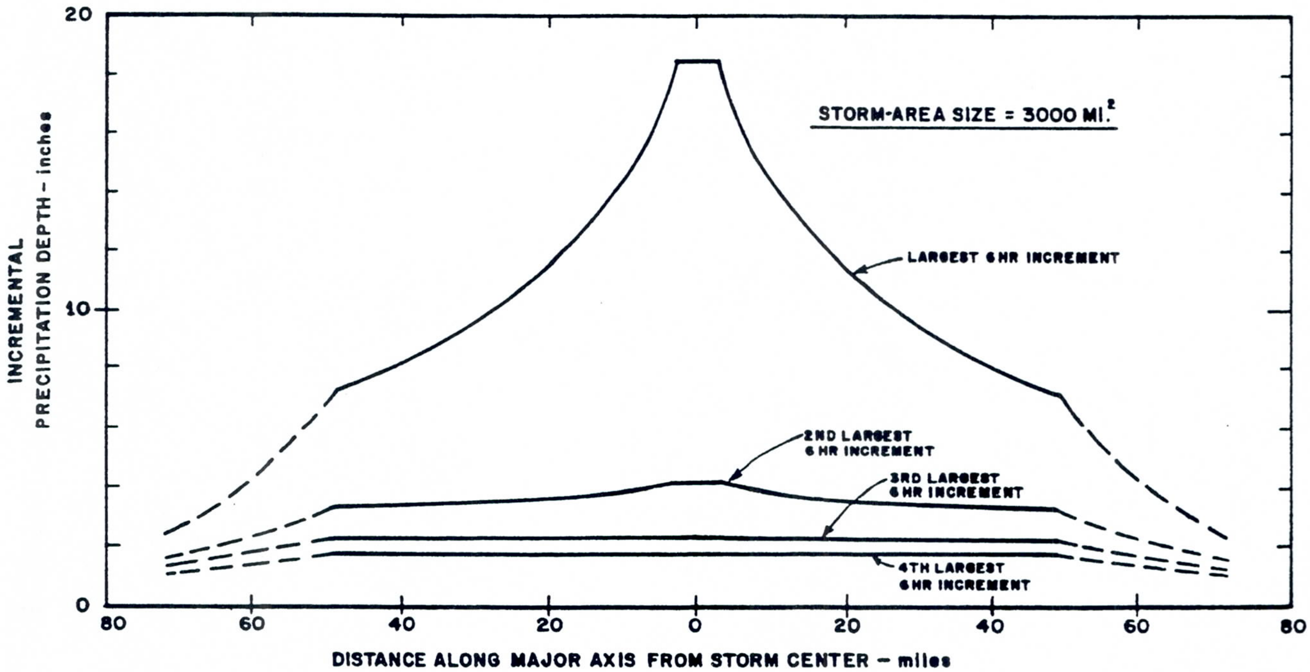


Figure 6. Spatial Variation in PMP Intensities

2.2.2 Temporal Distribution

The factors governing the temporal distribution of the PMS are as follows:

* PMP for all durations (up to 3 days) occurs in the same PMS. The PMP pattern is developed so that any duration of storms less than 72 hours is contained in the PMS.

* The four 6-hr periods with the greatest precipitation may occur any time except during the first 24 hours of the storm.

* The 6-hr increments of precipitation are arranged such that the increments decrease progressively to either side of the greatest 6-hr increment. An example of one such distribution is shown in Fig. 7.

* The 6-hr increments may be distributed into shorter intervals. Fig. 8 shows ratios of 1-hr to 6-hr precipitation for the 'A' isohyet of a 20,000 mi² storm. This ratio is determined for the storm-center location and used to adjust ratios read from Table 5 for each isohyet within the storm-area size. Maximum 5-, 15-, and 30-min intervals are given only for the maximum 1-hr increment within the maximum 6-hr increment.

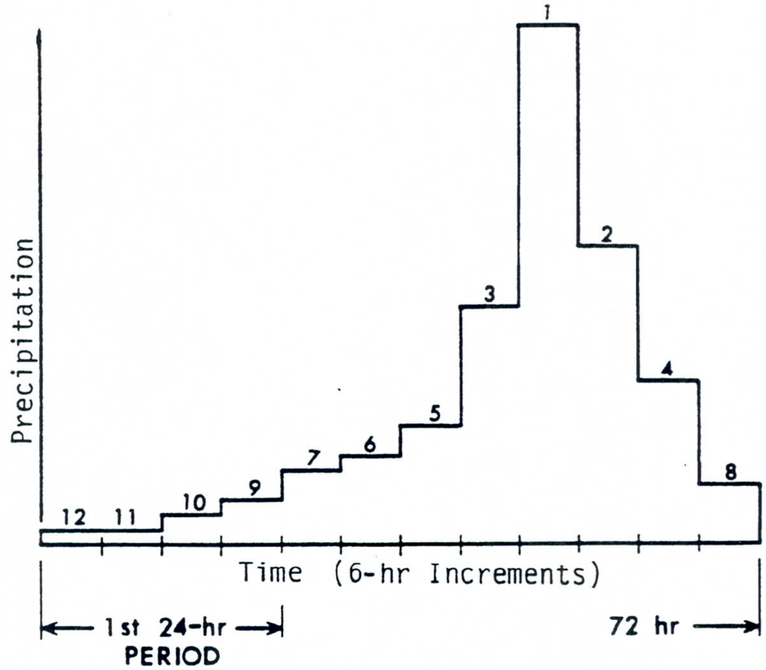


Figure 7. Schematic of One Temporal Sequence Allowed for 6-hr Increments of PMP (NWS, 1982)

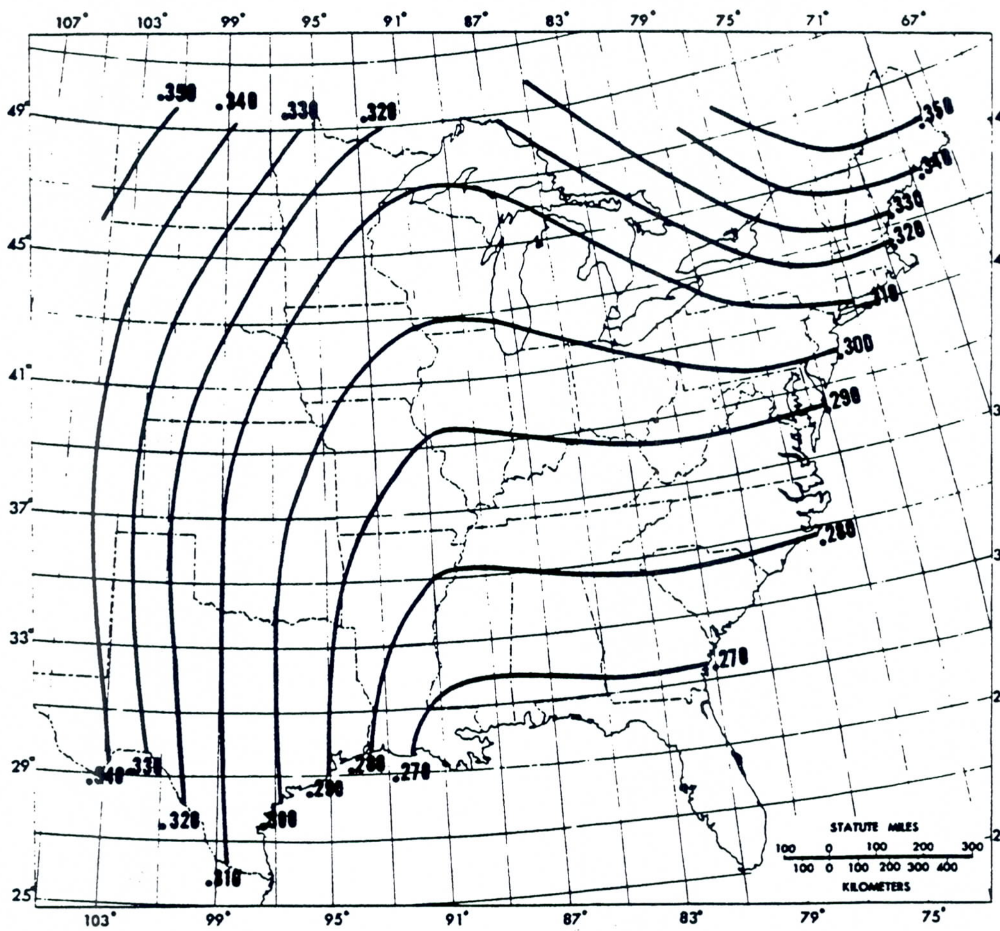


Figure 8. Ratio of 1-hr to 6-hr Precipitation for 'A' Isohyet of a 20,000 mi² Storms (NWS, 1982)

TABLE 1
Spatial Variation in PMP for Largest 6-hour Increment

PERCENT OF LARGEST 6-HOUR PMP INCREMENT

STORM AREA	ISOHYET A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
10	100.0	64.0	48.0	38.0	30.0	24.0	19.0	14.0	10.0	6.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	101.0	78.0	58.0	46.0	37.0	30.0	24.0	19.0	14.0	9.0	5.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	102.0	95.0	67.0	52.0	43.0	34.0	28.0	22.0	17.0	12.0	7.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	104.0	97.0	77.0	59.0	48.0	39.0	32.0	25.0	19.0	14.0	9.0	5.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
50	106.0	99.0	92.0	66.0	54.0	44.0	35.0	28.0	22.0	16.0	11.0	7.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0
75	109.0	102.0	95.0	77.0	62.0	50.0	40.0	32.0	26.0	19.0	14.0	9.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0
100	112.0	105.0	98.0	90.0	68.0	55.0	44.0	35.0	28.0	21.0	16.0	11.0	6.0	1.0	0.0	0.0	0.0	0.0	0.0
140	116.0	108.0	101.0	93.0	78.0	61.0	49.0	39.0	32.0	24.0	18.0	13.0	8.0	2.0	0.0	0.0	0.0	0.0	0.0
175	119.0	111.0	103.0	96.0	89.0	66.0	53.0	42.0	34.0	26.0	20.0	15.0	9.0	3.0	0.0	0.0	0.0	0.0	0.0
220	122.0	114.0	106.0	99.0	92.0	73.0	58.0	46.0	37.0	28.0	22.0	17.0	10.0	4.0	0.0	0.0	0.0	0.0	0.0
300	126.0	118.0	110.0	103.0	96.0	88.0	65.0	51.0	42.0	32.0	25.0	19.0	12.0	6.0	1.0	0.0	0.0	0.0	0.0
360	129.0	121.0	113.0	105.0	98.0	90.0	73.0	56.0	45.0	35.0	27.0	21.0	13.0	7.0	2.0	0.0	0.0	0.0	0.0
450	132.0	124.0	116.0	108.0	101.0	93.0	86.0	63.0	50.0	38.0	30.0	23.0	15.0	8.0	3.0	0.0	0.0	0.0	0.0
560	136.0	128.0	120.0	111.0	104.0	95.0	89.0	72.0	56.0	43.0	33.0	25.0	16.0	9.0	3.0	0.0	0.0	0.0	0.0
700	140.0	132.0	124.0	115.0	107.0	98.0	92.0	84.0	63.0	48.0	36.0	27.0	18.0	10.0	4.0	0.0	0.0	0.0	0.0
850	145.0	136.0	128.0	119.0	110.0	101.0	94.0	87.0	72.0	54.0	40.0	30.0	19.0	11.0	4.0	0.0	0.0	0.0	0.0
1000	149.0	140.0	131.0	122.0	113.0	104.0	97.0	89.0	82.0	60.0	44.0	32.0	21.0	12.0	5.0	0.0	0.0	0.0	0.0
1200	155.0	145.0	136.0	126.0	116.0	107.0	100.0	92.0	85.0	68.0	49.0	35.0	23.0	14.0	6.0	0.0	0.0	0.0	0.0
1500	162.0	152.0	142.0	132.0	122.0	112.0	105.0	96.0	88.0	80.0	56.0	41.0	26.0	16.0	7.0	0.0	0.0	0.0	0.0
1800	169.0	158.0	147.0	137.0	126.0	117.0	108.0	99.0	91.0	83.0	64.0	46.0	29.0	18.0	8.0	1.0	0.0	0.0	0.0
2150	176.0	165.0	154.0	142.0	131.0	122.0	113.0	103.0	95.0	86.0	77.0	52.0	33.0	20.0	9.0	2.0	0.0	0.0	0.0
2600	184.0	172.0	160.0	148.0	137.0	127.0	118.0	108.0	99.0	89.0	80.0	62.0	38.0	22.0	11.0	3.0	0.0	0.0	0.0
3000	191.0	179.0	166.0	154.0	142.0	132.0	122.0	112.0	102.0	92.0	83.0	74.0	44.0	25.0	13.0	4.0	0.0	0.0	0.0
3800	203.0	189.0	176.0	163.0	150.0	140.0	130.0	119.0	108.0	98.0	89.0	79.0	56.0	31.0	15.0	6.0	0.0	0.0	0.0
4500	212.0	198.0	184.0	170.0	157.0	146.0	135.0	124.0	113.0	103.0	93.0	83.0	71.0	37.0	18.0	8.0	0.0	0.0	0.0
5500	223.0	209.0	194.0	180.0	166.0	153.0	142.0	131.0	119.0	108.0	98.0	88.0	76.0	48.0	23.0	10.0	0.0	0.0	0.0
6500	233.0	218.0	203.0	187.0	174.0	160.0	148.0	137.0	125.0	113.0	103.0	93.0	81.0	70.0	29.0	13.0	1.0	0.0	0.0
8000	247.0	230.0	214.0	198.0	183.0	169.0	157.0	144.0	132.0	120.0	110.0	99.0	87.0	75.0	40.0	18.0	3.0	0.0	0.0
10000	262.0	243.0	227.0	209.0	194.0	178.0	166.0	152.0	140.0	128.0	117.0	107.0	93.0	82.0	68.0	26.0	7.0	0.0	0.0
12000	274.0	255.0	238.0	219.0	203.0	186.0	174.0	159.0	147.0	135.0	123.0	113.0	99.0	87.0	73.0	38.0	11.0	0.0	0.0
15000	290.0	271.0	253.0	232.0	214.0	196.0	183.0	168.0	156.0	143.0	131.0	120.0	106.0	94.0	80.0	65.0	18.0	2.0	0.0
18000	304.0	283.0	264.0	242.0	224.0	205.0	192.0	176.0	164.0	150.0	138.0	127.0	113.0	101.0	86.0	71.0	28.0	6.0	0.0
20000	312.0	291.0	271.0	248.0	229.0	210.0	197.0	181.0	168.0	154.0	142.0	131.0	117.0	104.0	89.0	74.0	36.0	8.0	0.0

TABLE 2
Spatial Variation in PMP for 2nd Largest 6-hour Increment

STORM AREA	PERCENT OF SECOND LARGEST 6-HOUR PMP INCREMENT ISOHYET																		
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
10	100.0	64.0	48.0	39.0	30.0	24.0	20.0	14.0	10.0	7.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	102.0	81.5	61.0	50.0	40.0	32.0	27.0	20.5	15.5	12.0	7.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	103.0	98.0	72.0	59.0	48.0	39.0	32.5	26.0	20.0	15.5	10.5	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	104.0	99.0	82.0	66.5	54.5	44.5	37.5	30.5	24.0	19.0	13.5	7.5	1.0	0.0	0.0	0.0	0.0	0.0	0.0
50	105.5	100.5	96.5	76.0	62.5	51.0	43.5	36.0	29.0	23.0	17.0	11.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0
75	107.0	102.0	98.0	86.0	72.0	59.5	50.0	42.0	34.5	27.5	21.0	14.5	7.0	0.0	0.0	0.0	0.0	0.0	0.0
100	108.0	103.0	99.0	95.0	79.0	65.0	55.0	47.0	38.5	31.0	24.0	17.0	9.0	1.0	0.0	0.0	0.0	0.0	0.0
140	109.0	104.0	100.5	96.5	88.0	73.0	62.0	52.5	43.5	35.0	27.5	20.5	12.0	3.5	0.0	0.0	0.0	0.0	0.0
175	110.0	105.0	101.5	97.5	95.0	79.0	66.5	56.5	47.0	38.5	30.0	23.0	14.5	5.0	0.0	0.0	0.0	0.0	0.0
220	110.5	106.0	102.5	98.5	96.0	85.0	72.0	61.0	51.0	42.0	33.0	26.0	17.0	7.5	0.0	0.0	0.0	0.0	0.0
300	111.5	107.0	103.5	100.0	97.5	95.0	80.0	67.5	57.0	47.0	37.5	30.0	20.5	10.0	1.0	0.0	0.0	0.0	0.0
360	112.0	108.0	104.0	101.0	98.5	96.0	85.0	72.0	61.0	50.0	40.5	33.0	23.0	12.0	3.0	0.0	0.0	0.0	0.0
450	113.0	109.0	105.0	102.0	99.5	97.0	95.0	77.5	66.0	54.5	44.5	36.5	25.5	14.0	4.5	0.0	0.0	0.0	0.0
560	114.0	109.5	106.0	102.5	100.5	98.0	96.0	85.0	71.5	60.0	49.0	40.0	28.5	17.0	6.5	0.0	0.0	0.0	0.0
700	114.5	110.0	107.0	104.0	101.0	99.0	97.0	95.0	78.0	65.5	54.0	44.0	32.0	19.5	9.0	0.0	0.0	0.0	0.0
850	115.0	111.0	107.5	104.5	102.0	100.0	98.0	96.0	85.0	71.0	58.5	48.0	35.0	22.0	11.0	0.0	0.0	0.0	0.0
1000	116.0	112.0	108.5	105.0	103.0	101.0	99.0	97.0	95.0	76.0	63.0	51.0	38.0	24.0	12.5	0.0	0.0	0.0	0.0
1200	116.5	112.5	109.0	106.0	104.0	102.0	99.5	97.5	96.0	82.5	68.0	55.0	41.0	27.0	14.5	0.0	0.0	0.0	0.0
1500	117.0	113.0	110.0	107.0	105.0	103.0	100.5	99.0	97.0	95.5	75.5	60.5	45.0	31.0	17.0	0.0	0.0	0.0	0.0
1800	118.0	114.0	110.5	108.0	105.5	104.0	101.5	99.5	98.0	96.0	83.0	66.0	49.5	34.0	19.5	1.5	0.0	0.0	0.0
2150	118.5	114.5	111.0	108.5	106.5	104.5	102.0	100.0	99.0	97.0	96.0	73.0	54.0	37.5	22.0	4.0	0.0	0.0	0.0
2600	119.0	115.5	112.0	109.5	107.0	105.5	103.0	101.0	99.5	98.0	96.5	83.0	60.5	41.5	25.5	7.0	0.0	0.0	0.0
3000	119.5	116.0	112.5	110.0	108.0	106.0	104.0	102.0	100.5	99.0	97.0	96.0	67.0	45.0	28.5	9.0	0.0	0.0	0.0
3800	120.5	117.0	113.5	111.0	109.0	107.0	105.0	103.0	101.5	100.0	98.0	97.0	81.0	52.5	34.0	13.5	0.0	0.0	0.0
4500	121.0	117.0	114.0	112.0	109.5	108.0	105.5	103.5	102.0	100.5	99.0	97.5	96.0	59.0	39.0	17.0	0.0	0.0	0.0
5500	122.0	118.0	115.0	112.5	110.5	108.5	106.5	104.5	103.0	101.5	100.0	98.5	97.0	72.5	46.0	22.0	0.0	0.0	0.0
6500	122.0	119.0	115.5	113.0	111.0	109.0	107.0	105.0	104.0	102.0	100.5	99.0	97.5	95.5	52.5	27.5	1.0	0.0	0.0
8000	123.0	120.0	116.5	114.0	112.0	110.0	108.0	106.0	104.5	103.0	101.5	100.0	98.5	96.0	66.0	37.0	6.0	0.0	0.0
10000	124.0	120.5	117.0	115.0	113.0	111.0	109.0	107.0	105.5	104.0	102.5	101.0	99.0	97.0	95.0	50.0	14.0	0.0	0.0
12000	124.5	121.0	118.0	116.0	114.0	112.0	110.0	108.0	106.5	105.0	103.0	102.0	100.0	98.0	96.0	64.0	21.0	0.0	0.0
15000	125.0	122.0	119.0	117.0	115.0	113.0	111.0	109.0	107.0	106.0	104.0	102.5	101.0	99.0	97.0	96.0	34.0	0.0	0.0
18000	126.0	122.5	119.5	118.0	116.0	113.5	112.0	110.0	108.0	106.5	105.0	103.5	102.0	99.5	97.5	96.5	47.0	4.5	0.0
20000	126.0	123.0	120.0	118.0	116.0	114.0	112.0	110.0	108.5	107.0	105.0	104.0	102.0	100.0	98.0	97.0	55.0	7.0	0.0

TABLE 3
Spatial Variation in PMP for 3rd Largest 6-hour Increment

PERCENT OF THIRD LARGEST 6-HOUR PMP INCREMENT

STORM AREA	ISOHYET A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
10	100.0	65.0	48.0	39.0	30.0	24.0	20.0	14.0	10.0	6.5	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	100.6	83.5	63.0	51.0	40.0	33.0	28.0	21.0	16.5	12.5	7.5	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	101.0	99.0	74.5	60.5	48.5	40.0	34.0	27.0	21.5	17.0	11.5	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	101.3	99.4	85.5	69.0	55.5	46.5	39.5	32.5	26.5	21.0	15.0	8.5	1.0	0.0	0.0	0.0	0.0	0.0	0.0
50	101.6	99.8	98.5	78.5	63.0	53.5	46.0	37.5	31.5	26.0	19.5	12.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0
75	102.0	100.3	99.0	90.0	73.5	61.5	53.0	44.0	37.5	31.5	24.5	16.5	8.5	0.0	0.0	0.0	0.0	0.0	0.0
100	102.3	100.7	99.3	98.6	81.5	68.0	59.0	49.0	42.0	35.5	28.0	20.0	11.5	1.0	0.0	0.0	0.0	0.0	0.0
140	102.6	101.0	99.7	99.0	92.0	76.5	66.0	55.0	47.5	40.5	32.5	24.0	15.0	4.5	0.0	0.0	0.0	0.0	0.0
175	102.8	101.3	100.0	99.2	98.8	83.0	71.0	59.5	51.0	44.0	35.0	26.5	18.0	7.0	0.0	0.0	0.0	0.0	0.0
220	103.1	101.5	100.3	99.5	99.0	89.0	77.0	64.0	55.5	47.5	38.5	29.5	20.5	10.0	0.0	0.0	0.0	0.0	0.0
300	103.4	101.9	100.7	99.8	99.3	99.0	86.0	72.0	62.0	53.0	43.0	33.5	24.5	14.0	2.0	0.0	0.0	0.0	0.0
360	103.6	102.1	100.9	100.1	99.5	99.2	92.0	76.5	66.0	56.0	46.0	36.0	27.0	16.0	4.0	0.0	0.0	0.0	0.0
450	103.8	102.4	101.2	100.3	99.8	99.5	99.2	84.0	71.0	60.0	50.0	39.5	30.0	19.0	7.0	0.0	0.0	0.0	0.0
560	104.0	102.7	101.5	100.6	100.0	99.7	99.4	91.0	77.5	64.5	54.0	43.0	33.0	22.5	10.0	0.0	0.0	0.0	0.0
700	104.2	102.9	101.7	100.8	100.2	99.9	99.6	99.2	85.0	70.5	58.5	47.0	37.0	25.5	13.0	0.0	0.0	0.0	0.0
850	104.4	103.2	102.0	101.1	100.4	100.1	99.7	99.4	92.0	76.5	62.5	50.5	40.0	28.5	15.5	0.0	0.0	0.0	0.0
1000	104.6	103.3	102.3	101.3	100.6	100.3	99.9	99.6	99.3	82.5	67.0	54.0	43.0	31.0	17.5	0.0	0.0	0.0	0.0
1200	104.7	103.5	102.5	101.5	100.8	100.4	100.0	99.7	99.5	89.5	72.5	58.5	46.5	34.0	20.5	0.0	0.0	0.0	0.0
1500	105.0	103.8	102.7	101.7	101.0	100.7	100.3	100.0	99.7	99.4	81.0	65.5	51.5	38.0	24.0	0.0	0.0	0.0	0.0
1800	105.2	104.0	102.9	102.0	101.2	100.8	100.4	100.1	99.8	99.5	89.0	72.5	56.5	42.0	27.0	2.5	0.0	0.0	0.0
2150	105.3	104.2	103.2	102.0	101.3	101.0	100.6	100.3	100.0	99.7	99.5	80.5	61.0	46.5	30.5	5.5	0.0	0.0	0.0
2600	105.5	104.4	103.4	102.4	101.5	101.2	100.7	100.4	100.1	99.8	99.5	90.5	69.0	52.0	34.0	9.0	0.0	0.0	0.0
3000	105.7	104.6	103.5	102.5	101.7	101.3	100.9	100.5	100.2	99.9	99.6	99.3	76.0	57.0	37.5	12.0	0.0	0.0	0.0
3800	105.8	104.8	103.8	102.8	101.9	101.5	101.1	100.7	100.5	100.1	99.8	99.5	88.5	67.0	43.5	16.5	0.0	0.0	0.0
4500	106.0	105.0	104.0	103.1	102.1	101.7	101.2	100.9	100.6	100.2	99.9	99.6	99.3	76.0	49.0	21.0	0.0	0.0	0.0
5500	106.2	105.3	104.3	103.2	102.3	101.8	101.4	101.1	100.8	100.4	100.0	99.7	99.4	88.0	57.0	27.5	0.0	0.0	0.0
6500	106.4	105.5	104.5	103.5	102.5	102.0	101.5	101.2	100.9	100.5	100.2	99.8	99.5	98.9	65.0	34.5	1.0	0.0	0.0
8000	106.6	105.7	104.8	103.7	102.7	102.2	101.7	101.4	101.1	100.7	100.3	100.0	99.6	99.0	79.0	44.5	8.0	0.0	0.0
10000	106.8	106.0	105.0	104.0	102.8	102.4	101.9	101.6	101.3	100.9	100.5	100.2	99.8	99.2	98.7	59.0	18.0	0.0	0.0
12000	107.0	106.2	105.3	104.2	103.0	102.6	102.1	101.8	101.5	101.0	100.7	100.3	99.9	99.3	98.8	71.5	27.5	0.0	0.0
15000	107.2	106.5	105.5	104.4	103.3	102.8	102.3	102.0	101.7	101.2	100.8	100.5	100.1	99.5	99.0	98.0	42.0	1.0	0.0
18000	107.4	106.7	105.8	104.6	103.5	103.0	102.4	102.2	101.8	101.3	101.0	100.6	100.2	99.6	99.1	98.7	54.5	7.5	0.0
20000	107.5	106.8	105.9	104.7	103.6	103.0	102.5	102.2	101.9	101.4	101.1	100.7	100.2	99.7	99.2	98.2	66.0	12.0	0.0

TABLE 4
Spatial Variation in PMP for 4th through 12th 6-hour Increment

PERCENT OF FOURTH THROUGH TWELFTH LARGEST 6-HOUR PMP INCREMENTS

STORM AREA	ISOHYET A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
10	100.0	65.0	48.0	39.0	30.0	24.0	20.0	14.0	10.0	6.5	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	100.0	83.5	62.5	50.5	40.0	33.0	27.5	21.0	16.0	12.0	7.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	100.0	100.0	74.5	60.5	48.5	40.0	34.0	27.0	21.5	17.0	11.5	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	100.0	100.0	86.0	68.5	55.0	46.0	39.0	31.5	26.0	21.0	15.0	8.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0
50	100.0	100.0	100.0	78.5	63.0	53.5	46.0	37.5	31.5	26.0	19.5	12.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0
75	100.0	100.0	100.0	89.5	73.0	61.5	53.0	44.0	37.0	31.0	24.0	16.0	8.5	0.0	0.0	0.0	0.0	0.0	0.0
100	100.0	100.0	100.0	100.0	81.5	68.0	59.0	49.0	42.0	35.5	28.0	20.0	11.5	1.0	0.0	0.0	0.0	0.0	0.0
140	100.0	100.0	100.0	100.0	91.0	76.5	65.5	55.0	47.5	40.0	32.0	23.5	15.0	4.0	0.0	0.0	0.0	0.0	0.0
175	100.0	100.0	100.0	100.0	100.0	83.0	71.0	58.5	51.0	44.0	35.0	26.5	18.0	7.0	0.0	0.0	0.0	0.0	0.0
220	100.0	100.0	100.0	100.0	100.0	89.0	77.0	64.0	55.0	47.0	38.5	29.0	20.5	9.5	0.0	0.0	0.0	0.0	0.0
300	100.0	100.0	100.0	100.0	100.0	100.0	86.0	72.0	62.0	53.0	43.0	33.5	24.5	14.0	2.0	0.0	0.0	0.0	0.0
360	100.0	100.0	100.0	100.0	100.0	100.0	91.5	77.0	65.5	55.5	46.0	36.0	27.0	16.0	4.0	0.0	0.0	0.0	0.0
450	100.0	100.0	100.0	100.0	100.0	100.0	100.0	84.0	71.0	60.0	50.0	39.5	30.0	19.0	7.0	0.0	0.0	0.0	0.0
560	100.0	100.0	100.0	100.0	100.0	100.0	100.0	91.0	77.5	64.5	53.5	43.0	33.0	22.0	9.5	0.0	0.0	0.0	0.0
700	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	85.0	70.5	58.5	47.0	37.0	25.5	13.0	0.0	0.0	0.0	0.0
850	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	92.0	77.0	62.0	50.5	40.0	28.0	15.0	0.0	0.0	0.0	0.0
1000	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	82.5	67.0	54.0	43.0	31.0	17.5	0.0	0.0	0.0	0.0
1200	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	89.5	72.0	58.5	46.5	33.5	20.0	0.0	0.0	0.0	0.0
1500	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	81.0	65.5	51.5	38.0	24.0	0.0	0.0	0.0	0.0
1800	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	89.0	72.5	56.0	41.5	26.5	2.5	0.0	0.0	0.0
2150	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	80.5	61.0	46.5	30.5	5.5	0.0	0.0	0.0
2600	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	90.0	69.0	51.5	33.5	9.0	0.0	0.0	0.0
3000	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	76.0	57.0	37.5	12.0	0.0	0.0	0.0
3800	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	88.5	67.0	43.5	17.0	0.0	0.0	0.0
4500	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	76.0	49.0	21.0	0.0	0.0	0.0
5500	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	88.0	56.5	27.0	0.0	0.0	0.0
6500	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	65.0	34.5	1.0	0.0	0.0
8000	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	79.0	44.0	8.0	0.0	0.0
10000	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	59.0	18.0	0.0	0.0
12000	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	71.0	27.0	0.0	0.0
15000	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	42.0	1.0	0.0
18000	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	54.0	7.0	0.0
20000	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	66.0	12.0	0.0

TABLE 5
RATIOS OF 1-HOUR TO 6-HOUR PMP
(Offset by Ratio for Isohyet A for 20,000 sq. mi. Storm)

STORM AREA	ISOHYET A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
10	.2555															
17	.2470															
25	.2370	.2355														
35	.2255	.2240														
50	.2115	.2100	.2085													
75	.1935	.1920	.1905													
100	.1800	.1785	.1770	.1750												
140	.1625	.1610	.1595	.1575												
175	.1500	.1485	.1470	.1450	.1435											
220	.1375	.1355	.1340	.1320	.1305											
300	.1185	.1170	.1155	.1135	.1120	.1100										
360	.1070	.1055	.1040	.1020	.1005	.0985										
450	.0935	.0915	.0900	.0880	.0860	.0840	.0825									
560	.0790	.0775	.0760	.0735	.0715	.0700	.0690									
700	.0640	.0620	.0605	.0585	.0570	.0545	.0530	.0510								
850	.0515	.0490	.0475	.0455	.0440	.0420	.0405	.0385								
1000	.0405	.0380	.0365	.0340	.0320	.0305	.0290	.0270	.0255							
1200	.0280	.0255	.0240	.0215	.0195	.0180	.0165	.0145	.0125							
1500	.0135	.0110	.0090	.0075	.0060	.0035	.0020	.0000	-.0020	-.0070						
1800	.0030	.0005	-.0010	-.0030	-.0045	-.0060	-.0075	-.0095	-.0115	-.0165						
2150	-.0055	-.0075	-.0090	-.0110	-.0125	-.0145	-.0160	-.0180	-.0195	-.0235	-.0280					
2600	-.0130	-.0150	-.0165	-.0180	-.0195	-.0215	-.0230	-.0250	-.0270	-.0305	-.0345					
3000	-.0185	-.0200	-.0215	-.0230	-.0245	-.0260	-.0275	-.0295	-.0315	-.0350	-.0385	-.0425				
3800	-.0245	-.0260	-.0275	-.0290	-.0305	-.0320	-.0335	-.0355	-.0370	-.0405	-.0440	-.0465				
4500	-.0275	-.0290	-.0305	-.0320	-.0335	-.0350	-.0365	-.0385	-.0400	-.0435	-.0465	-.0490	-.0540			
5500	-.0295	-.0310	-.0325	-.0340	-.0355	-.0370	-.0385	-.0405	-.0420	-.0455	-.0485	-.0505	-.0555			
6500	-.0300	-.0315	-.0330	-.0345	-.0360	-.0375	-.0390	-.0405	-.0420	-.0455	-.0485	-.0510	-.0555	-.0610		
8000	-.0295	-.0310	-.0325	-.0340	-.0355	-.0370	-.0385	-.0400	-.0415	-.0445	-.0475	-.0505	-.0550	-.0605		
10000	-.0275	-.0290	-.0300	-.0315	-.0325	-.0340	-.0355	-.0370	-.0385	-.0415	-.0450	-.0480	-.0525	-.0575	-.0640	
12000	-.0240	-.0255	-.0265	-.0280	-.0290	-.0305	-.0320	-.0340	-.0355	-.0385	-.0415	-.0445	-.0490	-.0535	-.0605	
15000	-.0155	-.0170	-.0180	-.0200	-.0215	-.0230	-.0245	-.0265	-.0280	-.0310	-.0350	-.0380	-.0425	-.0475	-.0550	-.0630
18000	-.0065	-.0080	-.0095	-.0110	-.0125	-.0140	-.0155	-.0175	-.0195	-.0235	-.0270	-.0305	-.0345	-.0410	-.0475	-.0555
20000	.0000	-.0015	-.0030	-.0045	-.0060	-.0080	-.0095	-.0115	-.0135	-.0175	-.0210	-.0245	-.0290	-.0355	-.0415	-.0505
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P

INSTALLATION INSTRUCTIONS OR MICROCOMPUTER VERSION OF HMR52

This version of HMR52 (April 1987) will run on an IBM or compatible microcomputer that has the following:

* 256 Kilobytes (KB) of Random Access Memory (RAM)
* MS DOS 2.1 or greater
* One 5 1/4 inch floppy diskette drive (360 KB or 1.2 MB)
* A 10 Megabyte (or larger) hard disk is recommended
* A math coprocessor (8087, 80287, or 80387) is highly recommended, but not required. The math coprocessor will greatly reduce the execution time of the program (increases computational speed by a factor of 5 to 10).

I. PROGRAM INSTALLATION

HMR52 DISKETTE: HMR52.EXE

Explanation of Files Included on the HMR52 Package Diskette

HMR52.EXE: The HMR52 program in an executable form.

HMR52T.DAT: HMR52 table file, which contains Hydromet Report No. 51 in tabular form (this is necessary for execution of the program).

B. Installation on a Hard Disk System

The following set of instructions will allow the user to run the HMR52 program from any of the user's data directories.

1. You will need to create three directories. One of the directories should be labeled \HECEXE. This directory will be used to store all of the HEC executable programs. A second directory should be labeled \HECEXE\SUP. This directory will be used to store all of the supplemental files required by the executable programs. A third directory should be created to store data files. This dat directory can be given any name. You may want this data directory to represent a specific project, person, or program. For this example, let's assume that you are going to label the data directory \HMR52. To accomplish these tasks do the following:

   * Go to the drive (e.g. C:) in which you would like to install the software.
   * Type MD\HMR52 then press the <ENTER> key.
   * Type MD\HECEXE then press the <ENTER> key.
   * Type MD\HECEXE\SUP then press the <ENTER> key.

2. Place the HMR52 diskette into the A (or B) drive.

3. The next step will be to copy the HMR52 input and output files. If you do not want these files copied to your hard disk, go to step 4. If you would like these files copied to your hard disk, do the following:

   * Type CD HMR52 then press the <ENTER> key.
   * Type COPY A:*.DAT C: then press the <ENTER> key.
   * Type COPY A:*.OUT C: then press the <ENTER> key.

4. The next step will be to copy the HMR52 program. The file is named HMR52.EXE. Use the following commands to do so:

   * Type CD \HECEXE then press the <ENTER> key.
   * Type COPY A:*.EXE C: then press the <ENTER> key.

* Type CD \ then press the <ENTER> key.

5. To allow access of the executable programs from any directory, it will be necessary to edit the AUTOEXEC.BAT file to include a path to the \HECEXE directory. The AUTOEXEC.BAT file should be in your root (C:\) directory. The following is an example PATH command that would allow access to the \HECEXE directory as well as the root (C:\) directory:

```
PATH C:\;C:\HECEXE
```

You may want to include a path to other directories on your system. If so, just add the names of the directories to this command. For more information on the PATH command and the AUTOEXEC.BAT file, consult your DOS manual.

6. The final step will be to modify your CONFIG.SYS file. Many HEC programs require the capability to open more than eight (8) files at any one time. Because eight is the system default, you will need to modify your CONFIG.SYS file to include the following two lines:

```
FILES=20
BUFFERS=20
```

For more information concerning the CONFIG.SYS file, consult your DOS manual.

II. PROGRAM EXECUTION

A. To run HMR52 from the hard disk do the following commands:

* Go to the directory in which your data are stored (e.g. \HMR52).
* Type HMR52 then press the <ENTER> key. The program then will prompt you for input filename, output filename, etc.

OR

* Type HMR52 INPUT=filename OUTPUT=filename then press the <ENTER> key; where:

  INPUT=filename: the filename where the HMR52 input data resides.

  OUTPUT=filename: the filename where the output data will be written. If the user wishes the output to go directly to the screen or printer, the commands CON (screen) or LPT1 (printer) can be used in place of the output filename.

B. To run HMR52 from a floppy diskette do the following commands:

* Place the diskette containing the HMR52 program on it in drive A
* Type A:HMR52 then press the <ENTER> key. The program then will prompt you for input filename, output filename, etc.

OR

* Type HMR52 INPUT=filename OUTPUT=filename then press the <ENTER> key; where:

  INPUT=filename: the filename where the HMR52 input data resides.

  OUTPUT=filename: the filename where the output data will be written. If the user wishes the output to go directly to the screen or printer, the commands CON (screen) or LPT1 (printer) can be used in place of the output filename.

APPENDIX A

HMR52 INPUT DESCRIPTION

TABLE OF CONTENTS

INPUT FORMAT

Input data is read from cards or card images. Each card is divided into a two-column card identification field (columns 1 and 2) and ten data fields. The first data field has six columns (columns 3-8). The remaining nine fields each have eight columns.

Field 0 (zero) is the card identification field (columns 1 and 2). Field 1 is the first data field (beginning in column 3).

Under the value heading a plus (+) is used to indicate where numeric values should be entered. A blank numeric value is interpreted as a zero. (AN) indicates that alphanumeric characters may be entered.

Data may be entered on the cards in either FREE FORMAT or FIXED FORMAT (default). The FORMAT (fixed or free) is controlled by a switch which can be changed at anytime by inserting a *FIX or a *FREE card in the data deck.

For FREE FORMAT each item is separated by one or more blanks or a comma. A blank field is designated by two successive commas. There may be more or less than ten coordinates on a BX or BY card. The FREE FORMAT reader will treat these cards as if they were on continuous cards.

For FIXED FORMAT each number which does not contain a decimal point must be right justified in its field.

A *FIX card indicates that the following data cards use FIXED FORMAT, and a *FREE indicates FREE FORMAT. The format may be changed as often as desired and at any location in the data deck.

Comments may be placed anywhere in the input deck on cards with double asterisks (**) in the card identification field.

HMR52 INPUT DESCRIPTION

CARD SEQUENCE

Cards are grouped by drainage basin. A BN card is used to indicate the beginning of data for a basin. The next cards are the BS, BX, and BY cards which describe the basin boundary. Next come the HO and HP cards which have meteorological data from HMR No. 52 and HMR No. 51, then the SA, SC, SD, and ST cards containing data for a particular storm.

The cards for a drainage basin may be followed by another group, beginning with a BN card for a different drainage basin, or a GO card followed by different storm data for the current basin, or a ZZ card indicating the end of data for this job.

Within a card group (beginning with BN or GO card) the cards may be placed in any order. However, it is helpful to use a consistent order such as alphabetical order.

DATA REPETITION

Once data has been read by the program it is retained in memory until a new card of the same type is read. For example, the HO or HP cards need only occur in the data for the first drainage basin and not repeated for each subsequent basin. Similarly, once the storm area and orientation have been established, they will be used for all subsequent calculations until a new SA card is read.

The only cards which must be included for each new drainage basin are the BN, BX, and BY cards. All other cards may be omitted for a new basin and the storm will be calculated using data from the previous basin.

BA

BN

BA CARD - BASIN AREA

This card is an optional card which is placed after the BN card. A BA card is required when a storm is calculated using isohyet areas on SI cards and boundary coordinates are not given. The area on a BA card is not used if boundary coordinates are given.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	ID	BA	Card identification.
1	BAREA	+	Subbasin area in square miles.

BN CARD - BASIN NAME

The BN card is placed at the beginning of data for each drainage basin and identifies the basin.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	ID	BN	Card identification.
1	NAME	AN	Alphanumeric name for drainage basin described by data on following cards. (Maximum 8 characters for FREE FORMAT, 6 characters for FIXED FORMAT.)

BS CARD - SCALE

FIELD	VARIABLE	VALUE	DESCRIPTION
0	ID	BS	Card identification.
1	SCALXY	+	Scale of boundary coordinates in miles per coordinate unit.

BX CARD - BOUNDARY COORDINATES

BX and BY cards contain X and Y coordinates for points on the basin boundary. The points may be entered in either clockwise or counter-clockwise direction. The beginning point should not be repeated since the program automatically closes the boundary.

The program counts the number of boundary points by finding the last non-zero value on a series of BX or BY cards.

If both BA and SI cards are used, BX and BY card may be omitted.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	ID	BX	Card identification.
1-10	XB	+	X-coordinates of drainage basin boundary. Corresponding to y-coordinates on BY cards. (Maximum - 100 values.)

BY CARD - BOUNDARY COORDINATES

FIELD	VARIABLE	VALUE	DESCRIPTION
0	ID	BY	Card identification.
1-10	YB	+	Y-coordinates of drainage basin boundary corresponding to x-coordinates on BX card. (Maximum - 100 values.)

GO CARD - COMPUTE STORM WITH CURRENT DATA

The GO card is used to indicate the end of data for a PMS calculation. The computer will calculate the PMS using the current data before reading the next card. A GO card is not required if the next card is a BN card or a ZZ card.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	ID	GO	Card identification.

HO CARD - PREFERRED ORIENTATION

FIELD	VARIABLE	VALUE	DESCRIPTION
0	ID	HO	Card identification.
1	PORNT	+	Preferred probable maximum storm orientation from HMR No. 52.

HP CARD - DEPTH-AREA-DURATION DATA

Use one HP card for each storm area (10, 200, 1000, 5000, 10000, and 20000 square miles). Six HP cards are required, one for each area.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	ID	HP	Card identification.
1	AREA51	+	Storm area from HMR No. 51 for PMP in Fields 2-6.
2	H51DAD(1,J)	+	Probable maximum precipitation for 6 hour duration for storm area in Field 1, from HMR No. 51.
3-6	H51DAD(I,J)	+	Similar to Field 2 for durations of 12, 24, 48 and 72 hours.

ID CARD - JOB IDENTIFICATION

The contents of this card are read and printed immediately after being read. There is no limit on the number of ID cards. ID cards are usually placed at the beginning of a data set to provide title information. They may be placed within a data set to describe individual basins or storm calculations.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	ID	ID	Card identification.
1-10	TITLE	AN	Alphanumeric job title or description.

PL CARD - PLOT CONTROL

PL

The PL card is used to control printer plots of the drainage basin boundary and PMS isohyets.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	ID	PL	Card identification.
1	PLTYP	0	No plots.
		1	Plot drainage basin boundary.
		2	Plot drainage basin boundary with PMS isohyets.
		3	Make two plots, a plot of drainage basin boundary and a plot of the boundary with PMS isohyets.
2	CHRPIN	+	Characters per inch for printer plot. Default is 10.)
3	LINPIN	+	Lines per inch for printer plot. (Default is 6.)

PU CARD - PUNCH PMS

The PU card is used to control writing the PMS to a file. The default format is (2HPI,F6.2,9F8.2).

FIELD	VARIABLE	VALUE	DESCRIPTION
0	ID	PU	Card identification.
1	PUNCH	ON	Write PMS precipitation to punch file.
		OFF	Do not write PMS to punch file (default).
2-10	PUNFMT	AN	Format to be used in writing to punch file. If Fields 2-10 are blank the previously defined format will be used.

NOTE: For program files maintained by HEC on HARRIS the punch file is W8 by default, and may be changed at execution time by:

HMR52,PUNCH=punfile

On LBL and BCS the punch file is TAPE7 by default and may be changed at execution time by:

HMR52,,,punfile.

SA CARD - STORM AREA AND ORIENTATION

FIELD	VARIABLE	VALUE	DESCRIPTION
0	ID	SA	Card identification.
1	PMSA	+	Probable maximum storm area size in square miles.
			If PMSA is zero, the program will compute PMS for several area sizes and select the area size which produces maximum precipitation on the drainage basin for the specified number of 6-hour periods.
2	ORNT	+	Probable maximum storm orientation in degrees, clockwise from north. (Range is 135-315 degrees.)
			If ORNT is less than or equal to zero, the program will compute PMS for several orientations and select the orientation which produces maximum precipitation on the drainage basin for the specified number of 6-hour periods.
		0	If ORNT is zero, the orientation which minimizes moment-of-inertia for the drainage basin about the major axis will be used to estimate PMSA when Field 1 is zero.
		-	If ORNT is negative, the absolute value of ORNT will be used to estimate PMSA when Field 1 is zero.
3	NINCS	+	Number of 6-hour periods to use for computing maximum precipitation on the drainage basin (default is 3).

Its actually the orientation of the Basin

SC
SD

SC CARD - STORM CENTER CORRDINATES

The storm center will be located at the drainage basin centroid if an SC card is not used.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	ID	SC	Card identification.
1	XCEN	+	X-coordinate of storm center.
2	YCEN	+	Y-coordinate of storm center.

SD CARD - ARRANGEMENT OF 6-HR INCREMENTS IN PMS TEMPORAL DISTRIBUTION

This card gives the arrangment of 6-hr increments of precipitation in the PMS. The default arrangement (if no SD card is given) is: 12, 10, 8, 6, 4, 2, 1, 3, 5, 7, 9, 11 where the numbers indicate the largest (1) to smallest (12) 6-hr increment.

If SD cards are included in a data set, all twelve increments must be listed on two cards.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	ID	SD	Card identification.
1	RELMAG(1)	+	Relative magnitude of first 6-hr period of PMS.
2-10		+	Relative magnitude of remaining 6-hr periods of PMS.

Continue with eleventh period in Field 1 of second SD card.

SI CARD - STORM ISOHYET AREAS

This card is optional. If SI cards are used the program will not calculate the basin area within each isohyet, but it will use the areas given on SI cards. Storm area and orientation must be given when SI cards are used.

If both SI and BA cards are used, then BX and BY cards may be omitted.

If SI cards are used, then there must be two SI cards.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	ID	SI	Card identification.
1	AREAIB(1)	+	Area within both basin boundary and isohyet A in square miles.
2-10	AREAIB(2-10)	+	Area within basin boundary and isohyet in square miles for isohyets B through J.

SECOND SI CARD

FIELD	VARIABLE	VALUE	DESCRIPTION
1-9	AREAIB(11-19)	+	Area within basin boundary and isohyet in square miles for isohyets K through S.
10	AREAIB(20)	+	Area in square miles within basin boundary and isohyet coresponding to the storm area size.

ST

ST CARD - TEMPORAL DISTRIBUTION

This card gives data for the temporal distribution of the PMS for intervals less than 6 hours.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	ID	ST	Card identification.
1	TIMINT	+	Time interval in minutes to be used for temporal distribution of PMS. (Range of 5 min to 360 min).
2	R16A20	+	Ratio of 1hr to 6 hr precipitation for isohyet A of 20,000 sq mi storm from Figure 39 of HMR No. 52. (Range 0.27 to 0.35).
3	POSMAX	+	Position of maximum 6-hr increment in PMS temporal distribution. Remaining 6-hr increments in descending order will be placed alternately, before and after maximum increment. This arrangement will replace any distributions from previous SD or ST cards. (Range 5 to 12, default=7).
		0	Use previously established arrangement of 6-hr increments of PMS.
4	RATIO	+	PMS precipitation will be multiplied by this ratio. (Default = 1.0.)

ZW CARD - WRITE PMS TO DSS

The ZW card is included with data for each basin for which the hyetograph is to be saved on DSS.

Each data record (hyetograph) is identified by a 6-part pathname, each part being designated by letters A through F.

Part A is project identification or description, 16 characters maximum. Default is blank.

Past B is hyetograph location, 8 characters maximum. Default is basin name from BN card, Field 1.

Part C is parameter name, 12 characters maximum. Default is PRECIP-INC.

Part D is start date of hyetograph. Default is 01JAN1999. Hyetographs are stored in blocks of 1 month or 1 day depending on time interval. The hyetograph will start at 0000 hours on the date given on the ZW card, but the date in the pathname will be the beginning date of the block.

Part E is time interval. This will be derived by the program.

Part F is alternative or description of hyetograph, 24 characters maximum. Default is blank.

The format of the ZW card is

```
ZW A=Part A, B=Part B, C=Part C, D=Part D, F=Part F
```

One or more of the pathname parts may be omitted from the ZW card. Once parts A, C, D, or F have been set they will retain their values until reset on a ZW card.

For example:

```
ZW    A =                F=PMS-1
```

Will set part A to blank, and part F to PMS-1.

ZZ

ZZ CARD - END OF DATA

FIELD	VARIABLE	VALUE	DESCRIPTION
0	ID	ZZ	Card identification.

EXAMPLE

```
ID PROBABLE MAXIMUM STORM CALCULATION FOR EXAMPLE 2 IN HMR NO. 52
ID OUACHITA RIVER BASIN
*FREE
BN OUACHITA
** CALCULATE STORM OVER ENTIRE BASIN
BS .79365
BX 108 108 107 97 98 97 95 93 88 83 77 71 67 66 64 62
BX 59 54 48 40 38 39 37 26 18 12 8 6 4 6 8 9 15 25 27
BX 30 33 35 38 41 47 53 56 67 70 76 80 82 85 90 100 105
BY 17 21 24 32 34 36 37 44 48 48 46 46 50 54 55 54 50 47
BY 47 43 41 38 37 42 39 40 40 42 41 37 34 28 23 19 20
BY 20 19 23 21 21 24 22 23 16 15 10 10 14 11 12 10 12
HP    10 30.0 35.9 40.6 44.6 47.1
HP   200 22.2 27.0 31.2 34.7 37.7
HP  1000 16.3 21.0 25.3 29.0 31.2
HP  5000  9.5 13.5 17.7 21.6 24.2
HP 10000  7.3 10.7 14.0 18.0 20.8
HP 20000  5.3  8.5 11.6 14.9 17.2
HO 235
**
** FIND STORM AREA AND ORIENTATION FOR PMS CENTERED AT BASIN CENTROID
SA 0 0
GO
**
** CALCULATE STORM CENTERED BETWEEN RENNEL DAM AND BLAKELY MT. DAM
** USING GIVEN STORM AREA AND ORIENTATION
SC 87.9 20.1
SA 2150 280
GO
**
** CALCULATE STORM FOR EACH SUBBASIN USING LAST SET OF PARAMETERS
BN PINERIDG
BX 26 18 12 8 6 4 6 8 9 15 25 27 30 33 35 33 35 33 35
BY 42 39 40 40 42 41 37 34 28 23 19 20 20 19 23 27 31 35 38
BN WASHITA
BX 35 38 40 40 44 47 57 63 58 55 54 51 53 48 40 38 39 37 35 33
BX 35 33
BY 23 21 21 23 25 30 31 35 42 42 44 44 47 47 43 41 38 37 38 35
BY 31 27
BN BLAKELY
BX 53 51 54 55 58 63 57 47 44 40 40 41 47 53 56 59 64 72 79 84 85
BX 96 95 93 88 83 77 71 67 66 64 62 59 54
BY 47 44 44 42 42 35 31 30 25 23 21 21 24 22 23 21 23 22 28 28 30
BY 36 37 44 48 48 46 46 50 54 55 54 50 47
BN RENNEL
BX 108 108 107 97 98 97 96 85 84 79 72 64 59 67 70 76 80 82 85 90 100 105
BY 17 21 24 32 34 36 36 30 28 28 22 23 21 16 15 10 10 14 11 12 10 12
ZZ
```

SPILLWAYS

Purposes:

- to pass the normal streamflow and to release surplus or floodwater which cannot be contained in the allotted storage space
- direct water away from the downstream face and toe of the dam

➢ many failures of dams have been caused by improperly designed spillways or by spillways of insufficient capacity

selection of the inflow design flood - *conservatism*

consider the *base flow*

inflow design flood

watershed data needed:

- geographical location
- maps showing topography, streams, and drainage area
- information about soils and vegetative cover and the distribution through the
- watershed
- field verification

antecedent moisture conditions (**AMC**):

- **AMC I** - watershed soils are dry
- **AMC II** - watershed soils are neither dry nor saturated
- **AMC III** - watershed soils are saturated

When spillways of small capacities in relation to the inflow design flood peaks are considered, precautions must be taken to insure that the spillway capacity will be sufficient to:

1. evacuate surcharge storage so that the dam will not be overtopped by a subsequent storm
2. prevent the surcharge from being kept partially full by a prolonged runoff whose peak, although less than the inflow design flood, exceeds the spillway capacity

The minimum spillway capacity should be in accord with the following general criteria:

1. For snow fed perennial streams, spillway capacity should exceed the peak snowmelt runoff discharge of record
2. should provide sufficient evacuation of surcharge water - net storm assumed to begin 2 to 7 days after the time of peak outflow from inflow design flood depending on regional annual rainfall

The accumulation of storage in a reservoir depends on the difference between the rates of inflow and outflow

Selection of spillway size and type

What is the best combination of storage and spillway capacity to accommodate the selected inflow design flood?

factors:

⇒ *hydrology*
⇒ *hydraulics*
⇒ *design*
⇒ *cost*
⇒ *damages*

the **three most** important factors:

1. safety
2. safety
3. safety

do not create a worse flood with the dam than before the dam

Three spillway categories:

1. principal or service spillway
2. emergency or auxiliary spillway
3. low level or reservoir emptying spillway (outlet works)

types of structures used for spillways:

culverts vertical and horizontal
saddle or depressed area
gated
fixed crest
fuse plug - Ross Barnett reservoir, Jackson, MS
siphon

spillway rating curves

INFLOW DESIGN FLOODS FOR DAMS AND RESERVOIRS

-sets forth the hydrologic engineering requirements for selecting and accommodating Inflow Design Floods (IDF) on the basis that a dam failure (overtopping) must not produce a hazard to human life.

dam safety standards

Standard 1 - dams capable of placing human life at risk - IDF computed from PMP

Standard 2 - run of river projects little head diff no unique IDF

Standard 3 - failure could be tolerated at some flood magnitude
the base safety standard will be met when a dam failure related to hydraulic capacity will result in no measurable increase in population at risk and a negligible increase in property damages over that which would have occurred if the dam had not failed. one half of the PMF is the minimum acceptable IDF

Standard 4 - farm ponds less than 20 AF

GEORGIA: Each dam shall be capable of safely passing the fraction of the flood developed from the PMP hydrograph depending on the subclassification of the dam. The design storm for each subclassificaton of a dam is as follows:

(a) Small Dam	25 percent PMP
(b) Medium Dam	33.3 percent PMP
(c) Large Dam	50 perecnt PMP
(d) Very Large Dam	100 perecnt PMP

GENERAL GUIDELINES

1. categorize dams according to hazard posed
   - low
   - medium
   - high

2. base hazard category on
   - population at risk
   - likely loss of life
   - economic losses
   - potential dam failure as a proportion of PMF

3. categorize dams according to
   - new
   - existing

retention of the PMF criteria for design of spillways for **new** dams in **high hazard** locations is "generally recommended."

existing, high hazard dams -

dam failure is presumed to mean dam overtoppping

Safety Evaluation Flood (SEF) - the largest reasonable hypothetical water inflow for which the safety of a dam is to be evaluated. The ***SEF*** is essentially the largest possible non failure flood that a dam can hold (e.g. HM33)

Are the incremental economic damages and/or loss of life due to dam failure flood significantly larger than the ***SEF?***

-"there is no single, universally correct approach to evaluating the safety of all existing high hazard dams" NRC Committee

two groups of existing, high hazard dams:

1. dams in which the incremental damages of "failure" are much greater than the current "non-damage" failures damages due the ***SEF***
2. dams where it is not clear that the remedial work needed to permit safe passage of a PMF are justified

"base safety standard (condition)" ***BSC*** is the ***SEF***

"threshold flood" - flood that fully utilizes the existing dam

ANALYSIS

1. determine at what point the dam would fail under existing conditions

2. determine the ***BSC*** - *met when a dam failure related to hydrologic capacity will result in no significant increase in downstream hazard over the hazard that would have existed if the dam had not failed*

Inflow Design Flood - the level of the Probable Maximum Flood which defines the base safety condition

Base Safety Condition - the minimum event for which the modification should be designed. The **BSC** is met when a dam failure related to hydrologic capacity will result in no significant increase in downstream hazard over the hazard that would have existed if the dam had not failed.

Separate the dams requiring remedial measures for hydrologic/hydraulic deficiencies into two categories:

1. those which should be upgraded to pass the PMF
2. those dams which are hydrologically adequate to without fully meeting PMF design

Threshold Flood - The threshold flood is the flood that just exceeds the design maximum water surface elevation at the dam (top of dam minus freeboard)

EVALUATION

Step 1- Project description

Step 2 - Define existing threshold flood

Step 3 - Determine outflows from the threshold flood with and without dam failure and from lesser floods

Step 4 - Compute the hypothetical maximum dam failure flows and downstream inundation

Step 5 - prepare inundation maps and collect data on damageble property and populations for the hypothetical maximum flooding determined in ***step 4***

Step 6 - Prepare inundations maps for threshold flood

Step 7 - determine population at risk from the threshold flood and lesser floods

Step 8 - determine economic losses from threshold flood and specified lesser floods

Step 9 -determine dam failure warning time

Step 10 - estimate the baseline probable PAR, probable TP, and probable LOL from the threshold flood and specified lesser floods

Step 11 - display existing condition results and propose additional action

Step 12 - identify alternatives to reduce the dam safety hazard to people and property

Step 13 - estimate the cost of BSC modification alternatives

Step 14 - evaluate effectiveness of alternatives in reducing hazard

Step 15 - determine the BSC

Step 16 - recommend alternative to meet BSC

Step 17 - determine whether breaching the dam should be evaluated as an alternative

RESERVOIR SEDIMENTATION

sediment- erosion, entrainment, transportation, and deposition

amount of sediment depends on

- geology,
- climate,
- vegetation,
- physical factors

erosion - the wearing away of the land

sediment is the by product of *erosion*

normal erosion

accelerated erosion - disturbance, development

The removal of natural timber cover and other land disturbing activities can increase the erosion rate more than one - hundred -fold.

Water is the most widespread agent of erosion

Water erosion - two general types

- *sheet erosion*
- *channel erosion*

sheet erosion - detachment of material from land surfaces by raindrop impact

tremendous kinetic energy exerted by rainfall

erosion is most closely related to the amount of rainfall occurring in a 30 minute duration

forces of resistance - nature of the soil and cover

predicting rates of sheet erosion

A = R K L S C P

A average annual soil loss in tons per acre
R rainfall erosion factor
K soil erodibility factor
LS slope, length, and steepness factor
C cropping and management factor
P supporting conservation factor such as terracing, strip cropping , contouring

channel erosion - the removal and transport of material by concentrated flow.
examples: gully, stream bank, stream bed, flood plain scour

rate depends on:

- hydraulic characteristics of flow
- channel materials - noncohesive, cohesive

tractive force theory

MOVEMENT OF SEDIMENT FROM WATERSHEDS

Sediment yield-

gross erosion - total watershed erosion
colluvium - sheet deposition
alluvium, channel splays, bars - stream deposition

sediment yield - total amount which does reach the downstream limit

$$\textbf{sediment delivery ratio} = \frac{\textit{sediment yield}}{\textit{gross erosion}}$$

function of :

- drainage area
- degree and length of watershed slopes
- channel density (?) ft/acre
- relief ratio - h/l
- rainfall and runoff

SEDIMENT ALLOWANCES IN THE DESIGN OF A RESERVOIR

sediment characteristics - grain size distribution
volume - weight relationship

grain size distribution - assigning a trap efficiency value to the reservoir
predicting the sediment distribution
determining space requirements

sediment particle - a mineral or rock fragment
mineralogical composition
shape
size (see table 17- I -2)

bulk characteristics grain size distribution
specific weight of deposited sediment

fine grain sediments - sediments with more than 50 percent in grains of less than 0.062mm
sheet erosion produces primarily fine grained sediment, since pre channel flow seldom exceeds 2 or 3 fps and is capable of transporting only the finer grains detached by rainfall

TRAP EFFICIENCY OF RESERVOIRS

- percent of sediment yield retained in the basin
- function of sediment characteristics and flow through the reservoir
- fall velocity of particles
- rate at which particles are transported through the reservoir
- delta deposits
- bottom set beds
- predicting sediment distribution - area-increment method; empirical area-reduction method
- reservoir sediment surveys
- sediment rating curve

PREDICTING SEDIMENT YIELDS

- use of existing data from comparative watersheds
- sediment load measuring stations
- estimating watershed erosion and the delivery ratio of sediment

CONTROL OF RESERVOIR SEDIMENTATION

- design of reservoir
- venting
- removal - hydraulic or mechanical means

REDUCING SEDIMENT YIELD

- vegetative screens
- watershed structure
- watershed land treatment
  1. soil improvement
  2. tillage
  3. strip cropping
  4. terracing
  5. crop rotation

WAVE RUNUP AND WIND SETUP ON RESERVOIR EMBANKMENTS

Runup computation checklist

⇒ estimate maximum winds

actual wind records from site

general wind statistics

⇒ plot a wind velocity-duration curve for the site

⇒ compute reservoir effective fetch

⇒ plot a wind velocity-duration curve for the reservoir effective fetch

⇒ select design wind

⇒ forecast design wave (deepwater)

⇒ refract or diffract wave to shore if needed

⇒ compute runup

⇒ compute wind setup

WAVES

Refraction - the process by which the direction of a wave moving in shallow water at an angle to the bathymetric contours is changed. the part of a wave advancing in shallower water moves more slowly than that part still advancing in deeper water, causing the wave crest to bend toward alinemenet with the bathymetric lines of contour.

Diffraction - energy is transmitted laterally along the wave crest. When a part of a train of waves is interrupted by a barrier, such as a breakwater, the effect of diffraction is manifested by the propagation of waves into the sheltered region within the barrier's geometric shadow

Wave Reflection

wave reflection from vertical, imperiable wall-clapotis
wave reflection in an enclosed basin -seiches
wave reflection from from plane slopes,beaches, revetments, and breakwaters
wave reflection from bathymetric variation shoal or off shore bar
deep water H/L 1/7

shoaling water breaking depth/breaker height 1.28

types; spilling, pluging, surging

Significant wave height - ave height of the 1/3 highest waves Rayleigh distribution

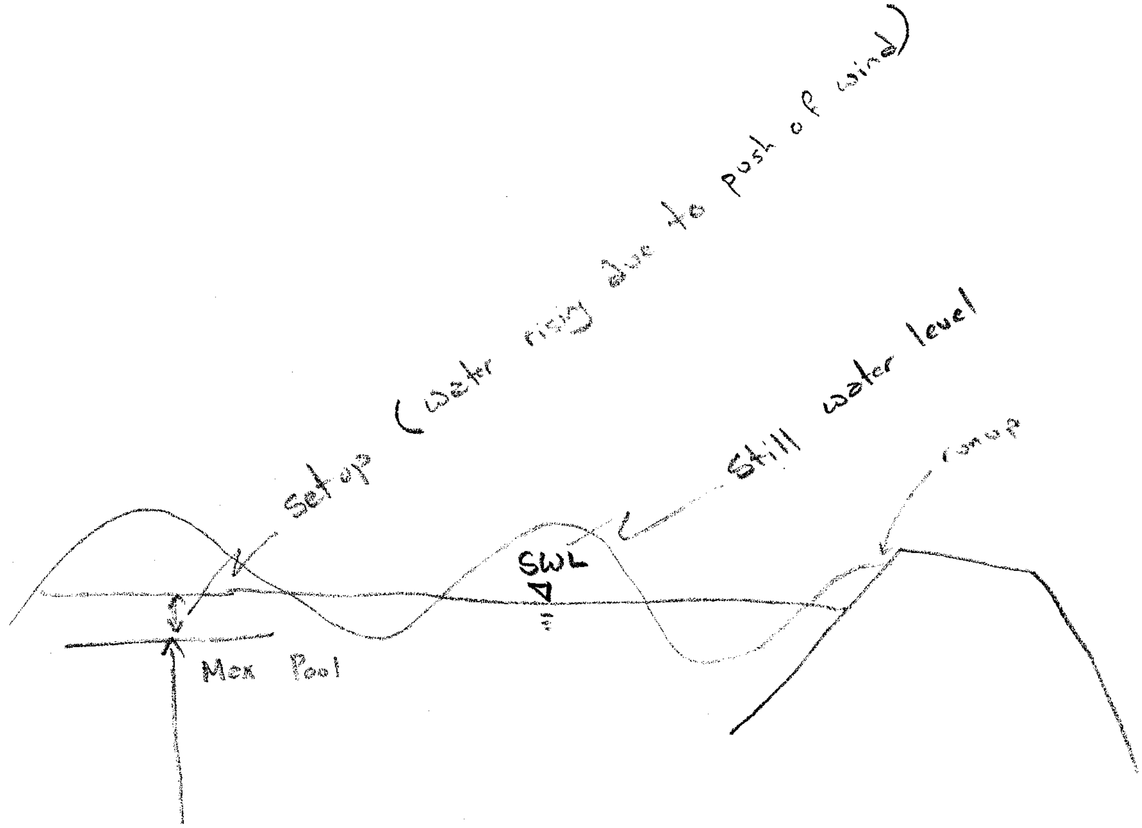
Wave spectrum - a graph, table, or mathematical equation showing the distribution of wave energy as a function of wave frequency - based on observation or theratical considerations

wave height - function of wind height, fetch length, wind duration

water level fluctuation

astronomical tide
wave setup
storm surge 9(26 feet)
wind setup

wind induced surge acompanied by wave action accounts for most of the damage to the shore


setup (water rising due to push of wind)
Still water level
runup
SWL
Max Pool

Coastal Engineering Technical Note

COMPUTER PROGRAM
NARFET - WIND-WAVE GENERATION ON RESTRICTED FETCHES

PURPOSE: The purpose of this technical note is to predict significant wave height, peak period, and mean direction for narrow or restricted fetches.

BACKGROUND: Wind-wave generation in lakes, rivers, bays, and reservoirs is generally limited by the geometry of the water body, which is often very irregular. Most approaches to this problem consider wave generation only in the direction of the wind with fetch lengths averaged over small arcs (Shore Protection Manual (SPM) 1984) or large arcs (Saville 1954). Donelan (1980) proposed wave generation on fetch lengths in off-wind directions with reduced wind forcing (reduced by the cosine of the angle between the off-wind and wind directions) for the Great Lakes. The NARFET model (Smith 1989) is based on the Donelan concept, allowing wave generation in off-wind directions. Smith developed expressions for wave height and period as a function of fetch geometry and wind speed based on linear regressions of wave data collected on Puget Sound (Washington), Fort Peck Reservoir (Montana), Denison Reservoir (Texas), and Lake Ontario. The mean wave direction is determined by maximizing the wave period. These equations differ from those given by Donelan which were developed for the longer, more regular-shaped fetches of the Great Lakes. The NARFET model is quick and inexpensive (runs on a PC), yet considers the complexity of fetch geometry.

ASSUMPTIONS:

1. Waves are locally generated and fetch-limited.
2. Water depths across the fetch are deep (depth is greater than half the wave length.
3. Wind speed and direction are steady (spatially and temporally).

INPUT: The input to NARFET describes the fetch geometry and the wind forcing. The program accepts interactive responses to questions. Responses are either numeric or alphabetic. Alphabetic responses are shortened to one letter abbreviations shown in parentheses. Capital letters must be used. When a file name is requested, the number of characters in the name is limited to eight. The input required includes:

1. Fetch Geometry. The fetch geometry is described by radial fetch lengths measured from the shoreline to the point of interest at even angle increments. The user must specify the

angle (measured clockwise from north) of the first radial length, the total number of radials (for some locations it is not necessary to input a full 360 degree arc - unspecified lengths are set to zero), and the angle increment between radials. Then, individual radial lengths are entered interactively. The program allows the user to review radial length entries and correct errors. NARFET internally interpolates fetch lengths at 1 degree increments around the entire 360 degree arc. Then the program averages fetch lengths over 15 degree arcs centered on each one-degree increment. These fetch lengths are used to calculate wave conditions. The option is given to write this information to a file for future computer runs. A file name is requested when this option is chosen.

2. Wind Forcing. Wind forcing is represented by wind speed, direction, and duration over the water body. Wind fields are distorted by friction effects, so the measurement elevation, the boundary layer stability, and the measurement location (over land or over water) are also needed to adjust the wind speed to standard conditions. The simplified corrections to wind speed used in NARFET are based on these three factors. The correction methods are given in the SPM. Wind speeds are adjusted to the standard 10-m elevation. The air-sea temperature difference represents the boundary layer stability. If the temperature difference is unknown, the SPM recommends a correction factor of 1.1 (unstable condition). This correction factor is equivalent to an air-sea temperature difference of approximately -3 degree C. Overland wind conditions differ from overwater conditions because of increases in surface roughness over land. An additional correction is made if winds are based on overland measurements. An option is also available to correct winds for nonconstant coefficient of drag (SPM). This correction was not used in developing the model, but current Corps of Engineers guidance recommends the correction. The duration input is used to check if wave generation is limited by duration. The program does not convert very short duration wind observations (e.g. fastest mile wind speeds) to longer durations.

PROGRAM OUTPUT: The primary output of NARFET is the significant wave height, peak period, and mean direction corresponding to the input wind forcing. The program also recaps the input wind conditions and states whether the solution is fetch-limited, duration-limited, or fully-developed.

SAMPLE PROBLEM: For central Puget Sound (Figure 1), find the significant wave height, peak wave period, and mean wave direction.

Given: wind speed = 15 m/s at 10-m elevation over water
wind direction = 200 degrees
wind duration = 5 hours
air-sea temperature difference unknown

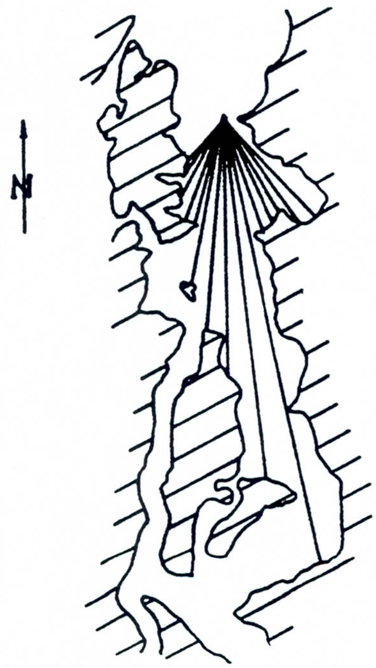


Figure 1. Southern Puget Sound Geometry.

Underlined values are user's input. Note the use of single-letter responses.

```
NARFET
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
          PROGRAM NARFET

THIS PROGRAM CALCULATES DEEPWATER WAVES FOR RESTRICTED FETCHES
BASED ON WIND SPEED, WIND DIRECTION, AND FETCH GEOMETRY
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
DO YOU WISH TO ENTER FETCH GEOMETRY (I)NTERACTIVELY
OR FROM A (F)ILE?
I

FETCH GEOMETRY IS DETERMINED BY INPUTING RADIAL
LENGTHS MEASURED FROM THE POINT WHERE YOU WANT WAVE
INFORMATION TO THE LAND BOUNDARY OF THE WATER BODY

INPUT THE ANGLE INCREMENT BETWEEN RADIAL MEASUREMENTS (DEG)
6.

INPUT THE DIRECTION OF THE FIRST RADIAL WITH RESPECT TO
THE LOCATION OF INTEREST (IN DEGREES MEASURED CLOCKWISE
FROM NORTH)
138.

INPUT THE NUMBER OF RADIALS
15
```

INPUT UNITS OF RADIAL LENGTHS: (K)ILOMETERS, (F)EET, (M)ILES, OR (N)AUTICAL MILES
K

INPUT RADIAL LENGTH FOR 138.0 DEG
10.24

INPUT RADIAL LENGTH FOR 144.0 DEG
9.75

INPUT RADIAL LENGTH FOR 150.0 DEG
7.88

INPUT RADIAL LENGTH FOR 156.0 DEG
8.21

INPUT RADIAL LENGTH FOR 162.0 DEG
8.62

INPUT RADIAL LENGTH FOR 168.0 DEG
35.68

INPUT RADIAL LENGTH FOR 174.0 DEG
28.24

INPUT RADIAL LENGTH FOR 180.0 DEG
20.20

INPUT RADIAL LENGTH FOR 186.0 DEG
16.01

INPUT RADIAL LENGTH FOR 192.0 DEG
12.76

INPUT RADIAL LENGTH FOR 198.0 DEG
8.21

INPUT RADIAL LENGTH FOR 204.0 DEG
8.17

INPUT RADIAL LENGTH FOR 210.0 DEG
7.48

INPUT RADIAL LENGTH FOR 216.0 DEG
5.20

INPUT RADIAL LENGTH FOR 222.0 DEG
5.08

RECAP OF INPUT ANGLES AND RADIAL LENGTHS

```
ANGLE = 138.0  RADIAL LENGTH =   10.24
ANGLE = 144.0  RADIAL LENGTH =    9.75
ANGLE = 150.0  RADIAL LENGTH =    7.88
ANGLE = 156.0  RADIAL LENGTH =    8.21
ANGLE = 162.0  RADIAL LENGTH =    8.62
ANGLE = 168.0  RADIAL LENGTH =   35.68
ANGLE = 174.0  RADIAL LENGTH =   28.24
ANGLE = 180.0  RADIAL LENGTH =   20.20
ANGLE = 186.0  RADIAL LENGTH =   16.01
ANGLE = 192.0  RADIAL LENGTH =   12.76
ANGLE = 198.0  RADIAL LENGTH =    8.21
ANGLE = 204.0  RADIAL LENGTH =    8.17
ANGLE = 210.0  RADIAL LENGTH =    7.48
ANGLE = 216.0  RADIAL LENGTH =    5.20
ANGLE = 222.0  RADIAL LENGTH =    5.08
```

HOW MANY VALUES DO YOU WISH TO CHANGE?
(ENTER 0 FOR NONE)
<u>0</u>

DO YOU WISH TO SAVE FETCH GEOMETRY FOR
FUTURE RUNS? (Y OR N)
<u>Y</u>

ENTER FILE NAME (MAX OF 8 CHARACTERS) TO
SAVE FETCH GEOMETRY
<u>PUGS.DAT</u>

INPUT UNITS OF WIND MEASUREMENT ELEVATION: (M)ETERS OR (F)EET
<u>M</u>

INPUT WIND MEASUREMENT ELEVATION
<u>10.</u>

IS THE OBSERVATION LOCATION OVER WATER (W) OR LAND (L)?
<u>W</u>

INPUT UNITS OF AIR-SEA TEMPERATURE DIFFERENCE: DEGREES (C) OR (F)
<u>C</u>

INPUT UNITS OF WIND SPEED: (M)ETERS/SEC, (F)EET/SEC, (K)NOTS,
OR MILES/HOUR (N)
<u>M</u>

INPUT AIR - SEA TEMPERATURE DIFFERENCE
<u>-3.</u>

INPUT WIND SPEED, WIND DIRECTION (DEG), AND DURATION (HR)
<u>15.,200.,5.</u>

```
INPUT CONDITIONS:
    ADJUSTED WIND SPEED (M/S) =  22.7    (  22.7 INPUT UNITS)
    WIND DIRECTION (DEG) = 200.0
    DURATION (HR)=   5.0
    AIR-SEA TEMP DIF (DEG C) =  -3.0

SIGNIFICANT WAVE HEIGHT (M) =   1.6
SIGNIFICANT WAVE HEIGHT (FT) =   5.3
PEAK WAVE PERIOD (S) =   4.7
MEAN WAVE DIRECTION (DEG) = 173.0

DURATION LIMIT (HR) =   2.9

FETCH LIMITED CONDITIONS

DO YOU WANT TO RUN ANOTHER WIND CONDITION?
N

RUN COMPLETE
FORTRAN STOP
```

AVAILABILITY: A FORTRAN listing of NARFET is available from the Coastal Engineering Research Center, Coastal Oceanography Branch. The program is internally documented via comment cards, and detailed information about the development of the model is given by Smith (1989). For further information, contact Jane McKee Smith at (601) 634-2079.

REFERENCES:

Donelan, M.A. 1980. "Similarity Theory Applied to the Forecasting of Wave Heights, Periods, and Directions," Proceedings of the Canadian Coastal Conference, National Research Council, Canada, pp. 47-61.

Saville, T. 1954. "The Effect of Fetch Width on Wave Generation," Technical Memorandum No. 70, Beach Erosion Board, Washington, DC.

Shore Protection Manual. 1984. US Army Engineer Waterways Experiment Station, Coastal Engineering Research Center, US Government Printing Office, Washington, DC.

Smith, J.M. 1989(in preparation). "Wind-Wave Generation on Restricted Fetches," US Army Waterways Experiment Station, Coastal Engineering Research Center, Vicksburg, MS.

HEC-HMS, Hydrologic Modeling System, Version 1.0

The **HEC-HMS** program supercedes **HEC-1** and provides a similar variety of options for simulating precipitation-runoff processes. In addition to unit hydrograph and hydrologic routing options, capabilities include a linear distributed-runoff transformation that can be applied with gridded (e.g., radar) rainfall data, a simple "moisture depletion" option that can be used for simulations over extended time periods, and a versatile parameter optimization option. Future versions will have capability for continuous moisture accounting and snow accumulation/melt simulation.

http://www.wrc-hec.usace.army.mil/software/software_distrib/hec-hms/hechmsprogram.html

http://www.hec.usace.army.mil/software...

HYDRAIN → http://www.fhwa.dot.gov/bridge/hydrain.htm

Hydrologic Analysis with HEC-1 on a Personal Computer

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List of Figures and Tables

Chapter 1

Introduction

1.1 Program Development

The HEC-1, Flood Hydrograph Package, computer program was originally developed in 1967 by Leo R. Beard and other members of the Hydrologic Engineering Center (HEC) staff. The first version of the HEC-1 program package was published in October 1968. It was expanded and revised and published again in 1969 and 1970. The first package version represented a combination of several smaller programs which had previously been operated independently.

Input and output formats were almost completely restructured in order to simplify input requirements and to make the program output more meaningful and readable when the 1970 version underwent a major revision in 1973. In 1981 the computational capabilities of the dam-break (HEC-1DB), project optimization (HEC-1GS) and kinematic wave (HEC-1KW) special versions were combined. These were put into a single easy to use package. In late 1984 a microcomputer version (PC version) was developed.

The latest version, Version 4.0 (September 1990), represents improvements and expansions to the hydrologic simulation capabilities together with interfaces to the HEC Data Storage System (DSS). The DSS capability allows storage and retrieval of data from/for other computer programs as well as the creation of report-quality graphics and tables. New hydrologic capabilities include Green and Ampt infiltration, Muskingum-Cunge flood routing, reservoir releases input over time, and improved numerical solution of kinematic wave equations. The Muskingum-Cunge routing may also be used for the collector and main channels in a kinematic wave land surface runoff calculation.

1.2 Overview of the HEC-1 Package

The basic steps in rainfall-runoff simulation include:

Gathering data (topographic maps, precipitation and streamflow data, aerial photos, soils and land use information, etc....).

Estimate model parameters (unit hydrograph, loss rate, and routing parameters, etc...).

Develop HEC-1 input data file representing the watershed and rainfall-runoff.

Simulate the flood event by executing HEC-1.

Review and evaluate model results as compared to observed information. (HEC-1 output and/or graphical displays with DSS.)

Calibrate model parameters to obtain best fit of several observed events.

Use calibrated model for design or analysis purposes.

The programs distributed with the HEC-1 package provide the necessary tools to accomplish all the basic steps for a rainfall-runoff simulation on the personal computer (PC). The computational process for doing a flood runoff analysis is illustrated in Figure 1. A menu program, MENU1, has been developed to provide program users convenient access to the HEC-1 package of programs and related files, when operating a PC with a hard disk. The MENU1 program, described in chapter 3, eliminates repeated typing of program and filenames while using the HEC-1 package of programs.

Text editors can be used to create or modify an input data file for the HEC-1 program. The Corps editor COED, has been developed with some features specifically designed around the HEC format for computer program input. COED will place the input data in the format expected by HEC-1 as the data file is created. It also has help information for HEC-1 input data. Chapter 4 provides information on creating and editing input files with COED.

An interactive data input program (HEC1IN) has been developed for new to intermediate users of the HEC-1 program. This program leads the user through a sequence of formatted screens and tables that describe the watershed and the type of hydrologic processes to be used in the computations. After all the screens and tables are filled out, the program creates a skeleton HEC-1 input file. This file will contain all of the data records required to simulate the rainfall-runoff process, but not all of the data. It is the users responsibility to edit the file (using COED or any other text editor) and fill in the necessary data associated with each record. Appendix A of this document contains more information about the HEC1IN program.

After the HEC-1 input file is developed, the model can be executed. Chapter 5 provides information on running HEC-1 on the PC. Once the HEC-1 program has finished executing, the user can begin to review the results. Reviewing model results is described in Chapter 6.

1.3 Acknowledgments

This document was developed by Gary W. Brunner. Arlen Feldman, Chief of the Research Division, provided valuable input and editorial comments. Word processing and graphics were accomplished by Diane Harris and Penni Baker.

1.4 Program Documentation

The primary documentation for the HEC-1 program is the User's Manual. The manual provides a complete description of the HEC-1 program capabilities, theoretical basis for computations, and example problems with input and output. A careful review of the User's Manual should be made before using the computer program.

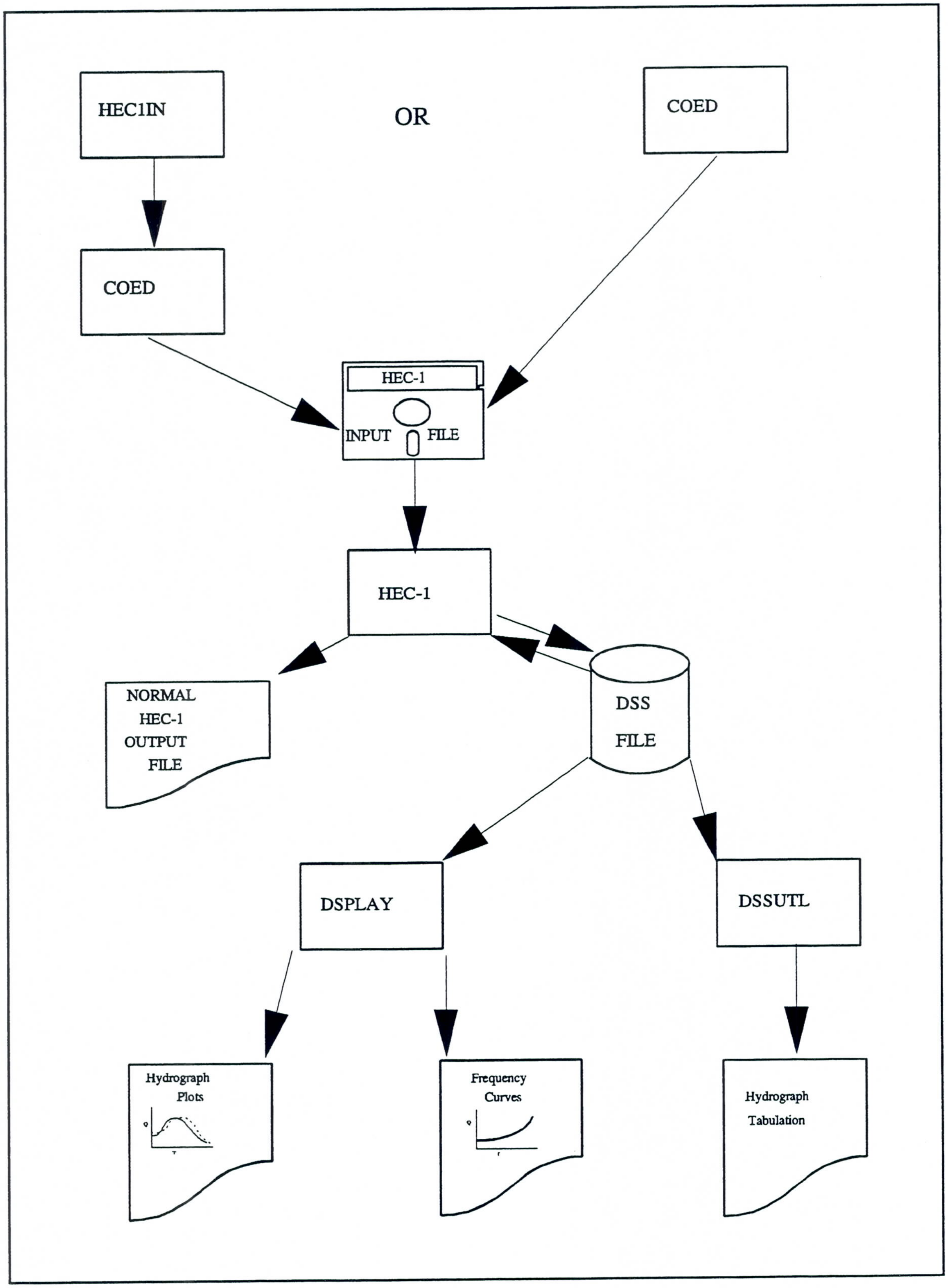

Figure 1. HEC-1 Computation Process

Supplemental technical information is available through the following HEC publications:

Probable Maximum Storm (Eastern United States) (HMR52) User's Manual

Training Document No. 10, Introduction and Application of Kinematic Wave Routing Techniques Using HEC-1.

Training Document No. 15, Hydrologic Analysis of Ungaged Watersheds with HEC-1

Training Document No. 19, Application of Spatial Data Management Techniques to HEC-1 Rainfall - Runoff Studies

Technical Paper No. 54, Adjustment of Peak Discharge Rates for Urbanization

Technical Paper No. 59, Testing of Several Runoff Models on an Urban Watershed

Technical Paper No. 62, Flood Hydrograph and Peak Flow Frequency Analysis

Technical Paper No. 70, Corps of Engineers Experience with Automatic Calibration of a Precipitation - Runoff Model

Technical Paper No. 100, Probable Maximum Flood Estimation - Eastern United States

Technical Paper No. 116, The HEC's Activities in Watershed modeling

Technical Paper No. 118, Real-Time Snow Simulation Model for the Monongahela River Basin

Technical Paper No. 121, Development, Calibration and Application of Runoff Forecasting Models for the Allegheny River Basin

Technical Paper No. 122, The Estimation of Rainfall for Flood Forecasting Using Radar and Rain Gage Data

Computer Program Documentation No. 45, HECDSS, User's Guide and Utility Program Manuals

Computer Program Documentation No. 56, Corps of Engineers Editor Users's Manual (COED)

Supplemental information on the computer hardware/software installation for HEC-1 is available through the following HEC publications:

Installation Instructions for Microcomputer Version of HEC-1

HEC-1 Flood Hydrograph Package, Large-Array Version Implementation

Installation Instructions for Device Drivers

The supplemental material, as well as other HEC publications, are listed in the Publication Catalog; along with prices and ordering information. This free catalog is available from:

Hydrologic Engineering Center
609 Second Street
Davis, CA 95616-4687

HEC provides training in HEC-1 primarily for Corps and other Federal offices; Basic and Advanced HEC-1 courses and a Floodplain Hydrology Course are offered. HEC also provides user assistance for Corps offices and other federal agencies. There are several university extension short courses on the use of the HEC-1 program. A one-week course provides a good overview of the basic program capabilities.

For those unable to attend a course, there are video tapes of most lectures given in HEC training courses on HEC-1. The tapes are distributed only in the USA by a contractor. A Video Tape Catalog with ordering information is available from the HEC at no charge.

1.5 Program Distribution

Corps of Engineers offices and other Federal agencies may receive copies of the HEC-1 package from HEC at no charge. Other offices may obtain the program from National Technical Information Service (NTIS) or a number of private distributors. A list of these private distributors is available from HEC.

A free Computer Program Catalog is available from HEC. The catalog provides a description of all available computer programs and program support information. The catalog can be ordered at the address shown on the previous page.

Chapter 2

Program Installation Overview

This chapter is only an overview of the installation instructions. Please see seperate "Installation Instructions for Microcomputer Version of HEC-1" for detailed installation information.

2.1 Computer Requirements

This version of HEC-1 will run on an IBM or compatible microcomputer that has the following:

* **640 Kilobytes (KB) of Random Access Memory (RAM), with 571,000 bytes of base memory free for program execution.**

* **MS DOS 2.1 or greater.**

* **One 5¼ inch floppy diskette drive (360 Kb or 1.2 Mb).**

* **A 10 Megabyte (or larger) hard disk (a minimum of 3 Mb of storage should be available when installing the system).**

* **A math coprocessor (8087, 80287, or 80387) is highly recommended, but not required. The math coprocessor will greatly reduce the execution time of the program (increases computational speed by a factor of 5 to 10).**

NOTE: GSS DEVICE DRIVERS REQUIRED

The HECDSS DSPLAY graphics program included with the HEC-1 package of programs requires GSS device drivers to create graphical displays. Device drivers are software packages for specific plotters, printers and graphics adapters. Please review the installation instructions for device drivers.

GSS device drivers for non-Corps offices may be obtained from GSS (Graphic Software Systems, inc., 9590 S.W. Gemini Drive, Beaverton, OR 97005). Device drivers for Corps of Engineers offices may be obtained from HEC (Hydrologic Engineering Center, 609 Second Street, Davis, CA 95616).

2.2 Installation Options

Installation is usually accomplished through the execution of an interactive program called **INSTALL1** which is provided with the HEC-1 package. See "Installation Instructions for Microcomputer Version of HEC-1" for details. The INSTALL1 program:

- Creates directories **\HECEXE** and **\HECEXE\SUP**. The **\HECEXE** directory is used to store all of the executable programs and the **\HECEXE\SUP** subdirectory is used for any supplemental files required by the executable programs.

- Un-compresses and copies files into the appropriate directories.

- Displays information about modifying the **CONFIG.SYS** and **AUTOEXEC.BAT** files in order to execute the programs.

The recommended directory configuration that **INSTALL1** creates is shown in Figure 2. After completing the installation, make sure that your PC has all of the same files in the **\HECEXE** and **\HECEXE\SUP** directories as shown in Figure 2. Alternative installation instructions (not using INSTALL1) are provided in "Installation Instructions for Microcomputer Version of HEC-1." However, <u>the INSTALL1 program is the preferred method for HEC-1 installation on your computer.</u>

2.3 Contents of the HEC-1 Package Diskettes

The **HEC-1** computer program, example input data, example output, menu system and auxiliary programs are provided on five **360 Kb,** 5 1/4 inch floppy diskettes. The files may be de-archived and loaded onto your computer using the INSTALL1 program or by manual installation; see separate "Installation Instructions for Microcomputer Version of HEC-1."

2.4 Memory Requirements

The standard **HEC-1** Package of programs was compiled under the **DOS** operating system, and is therefore constrained to the **640 kilobytes** of main memory limitation. In order for the **HEC-1** package to function correctly, there must be **571,000 bytes** of base memory available for program execution. The **DOS** command **CHKDSK** can be run to determine the amount of available base memory on your machine. If you do not have enough free memory, check your **AUTOEXEC.BAT** file to see if you are loading any **RAM** resident programs. You may have to remove some RAM resident programs to obtain the needed base memory. A large-array version of HEC-1 is available that requires 2.5 megabytes of total memory. See "HEC-1 Flood Hydrograph Package, Large-Array Version Implementation."

2.5 Configuration of Computer System

To allow access of the executable programs from any directory, it will be necessary to edit the **AUTOEXEC.BAT** file to include a path to the **\HECEXE** directory. Many **HEC** programs require the capability to open more than eight (8) files at any one time. Because eight is the system default, you will need to modify your **CONFIG.SYS** file to include the following two lines: **FILES=20**, and **BUFFERS=15**.

For more information concerning the **PATH** command and the **AUTOEXEC.BAT** and **CONFIG.SYS** files, consult your **DOS** manual and "Installation Instructions for Microcomputer Version of HEC-1."

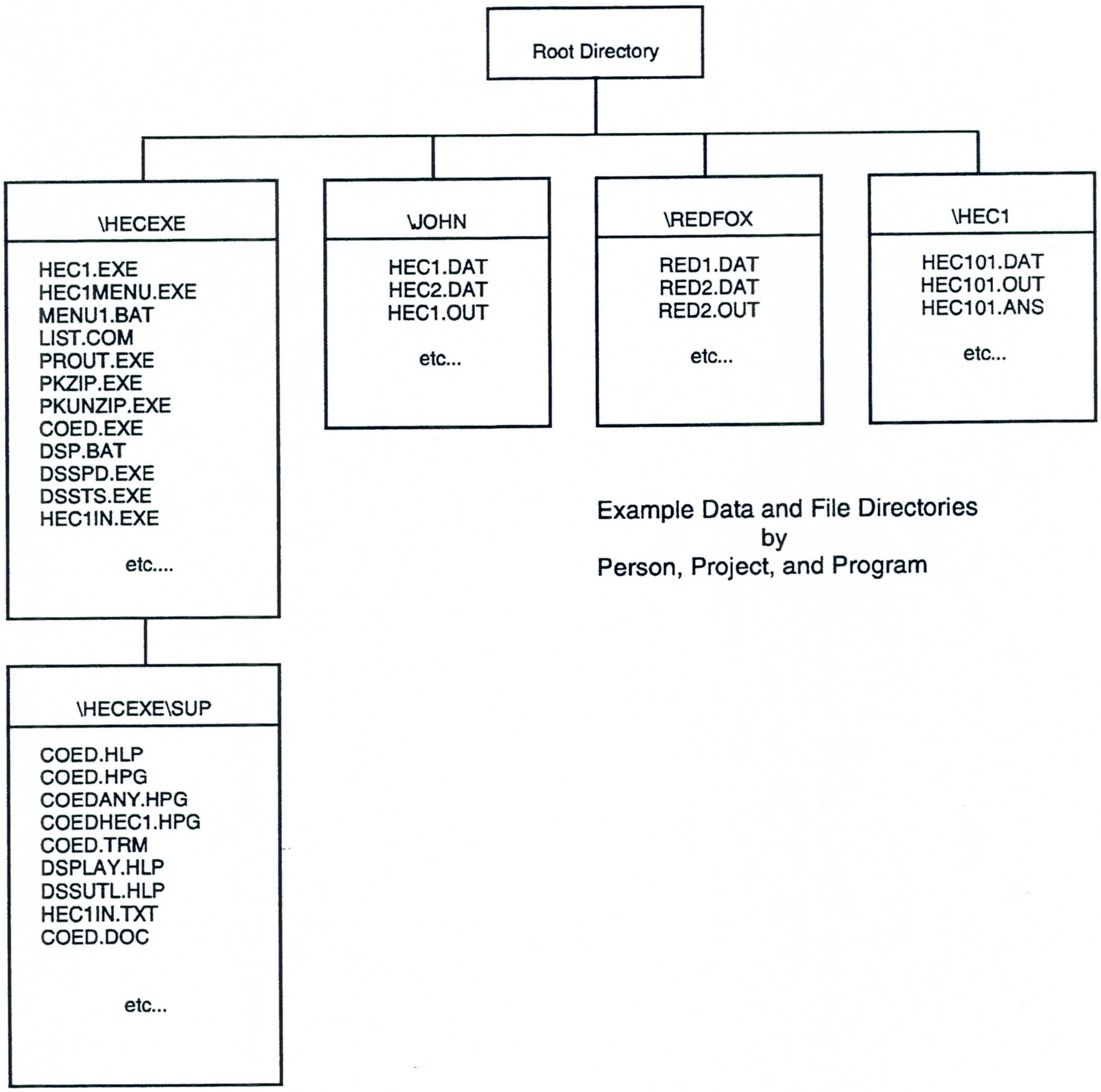

Figure 2. Recommended HEC Directory Configuration

Chapter 3

HEC-1 Package Menu Program

3.1 Purpose of Program

The HEC-1 package menu, MENU1, has been created to aid the user in operating the program on the PC. The menu system provides the capability to: create and edit input files; execute HEC-1, DSPLAY, HEC1IN, and DSSUTL programs; and to display output conveniently to the screen or the printer. The following provides a description of the menu operation.

3.2 Program Operations

After all of the files have been installed on your hard disk, execution of the HEC-1 Package Menu program is accomplished by typing **MENU1** and pressing the **<ENTER>** key. You must execute the menu system through this batch file or the programs will not function correctly. The HEC-1 Package Menu should appear on the screen as shown in Figure 3. As you can see there are five choices, with the first choice being highlighted. Also highlighted is a status line at the bottom of the screen. This status line is used to direct the user on how to proceed at any point. The background and text colors of the menu can be changed for color monitors by pressing the F9 and F10 keys, respectively. The program will save the selected colors via the PARMS.DFT file. In general the menu operates by using the cursor arrow keys to move to the desired option, and then pressing **<ENTER>** to execute that option. Another way to execute an option is to press the number of the desired function. The following paragraphs describe each of the five options specifically.

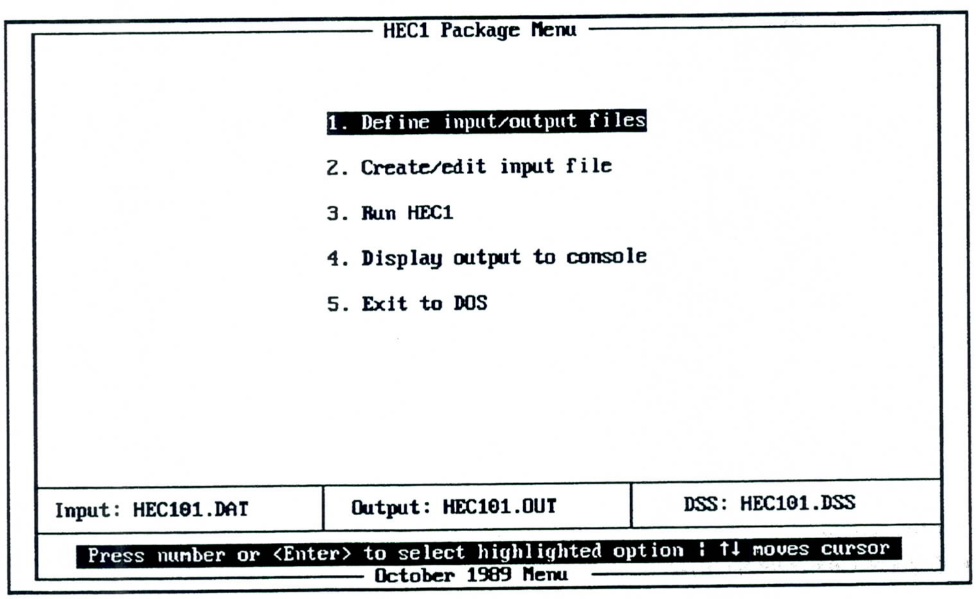

Figure 3. HEC-1 Package Menu

1. **Define Input/Output/DSS Files:**

This option is used to define the target input and output filenames that will be used when executing HEC-1. When this option is selected a pop-up menu will appear as shown in Figure 4. The menu is set up to use the default extensions ".DAT", ".OUT", and ".DSS" for the input, output and DSS filenames, respectively. This can be overridden by turning off the default extension option. The filenames can be entered directly, or a "?" can be entered to get a listing of the files available on the current data directory. You may choose a file by using the cursor keys to highlight the appropriate filename and then pressing the **<ENTER>** key. If the input file does not exist, you will be asked if you would like to create it. If you say yes to this question, a blank file will be created with the name that you specified. The next step would be to execute option 2 (Create/edit input file), which will allow you to enter the necessary data. Also note that at the bottom of the screen there is a line that displays the names of the current input, output and DSS files that are being used.

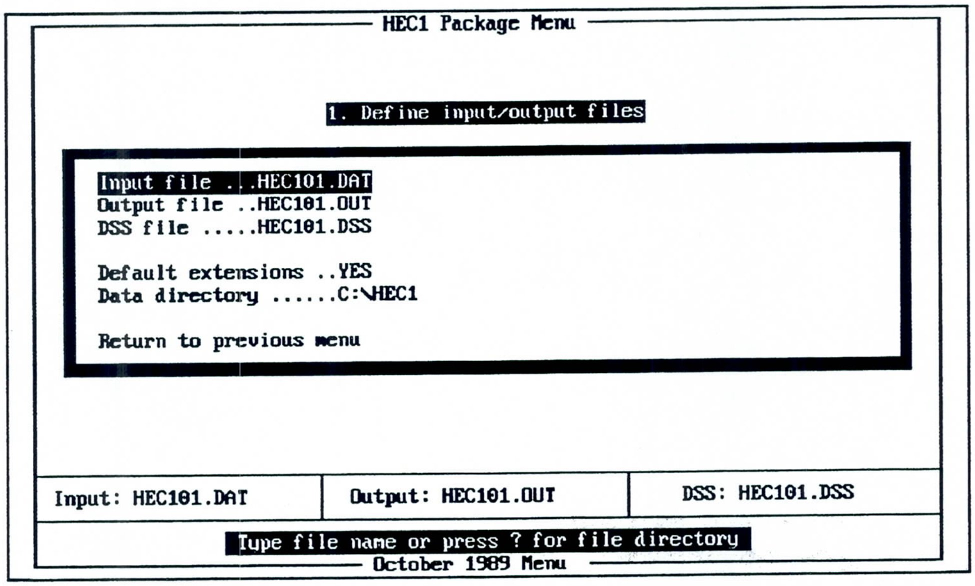

Figure 4. Define Input/Output/DSS Files Menu

2. **Create/Edit Input File:**

This option is used to create an input file, or to edit an existing input file, to be used by HEC-1. This option will only function if you have also installed the full screen editor COED on to your system ("COED," Corps of Engineers Editor, November 1987). If you have COED on your system, this option will allow you to go into the full screen editor with the previously defined input filename as the target file. When COED is executed through the menu system, the HEC1 help file is automatically loaded and the editor goes directly into full screen mode. While in COED you can create or edit an HEC1 input data file. When you are finished the program will return to the main HEC1 Package Menu. For help in using COED refer to the COED User's Manual. The next chapter describes "creating an input data file" in detail.

3. **Run HEC1 (or DSPLAY, HEC1IN, and DSSUTL):**

This option executes the HEC1, DSPLAY, HEC1IN, and DSSUTL programs. To switch between programs, just press the space bar while option 3 is highlighted. The input, output and DSS filenames, defined under option 1, will be passed to the appropriate programs. When the HEC-1 program is finished executing, you should get the message "NORMAL END OF HEC1" if your input data were entered correctly. If you do not get this message, more than likely there is an error in your input data file. Review the output file, using the next option, to learn more about any possible input data errors. If no errors occurred, and the "NORMAL END OF HEC-1" message was printed, just press any key to return to the main HEC1 Program Menu.

4. **Display Output to the Console (or printer):**

   This option is used to display output to the console or the printer. To switch from console to printer, just press the space bar while you are on option 4 (in other words, while option 4 is highlighted). If you choose to view output on the console, the utility LIST will be executed with the output filename being passed to it. If you choose to send output to the printer, the utility PROUT will be executed with the output filename being passed to it. Note: printer output is 132 characters wide. Therefore, set your printer font accordingly. Upon completion of either task, control will be given back to the HEC1 Package Menu.

5. **Exit to DOS:**

   If this option is chosen it is assumed that you are completely finished with the menu system and control is given back to DOS.

Chapter 4

Input Data Files

4.1 General

The HEC-1 program is a batch program. That means the necessary data for the program is provided as input at program execution and the program processes the entire job to completion. The program user does not interact with the program during execution. This section describes the sequence of an HEC-1 computation process, the input data format, and the basic steps for creating and storing an input data file.

4.2 Input Data Format

The structure of the HEC-1 input data file can be seen by reviewing any of the test data sets provided with the program. The detailed input description is provided in Section 10 of the HEC-1 User's Manual. See tables 10.4 through 10.11 of the HEC-1 User's Manual for summaries of data required for several different simulation options.

The format for the HEC-1 data is a "standard" HEC format. The concept is based on the eighty-column data card associated with batch input. The term card is used here even though the cards are more appropriately defined as records in a file. The first two columns are used for record identifier (ID); the program reads and sorts through the data based on the record ID. Each record is divided into ten (10) fields of eight columns each. However, a variable in field one may only occupy record columns 3 through 8 because the record ID is in columns 1 and 2. The HEC-1 User's Manual, and this text, refer to the individual records by their ID and the variable location of the record by the field number (1 through 10).

4.3 Creating an Input File

Data entry into fields requires careful counting of columns to ensure that the data are located in the correct fields. If a datum is entered across a boundary (column) between fields, the program will read part of the value as one variable and the remainder of the datum as the value for the variable in the next field.

There are several options available to assist the program user to enter data into fields without counting record columns to space data entries into the correct fields. The HEC-1 program will accept input data in "FREE" format and convert the data into fixed-format (see Section 4.3.3, "Other Methods"). The preferred data entry method is the Corps' interactive edit program, COED. It will automatically place input data into the standard (10 fields of eight columns) format. COED also provides on-screen help features that enhance the data entry function of the editor. The use of COED and other tools is described in the following sections.

4.3.1 Using COED

Creating or editing an input file from MENU1 calls COED. Calling COED from MENU1 also includes two parameters: **FS** and **HP HEC1**. If you run COED separately, these parameters can be entered while in COED. Entering **HP HEC1** will cause the HEC-1 input help file to be loaded, providing the tab settings for data entry and the input variables for HEC-1. Entering **FS** puts you into the Full Screen working environment. COED operates as a command editor (where you enter edit command codes and parameters) and also as a full screen editor (like a word processor). See the COED User's Manual for detailed documentation. Figure 5 shows an input data file in COED full screen edit mode, which is better for data entry.

```
TOF..
ID  TEST EXAMPLE NO. 13
ID USE OF DSS TO READ AND WRITE DATA
ID USE OF THE DSPLAY PROGRAM TO PLOT RESULTS
IT    15 14SEP88    1200     100
KK  SUB1
BA   5.7
BF   100    -.20   1.020
PB
ZR=PI A=EXAMPLE13 B=SUB1 C=PRECIP-INC E=1HOUR F=OBS
LU   0.3    0.15
UC   2.0     5.5
ZW  A=EXAMPLE13 C=FLOW F=COMP
KK   CMP
ZR=QO A=EXAMPLE13 B=SUB1 C=FLOW E=10MIN F=OBS
ZZ
EOT..




ID . . . . . . . . . . . . . Title information. . . . . . . . . . . . . . . . . . . . .
Help=F1                                                     Col=1    Line=1
```

Figure 5. HEC-1 Input Data File in COED Full Screen Mode

Once in COED, with HEC-1 help file and full screen edit mode, data entry will automatically use the first two columns for the record identifier, the next six columns for Field 1, and the remaining nine sets of eight columns as Fields 2 through 10. With the cursor at the first column, enter any appropriate HEC-1 record identifier (e.g., ID). The bottom of the screen will display a line of input information for the entered identifier (e.g., "Title Information" for ID). If the identifier is not appropriate for HEC-1, the bottom of the screen will display an error message. For example, if the invalid record identifier ZX is entered, you will get the message:

ZX >> >>> Record ID not valid for HEC-1 input <<< <<<

For title record information the entire line is available to enter text; there are no fields. For data records, most fields represent variables, and the variables are shown on the line at the bottom of the screen. For example, enter IT, and the variables for the IT record are shown on the bottom line. Use the **<TAB>** key (usually shown with two horizontal arrows) to move the cursor from field to field. The cursor automatically moves to the right of each field. Data entry will also fill the field from the right. Therefore, the data are always right justified.

Data entry only affects the field the cursor is on. Therefore, inserting or deleting data in a field only works in the one field. If you continue to enter data in a field, the previously entered data is displaced to the left until it is moved completely out of the field. Use the **<TAB>** key, or a cursor key, to move to another field. Use the **<SHIFT><TAB>** to move the cursor to the left.

Help information for COED is provided by pressing **<F1>**. The function keys are defined, and a list of additional help information is provided, as shown in Figure 6. The COED User's Manual is essentially provided through the help file.

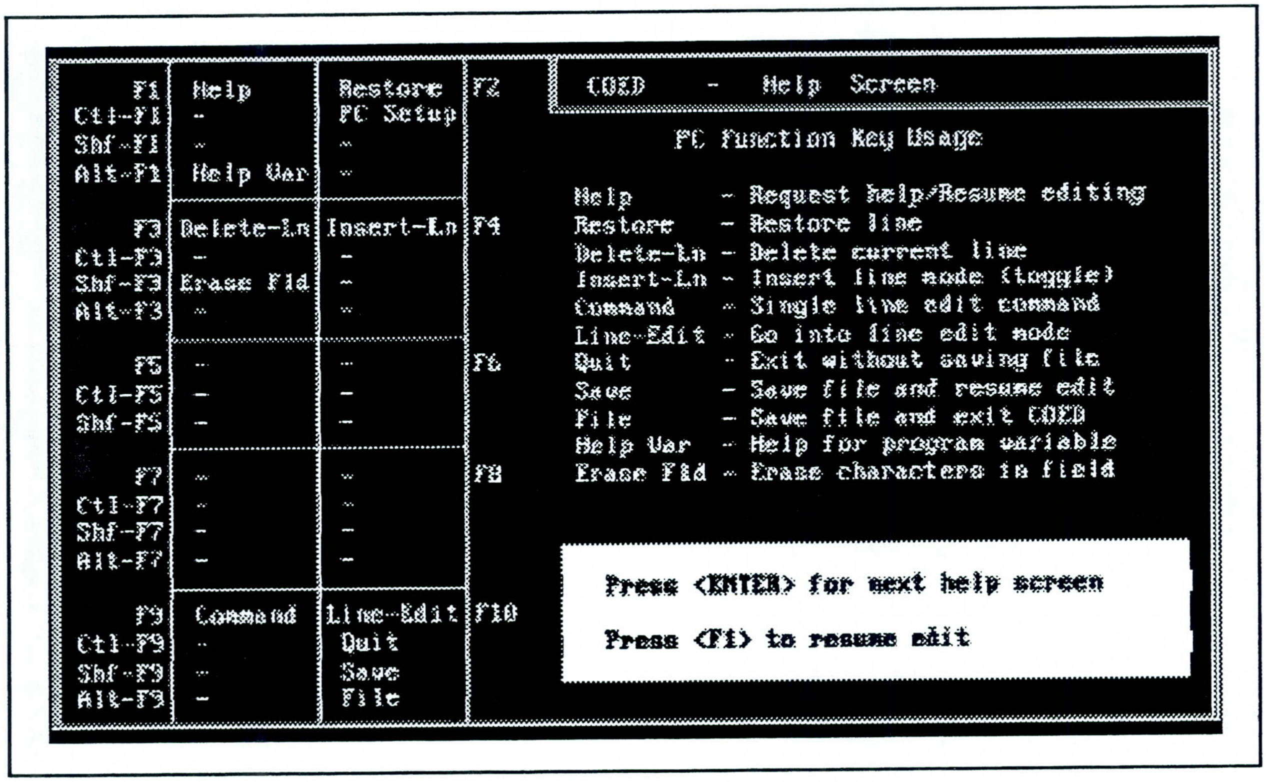

Figure 6. COED Help Screen

Help information for HEC-1 variables is provided by pressing **<ALT><F1>**. The HEC-1 ID in columns one and two provides the line of variables, for that record type, listed at the bottom of the screen. Moving the cursor to any field on the data input line and pressing **<ALT><F1>** provides the input description for that field's variable. Therefore, while you are entering data, you can obtain the input description for any input variable in the HEC-1 program.

With the HEC-1 help file loaded, COED can recognize legal input types. That is, the program will not accept a letter **<O>** for an entry that requires a number. This feature should reduce illegal input data errors.

4.3.2 Using the Interactive Input Program, HEC1IN

The HEC1IN program was designed to aid beginning and first-time users in developing the correct sequence of records for an HEC-1 input file. Currently the program is limited to the basic rainfall-runoff processes available in the HEC-1 program. The use of this program consists of filling out a series of tables that describe the watershed and the type of hydrologic techniques that will be used to analyze the basin. Once all of the necessary information is entered, a skeleton HEC-1 input file can be created. The skeleton file will contain all of the data records needed to simulate the rainfall-runoff process for the user's watershed, but not all of the actual data. The file will contain the two-character alphabetic codes in columns one and two for each line of input. It is the users responsibility to edit the file (using COED or any other text editor) and fill in the necessary data associated with each record. Review section 10 of Appendix A of the HEC-1 User's Manual for details about the input structure and specific data requirements for each records. Appendix A of this document is a detailed description of the Interactive Input Developer for HEC-1 (HEC1IN).

4.3.3 Other Methods

COED and HEC1IN have been developed to facilitate the creation of input data files. However, any other program that creates text files can be used. This may be convenient when some of the data needed is already in the file format of another program. Conversely, if the data is a block of time series data, it may be more practical to incorporate it into an input data file that is created using COED or HEC1IN. There are avenues for doing this without manually retyping the data into an HEC-1 input data file. The data can be moved as a block using COED or some other text editor. See the GET command in the COED manual. Bringing blocks of data in from an external source does carry with it the burden of converting it into HEC-1 input file format. One method is to use the *FREE command before the block of data and a *FIX command after the data. All records between these commands will be preprocessed into the standard 8-character field structure. This method depends on the data meeting the minimal requirements of the free-format. See the HEC-1 User's Manual for more information on the *FREE command. Another way to use time series data without retyping it into an HEC-1 input data file is to incorporate it into an input file for use with DSSTS. DSSTS creates a DSS file from the text data given in the input. This method accommodates up to 132 columns of data per line instead of the 80 columns allowed by the previous method. The following section gives references for DSSTS.

4.4 Using HEC Data Storage System (DSS) for Input Data

Several DSS utility programs are included in the HEC-1 package. Programs DSSTS and DSSPD can be used to input time series data and paired function data into a DSS file. Once data are stored in DSS, program DSSUTL can be used to perform various tabulation and data manipulations. Plots and tables can also be generated with a program called DSPLAY. Detailed information on any of the utility programs can be found in the HECDSS User's Guide and Utility Program Manuals. Use of macros with DSS utility programs is described in the PREAD user's manual. The input records used to interface between HEC-1 and DSS are described in Appendix B of the HEC1 user's manual.

Chapter 5

Program Execution

5.1 Executing HEC-1 Through the Menu System

After installation and prior to execution, your system must be rebooted. You are now ready to test the computer program. The preferred mode of execution is through the menu system, though you can run the program without going through the menu (see Section 5.2, "Executing **HEC-1** Without the Menu"). To execute the program through the menu system do the following:

1. Go to the directory containing your **HEC-1** data files (e.g., **CD\HEC-1,** see Figure 2).

2. Type **MENU1** and press the **<ENTER>** key. This will invoke the batch file used to run the menu system of programs. You must operate the menu system through this batch file or the HEC-1 Package of programs will not function correctly.

3. The **HEC-1** Package Menu should now appear on the screen, as shown in Figure 3. As you can see you have five choices.

4. If you have reviewed the section on the **HEC-1** Package Menu you will know that it is necessary to do option 1 first. While option 1 is highlighted press the **<ENTER>** key and then type in the input file name in the pop up window shown in Figure 4. For this example type **HEC101** for the input filename and the default extension ".DAT" will be provided for you. Also provided automatically will be the output file name **HEC1.OUT** and the DSS file name **HEC101.DSS.** This is accomplished by having the default extension option turned on. If you do not wish to use the default extensions, you may turn this option off by pressing the space bar while the default extension option is highlighted.

5. If your input file needs editing, you should select option 2. For now we will bypass this step since the defined input file, "HEC101.DAT," already exists and requires no further editing. If you wish to create or edit your own input file you should use option 2.

6. Now select option 3 which is to run HEC-1. Note that the input, output and DSS file names are passed to the HEC-1 program. When the HEC-1 program has finished executing, you should see the message, "NORMAL END OF HEC-1." To return control back to the main HEC-1 Package Menu, press any key.

7. At this point you may want to view the output on the screen, to do this select option 4. Viewing output on the screen is done by executing the LIST utility. LIST has several

nice features for viewing the output file. To become more familiar with the LIST features type a **"?"** or F1 while in the LIST utility, or review the LIST.DOC file. To get out of LIST type an X or ESC, which will terminate the program and give control back to the HEC-1 Package Menu. You may also want to send the output to the printer to get a hard copy. This can be accomplished by toggling the printer using the space bar while option 4 is highlighted, and then pressing the **<ENTER>** key. Note: output is 132 columns wide so you may need to set your printer font accordingly.

8. At this point you can exit the menu program by invoking option 5, or you can continue working with the previous four options.

5.2 Executing HEC-1 Without the Menu System

Though the preferred mode to execute HEC-1 is through the MENU1 program, you can run the program without using the menu. One such application would be for running several HEC-1 jobs in series without further user input. To run the program without using the menu system, do the following:

* Go to the directory in which your data are stored (e.g.,\HEC1).
* Type **HEC1 INPUT=inpname OUTPUT=outname DSS=dssname** then press the **<ENTER>** key.

Where: inpname = The name of the input file (e.g., HEC101.DAT).
outname = The name of the output file (e.g., HEC101.OUT).
dssname = The name of DSS file (e.g., HEC101.DSS).

Chapter 6

Reviewing Model Results

6.1 General

The major portion of the HEC-1 model results is in the form of an ASCII file, often referred to as the HEC-1 "Output File." This file includes an echo print of the users input data, intermediate simulation results, summary tables, and error messages. The degree of detail of virtually all of the program output can be controlled by the user.

Besides the normal HEC-1 output file, model results can be written to the HEC Data Storage System (HECDSS or just DSS). The DSS system stores data in a fashion convenient for inventory, retrieval, archiving, and model use. The DSS was primarily designed for water resources applications. Using DSS provides a means for storing and maintaining data in a centralized location, providing input to and storing output from applications programs, transferring data between application programs, and displaying the data in graphs and tables.

6.2 HEC-1 Formatted Output File

OUTPUT is the "print" file from HEC-1. Generally, this file would go directly to a disk file or to the printer. Because the printer is usually very slow, it is often easier to write the HEC-1 output to a disk file and review it with a program like LIST. There may be several computer runs required before the final results are obtained. By using the disk file approach, only the final results would be sent to the printer.

The OUTPUT file is easy to review from MENU1. Move the cursor to "**4. Display output to console**," and press **<ENTER>**. This will call LIST with the output filename. Portions of the output file can be printed from LIST; **P** turns the printer on or off. Press **<F1>**, while in LIST, to see available LIST commands.

The entire output file can be sent to the printer from MENU1. At "**4. Display output to console**" press the **<SPACE BAR>** to display "**Display output to printer**," and press **<Enter>**. This will send the output file to the printer with the utility program PROUT. PROUT will recognize the carriage control characters in the output file and thus provide spacing and paging as a high-speed printer would. PROUT output can be set to eighty or 132 columns. PROUT does not set the printer width; that must be done external to the program.

The DOS COPY command can be used to send the output file to the printer (e.g., COPY A:HEC101.OUT PRN). As with PROUT, this will tie up the computer while the file is printing. Alternatively, the DOS PRINT command can be used (e.g., PRINT A:HEC101.OUT). The system will request the name of the print device; simply press **<ENTER>** to send the output to the printer. This approach does not tie up the computer. However, neither of the above approaches will allow your printer to recognize the print control characters in column one of the output file. Therefore, the printed output will not start a new page or skip a line the way the file would be normally printed if directed to the printer at the time of execution.

To use PROUT as a separate program, at the DOS prompt enter:

PROUT "filename" "column width"

where: "filename" is the output file to print
"column width" is the column width for the printer

(e.g., PROUT A:HEC101.OUT 132)

6.3 Using DSPLAY to Generate Graphs and Tables

In the case that model results have been stored in a DSS file, the DSS utility program DSPLAY can be used to dsplay the data in tables and graphs. Appendix B provides an overview of DSPLAY for the PC. Detailed information about DSPLAY can be found in the HECDSS Users Guide and Utility Program Manuals.

DSPLAY uses proprietary "drivers." Drivers provide a means of plotting on several different types of devices (monitors, pen plotters, printers, etc.), without having information about each device in the program. More information about the drivers can be found in "Installation Instructions for Device Drivers."

6.4 Using HEC-1 and DSPLAY Output in Other Programs

HEC-1 and DSLPAY output can be incorporated into documents via word processors or used in spreadsheets and graphics packages. Procedures for importing text and graphics files into other programs will vary across programs. Refer to their respective manuals for more information. The following paragraphs highlight some concepts related to incorporation of HEC-1 and DSPLAY output into other programs.

The HEC-1 output file is an ascii text file that can be used in other programs that allow importation of text. In the case of word processors, there are a few generic tips that will facilitate the process. When selecting the method of bringing text into your word processor, choose to have carriage return/ line feed combinations converted to "hard" returns to avoid unintentional concatenation of lines. Similarly, select a font that is monospaced (i.e., not proportional spaced) so that the HEC-1 output will not be distorted. If the entire width of an HEC-1 output file is to be used in the context of an 8 1/2 by 11 inch page, a small font, such as 16.6 characters per inch, and reduced margins will be needed because the HEC-1 output is 132 columns wide. Once the HEC-1 output file is in your word processor, it can be printed or altered.

Any graph or table that can be generated and shown on the screen by DSPLAY can also be generated and sent to a CGM graphics file instead. This enables the use of DSPLAY output in other graphics programs or word processors that use the CGM file format. To generate a CGM file in DSPLAY, the DEVICE command is used with the META parameter before the desired PLOT or TABULATE commands are issued. Refer to the HECDSS Users Guide and Utility Program Manuals for more information on the DEVICE command.

Appendix A

Interactive Input Developer for HEC-1 (HEC1IN)

Introduction

Overview of the HEC1IN Program

This program was designed to aid beginning and first-time users in developing the correct sequence of records for an HEC-1 input file. Currently the program is limited to the basic rainfall-runoff processes available in the HEC-1 program. The use of this program consists of filling out a series of tables that describe the watershed and the type of hydrologic techniques that will be used to analyze the basin. Once all of the necessary information is entered, a skeleton HEC-1 input file can be created. The skeleton file will contain all of the data records needed to simulate the rainfall-runoff process for the user's watershed, but not all of the actual data. The file will contain the two-character alphabetic codes in columns one and two for each line of input. It is the users responsibility to edit the file (using COED or any other text editor) and fill in the necessary data associated with each record. Review section 10 and Appendix A of the HEC-1 User's Manual for details about the input structure and specific data requirements for each record.

Computer Requirements

The HEC1IN program was developed for IBM-compatible computers with the MS DOS operating system. The following is required in order to execute the program:

* **MS DOS 2.1 (or later)**
* **512 Kb of RAM (300 Kb free)**
* **One 360 Kb floppy-disk drive (or 1.2 Mb)**
* **10 Megabyte or larger hard-disk**

The HEC1IN program is included in the HEC-1 package of software. Installation is accomplished through the use of the HEC-1 install program. For further information on installing the HEC1IN program, review the HEC-1 package installation instructions.

Acknowledgements

This program was designed by Mr. Gary W. Brunner and Mr. Arlen D. Feldman of the Hydrologic Engineering Center. The computer program was written in FORTRAN and assembly language by Gary W. Brunner, Denise Nakaji, and Tracy Colwell.

Executing the HEC1IN Program

Running From The HEC-1 Menu System (MENU1)

Executing the HEC1IN program can be accomplished through the HEC-1 menu system (MENU1). As shown in Figure A.1, while option three of the menu is highlighted, press the space bar to change the program execution to HEC1IN. Then press the <ENTER> key to execute the HEC1IN program.

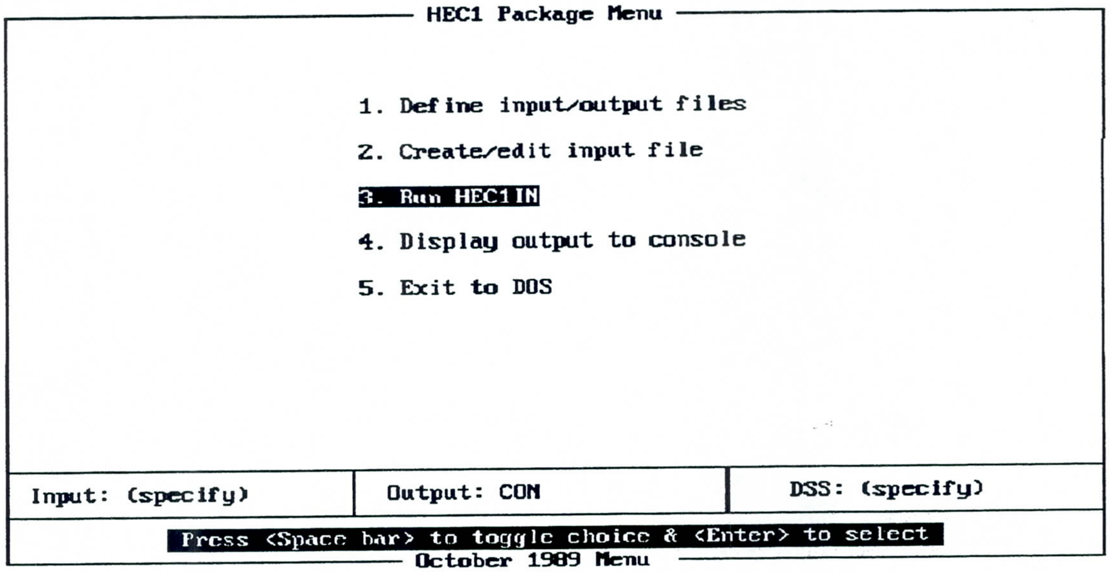

Figure A-1. HEC-1 Menu System

Files Associated With The HEC1IN Program

The HEC1IN program uses three files during execution:

1. HEC1IN.TXT - Text file containing HEC1IN screens.
2. filename - User-specified name for the HEC-1 input file.
3. filename.INT - File containing information entered into HEC1IN tables.

The HEC1IN.TXT file should be placed in the \HECEXE\SUP directory. This file contains all of the screens that come up in the HEC1IN program. The user-specified HEC-1 input file is identified while in the MENU1 program. The third file (filename.INT) is used to store all of the information that the user enters during the HEC1IN session. This file is given the same name as the user-specified HEC-1 input file, but the extension ".INT" is attached. The ".INT" file is preserved so the user can exit the HEC1IN session at any time and return to it as necessary.

WARNING: data should not be added to the HEC-1 input file until the user is completely finished building the skeleton file with HEC1IN. The HEC1IN program re-writes the skeleton HEC-1 input file and will not preserve data added by using COED.

Creating an Input Data File

General Philosophy of the Program

In general, this program operates by filling out a series of formatted screens and tables that describe the rainfall-runoff process that the user is trying to simulate. The river basin shown in Figure A.2 will be used in the following demonstration of HEC1IN.

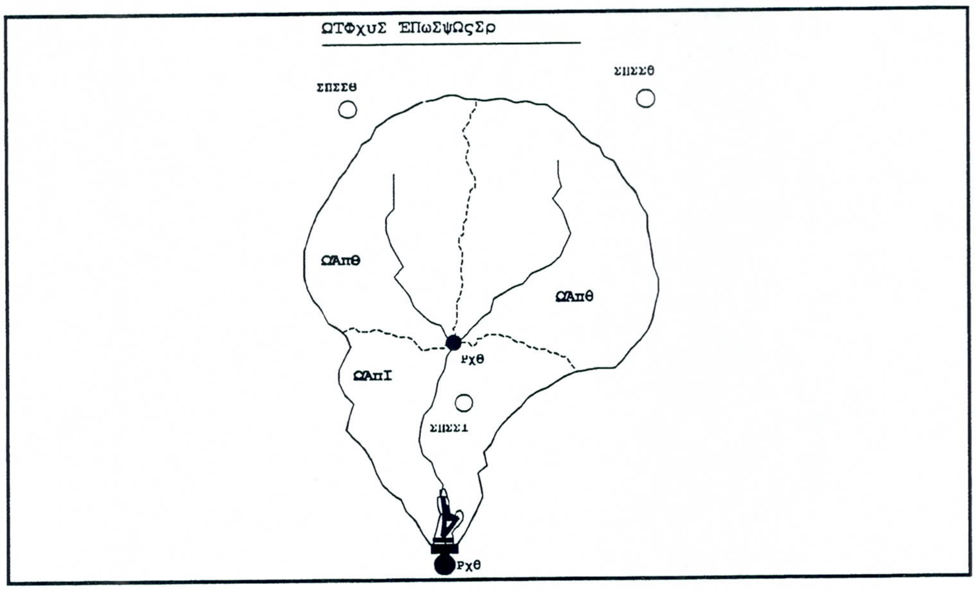

Figure A-2. Example Watershed

When HEC1IN is executed, the first screen to be filled out by the user is shown in Figure A.3. This Job Initialization screen is used to enter job title information and time specifications. In the job title information section, the user should enter comments that describes the rainfall-runoff process that is being simulated. Under the time specifications section, the user is required to enter a computation interval, simulation starting date and time, and the number of hydrograph ordinates to be computed. The computation interval is one of the most important parameters required by the model. The length of the computation interval is dependent on the size of the smallest subbasins and routing reaches within your watershed. A general rule of thumb is that the computation interval should be less than one fifth (1/5) of the smallest subbasin's time of concentration (Tc). The total simulation time for the job is the number of ordinates multiplied by the computation interval. Remember, the total simulation time should equal or exceed the duration of the precipitation event being analyzed.

JOB INITIALIZATION DATA   FILE: TEST.DAT

Please fill out this table completely, then press the <F8> key to get to the next screen.

Enter job title information (At least one line must be entered):

1. TEST OF THE HEC1IN PROGRAM
2. SIMPLE THREE SUBBASIN WATERSHED
3. GARY W. BRUNNER

Simulation time specifications

1. Enter computation time interval in minutes : 5
2. Enter the simulation starting date (e.g., 17MAR88): 17MAR88
3. Enter the simulation starting time (e.g., 1645) : 1200
4. Enter the number of ordinates to compute (300 Max): 300

F1 Help   F6 Creat   F7 Prev   F8 Next   F9 Save   F10 Exit

Figure A-3. Job Initialization Data

The next screen that the user must fill out is shown in Figure A.4. The subbasin connectivity table is used to enter a name for each of the subbasins in the watershed and to describe how these subbasins fit together. The term "Headwater Subbasin" is used for those subbasins where a stream initiates. Every subbasin that is entered in the table must be assigned a downstream control point name. For those subbasins that are not headwater subbasins, an upstream control point name must also be provided. This control point name must be the same as the downstream control point name of the subbasin immediately upstream.

SUBBASIN CONNECTIVITY TABLE   FILE: TEST.DAT

Enter a name for each subbasin in your watershed.
(maximum of six (6) letters/numbers)

Subbasin Identifier	Headwater Subbasin (Y/N)	Upstream Control Point Name	Downstream Control Point Name	Reservoir (Y/N)	Reservoir Identifier
SUB1	Y	N/A	CP1	N	N/A
SUB2	Y	N/A	CP1	N	N/A
SUB3	N	CP1	CP2	Y	RES1

F1 Help   F3 Del   F6 Creat   F7 Prev   F8 Next   F9 Save   F10 Exit

Figure A-4. Subbasin Connectivity Table

After the user has completely filled out the subbasin connectivity table for all of the subbasins within the watershed, simply press the F8 function key to go to the next screen. The third screen, which is titled "Subbasin Runoff Table," is shown in Figure A.5. The subbasin runoff table is used to identify the methodologies that will be used in developing a runoff hydrograph for each subbasin. The information required consists of: basin area; the type of precipitation data that will be used; a loss rate function; rainfall excess to runoff transformation (unit hydrograph or kinematic wave); and whether or not baseflow will be added to the direct runoff. The available choices for each column are shown in a menu at the top of the screen. The <TAB> key is used to move through the menu choices and the <ENTER> key is used to make a selection from the menu. Selecting a specific hydrologic method will depend upon the amount of historical data available; the experience of the user; and the characteristics of the watershed to which the method will be applied. Detailed explanations of the techniques listed in the menus are found in chapter three of the HEC-1 User's Manual.

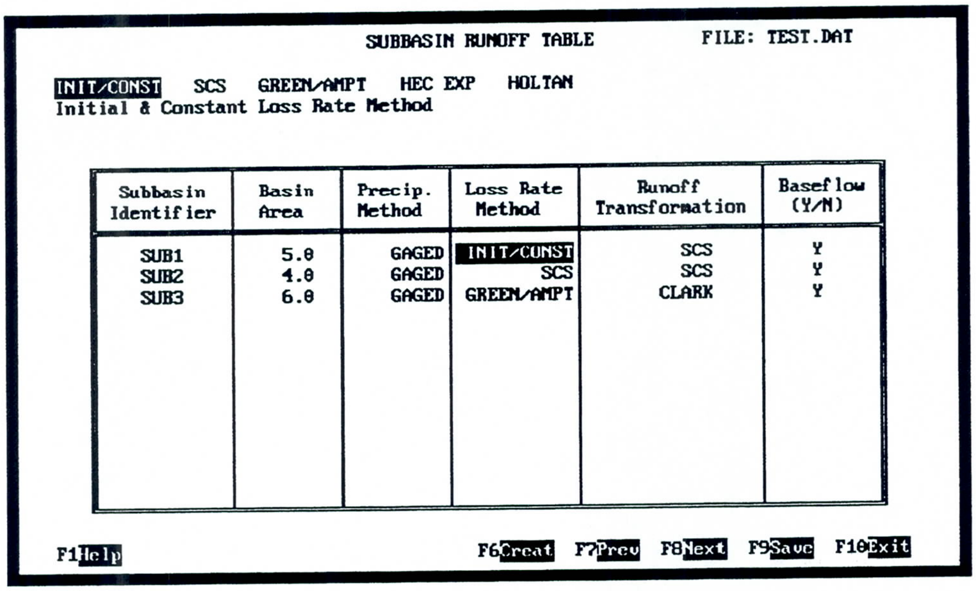

Figure A-5. Subbasin Runoff Table

The next screen will depend upon what was entered into the subbasin runoff table for precipitation. If the user had entered "Gaged" or "Basin Average" precipitation, then a precipitation table will come up to get more information. Otherwise, the program will go straight to the channel routing table. Shown in Figure A.6 is the gaged precipitation table.

The gaged precipitation table is used to identify all of the gages (recording and non-recording) that will be used in developing rainfall hyetographs for the watershed. The user is required to enter a name for each gage; whether the gage is recording or non-recording; and if the data will be entered incrementally or cumulatively. If the "Basin Average" precipitation method had been chosen by the user, the program will only ask if the data is going to be entered incrementally or cumulatively. When using the basin average precipitation method, the user must compute the basin average precipitation for each subbasin outside of the model and enter it directly. Computing the basin average precipitation can be accomplished by using Thiesson polygon or isohyetal averaging techniques.

If hydrograph routing is required, the next screen will be the channel routing table. The channel routing table, shown in Figure A.7, is used to define which routing techniques will be used to route hydrographs from upstream to downstream control points. The Hec1IN program will automatically

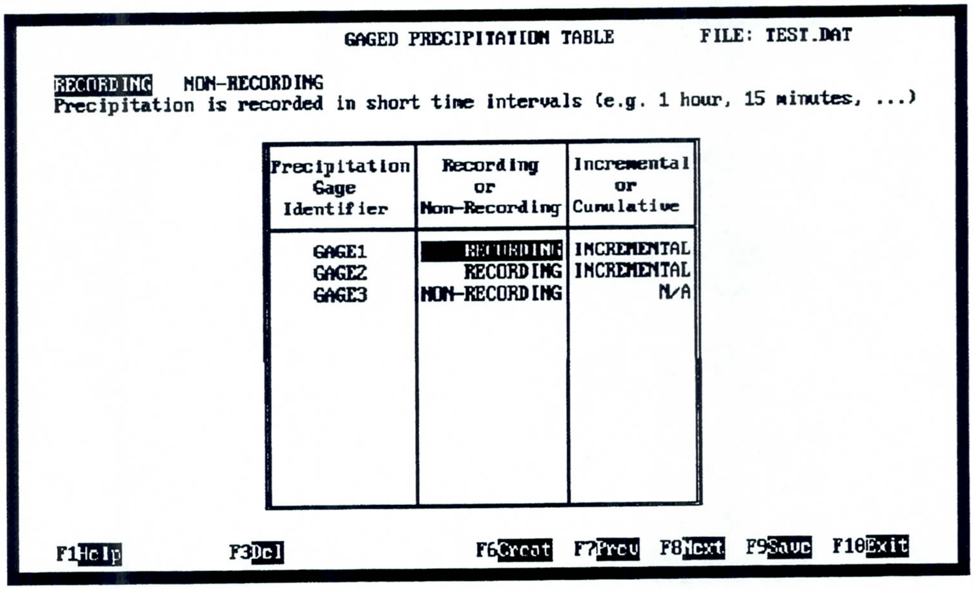

Figure A-6. Gaged Precipitation Table

determine the number of routing reaches are required. The upstream and downstream control points for each routing reach will be displayed in the table. The user is required to enter a name that will uniquely identify each routing reach, and then select the type of routing technique that will be used for that particular reach. The selection of a routing methodology is dependent upon the available data, the physical characteristics of the channel, and the nature of the flood wave to be routed. To learn more about a specific routing technique, please review chapter 3 of the HEC-1 user's manual.

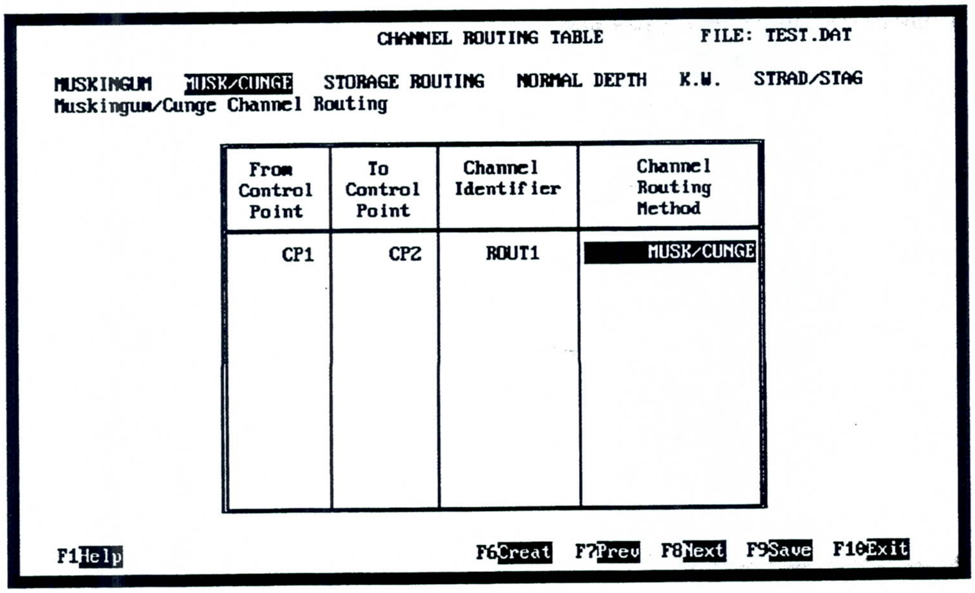

Figure A-7. Channel Routing Table

The last screen that may appear is used for reservoir routing. The reservoir routing table, shown in Figure A.8, will only come up if the user has specified that a reservoir is located in at least one of the subbasins. The reservoir routing table is used to identify how the elevation versus volume and elevation versus outflow relationships will be defined in the model. The user can define the storage behind the dam by entering elevation versus volume directly, or elevation versus surface area, and the HEC-1 program will calculate the volumes. To describe the outflow from the dam, the user can enter a single rating curve (which is a composite of all outflow mechanisms) or explicitly describe the physical dimensions of each outflow mechanism. The model also has the capability to simulate a dam breach, or flow going over top of the dam.

RESERVOIR ROUTING TABLE   FILE: TEST.DAT

Do you want Elevation vs Volume (V) or Elevation vs Area (A) to describe the storage behind the dam?

Reservoir Identifier	Elevation vs Volume/Area (V/A)	User Defined Elev vs Outflow (Y/N)	Low Level Outlets (Y/N)	Spillway (Y/N)	Dam Breach (Y/N)	Dam Overtopping (Y/N)
RES1	V	N	Y	Y	N	Y

F1 Help   F6 Creat   F7 Prev   F8 Next   F9 Save   F10 Exit

Figure A.8 Reservoir Routing Table

After all of the tables have been filled out completely, the HEC-1 input file can be created by simply pressing the F6 function key. The HEC-1 input file generated for this example is shown in Table A.1. **Remember**, the HEC-1 input file will only contain the two character identification codes for each record required for the rainfall-runoff simulation. It is the user's responsibility to edit the file and fill in all of the necessary data for each record.

WARNING: data should not be added to the HEC-1 input file until the user is completely finished building the skeleton file with HEC1IN. The HEC1IN program re-writes the skeleton HEC-1 input file and will not preserve data added by using COED.

Help System

Help within the HEC1IN program is available by pressing the F1 function key. The first two screens of the help system deal with editing and function keys, while the third screen is specific to the HEC1IN tables. The first screen of the help system lists all of the available function keys and their corresponding capabilities. The second help screen describes how the key pad, <TAB> key, and <ENTER> key can be used to enter and edit information. The third help screen is always specific to the table the user was working in when the F1 key was pressed. Therefore, if the user is working on the subbasin connectivity table when the F1 key is pressed, the third help screen will describe what information is required for that specific table. Moving through the help screens is accomplished by pressing any key. After the third screen is viewed, pressing any key will return the user back to the table being used when help was requested.

Table A-1

HEC-1 Input File for Example Watershed

```
ID TEST OF THE HEC1IN PROGRAM
ID SIMPLE THREE SUBBASIN WATERSHED
ID GARY W. BRUNNER
IT      5 17MAR88    1200      300
IO
PG GAGE1
PI
PG GAGE2
PI
PG GAGE3
* **********
KK  SUB1
KM Basin runoff calculation for   SUB1
BA   5.0
BF
PT
PW
PR
PW
LU
UD
* **********
KK  SUB2
KM Basin runoff calculation for   SUB2
BA   4.0
BF
PT
PW
PR
PW
LS
UD
* **********
KK  SUB2
```

```
KM Combining two hydrographs at control point       CP1
HC     2
* **********
KK ROUT1
KM Muskingum-Cunge channel routing from      CP1 to CP2
```

```
RD
* **********
KK   SUB3
KM Basin runoff calculation for   SUB3
BA    6.0
BF
PT
PW
PR
PW
LG
UC
* **********
KK   SUB3
KM Combining two hydrographs at control point      CP2
HC      2
* **********
KK   RES1
KM Reservoir routing operation
RS
SV
SE
SL
SS
ST
* **********
ZZ
```

Appendix B

Overview of DSPLAY for the PC

DSPLAY is a HECDSS utility program that allows the user to plot or tabulate data stored in an HECDSS (HEC Data Storage System) file. The PC version of DSPLAY can generate plots on several different devices (such as monitors, printers, and plotters) and also generate metafiles.

Executing DSPLAY

DSPLAY can be executed through the menu programs (e.g. MENU1, MENU5, etc.) or a special batch file labeled DSP.BAT. Before running DSPLAY, the GSS device drivers must be loaded into memory. Loading the device drivers is accomplished by executing the DRIVERS.EXE program. The menu programs, as well as the DSP batch file, automatically load the device drivers, execute the DSPLAY program, and unload the device drivers when the user is finished working in DSPLAY. DSPLAY and the device drivers require about 550 Kb of free base memory. If the DSPLAY program aborts with the message "Program to big to fit in memory," remove any RAM resident programs that you may have loaded in the AUTOEXEC.BAT file. Reboot your computer and try running DSPLAY again.

User Input Commands

DSPLAY is a "command" driven program, rather than being menu driven. Input consists of a command, option(s), and parameter(s) in the following format:

Command.Option(s), Parameter(s)

A list of the most frequently used DSPLAY commands is shown in Table 1. In general, the user enters a sequence of commands to generate a plot. The following is an example sequence of commands to plot data stored in a DSS file. These commands would be entered after selecting DSPLAY on a menu or running DSP.BAT.

Command	Description
CA.NA	Develop a new catalog of all the data stored in the currently opened DSS file and display it in an abbreviated format on the screen.
TI 17JAN90 1200 18JAN90 1800	Establish a time window for retrieving and plotting data.
PL 1,3	Plot on the screen (default device) data referenced by pathnames 1 and 3 in the DSS file catalog listing.

DEV PRINTER	Change device option to the printer.
PL	Send the previously defined plot (PL 1,3) to the printer.
DEV SCREEN	Reset current device to the screen.
FI	End DSPLAY session and return to main menu or DOS.

For more information on DSPLAY's capabilities and commands, refer to "HECDSS Users Guide and Utility Program Manuals," or type "HELP" while in DSPLAY. The online help system in DSPLAY has the most current information on commands.

Table B-1
Frequently Used DSPLAY Commands

Command	Purpose	Examples
CATALOG	Catalog of all pathnames in the opened DSS file.	CA (List files in catalog) CA.N (New Catalog) CA.A (Abbreviated List)
PLOT	Used to plot data in the DSS file opened.	PL 1,3 (Plot Paths 1 and 3) PL A=SCIOTO,C=FLOW (plot data with pathnames that have A=SCIOTO and C=FLOW) PL (Plot last specified plot)
OPEN	Open a new DSS file.	OP filename
FINISH	Terminate the DSPLAY session.	FI
DEVICE	Used to specify which device the plot will be sent to.	DEV SCREEN (This is the default) DEV PRINTER (PLOTTER, MOUSE, or META)
HELP	List or define available DSPLAY commands.	HE (List all available commands) HE PL (Define PLOT command)
TABULATE	Display the data in tabular form.	TA 2 (Tabulate data in path 2) TA A=SCIOTO C=FLOW
TIME	Used to specify a time window for retrieving and plotting data.	TI 01DEC88 0900 02DEC88 1200 (set time for retrieving window from beginning date and time to ending date and time)
STATUS	List the current DSPLAY settings.	ST (List all status settings)

Advanced DSPLAY Operations: Environment Settings

The default attributes of most device drivers can be changed using the DOS SET command before running DSPLAY. The following is a description of the most commonly used **SET** commands dealing with the GSS software.

A. **Printers**

Printers have a wide selection of **SET** commands, though not all printers recognize each SET command.

ORIENTATION=[PORTRAIT, LANDSCAPE] rotates the printer output.
PORTRAIT no rotation (default)
LANDSCAPE rotates the plot by ninety degrees

C:\> **SET ORIENTATION=LANDSCAPE**

PAPER=[NARROW, WIDE, ISOA4] the paper size can be changed, which will scale the plot to fill the page. Not all page sizes are supported by every printer.

NARROW 8.5x11 (default)

WIDE 11x14

ISOA4 210x297mm

C:\> **SET PAPER=WIDE**

TEMPDIR=<directory> specifies the directory where the printer driver writes a temporary file. Unless a directory is specified, the file is written to the current directory. If DSPLAY isn't aborted the temporary file is automatically deleted when the printer is finished. Example:

C:\> **SET TEMPDIR=C:\GSS**

PLISTSIZE=<buffer size> allocates space for a printer I/O buffer. Increasing its size will reduce the amount of disk access. The default buffer size is 512 bytes, and the maximum buffer size allowed is 64K. Example:

C:\> **SET PLISTSIZE=2048**

RESOLUTION=<resolution> several printers will support multiple resolutions. The coarser the resolution, the faster the plot will be completed.

Printer	**Resolution (bpi)**			
Canon Laser Beam Printer 8II	300	150		
Epson LQ	180	120		
HP DeskJet	300	150	75	
HP LaserJet	300	150	100	75
HP ThinkJet	192	96		
IBM Proprinter II/XL	120	60		
IBM Proprinter X24 and XL24	180	120		
NEC Pinwriter P5	180	120		
Okidata 290-Series Printers	120	60		
IBM Quietwriter II	120	60		
Toshiba P321SL/P351	360	180		
Xerox 4045 Laser Printer	300	150		

C:\> **SET RESOLUTION=192**

B. **Versatec Printers**

The Versatec printer driver recognizes ORIENTATION, TEMPDIR and PLISTSIZE set commands.

PAPER=[A,B,C,D,E,F] set the page size according to the ANSI standard:

C:\> **SET PAPER=B**

VERSA=<printer code> tells the printer driver which Versatec Printer it is controlling.

Printer	Printer Code
V-80	V80 (default)
C25xx	25xx
CE 32xx	32xx
CE 34xx	34xx
72xx	72xx
74xx	74xx
ECP 42	9242
Versacolor	VERSACO

C:\> **SET VERSA=7236**

C. **Plotters**

ORIENTATION=[LANDSCAPE, PORTRAIT] works the same for either printers or plotters.

FLAGGING=[HARDWARE, XONOFF] will change the handshaking protocol for HP and HP Graphics Language Plotters.

C:\> **SET FLAGGING=XONOFF**

The plotter redirect and type set commands, while having the same form, don't have a specific set command.

Plotter Driver	<device driver>	<device type>
HP Pen Plotter	HPPLOT	
HP Graphics Language	HPGLPLTR	HP_TYPE
Houston Instruments	HIPLOTTR	HI_TYPE
Roland DG Plotters	ROLAND	RD_TYPE

<DEVICE DRIVER>=[COM1, COM2, COM3, COM4] will redirect the plotter to a different serial port. The Roland DG Plotter driver only supports COM1. If the plotter is redirected, remember to set the Baud rate for that serial port as well.

C:\> **SET HPPLOT=COM3**

<DEVICE DRIVER>=<output file> will redirect the plotter instructions to a file. This set command is only supported by the HP Graphics Language and Houston Instrument drivers.

C:\> **SET HIPLOTTR=PLOTTER.GLP**

<DEVICE TYPE>=<plotter code>,<page size>,<number of pens> tells the plotter driver what model plotter it is controlling.

Plotter	Plotter Code	Defaults (Page size & Number of Pens)
Roland DG		
880 and 980	980	A 8
885 and 990	990	B 8
2000	2000	C 8
3300	3300	D 8
Hewlett Packard		
6180, 7370 or 7440	7440	A 8
7371 and 7470	7470	A 2
7372 and 7475	7475	B 6
6182 and 7550	7550	A 8
6184, 6186, 7374, 7375, 7570, 7580, 7585, 7586, 7595 and 7596	7580	D 8
Houston Instruments DMP		
29	29	B 8
40	40	B 1
41	41	C 1
42	42	A 1
51	51	C 1
52	52	A 1
56	56	B 1
61	61	B 1
62	62	B 1

The Page Size is the ANSI page size [A - F]. The Houston Instruments driver will also support the ISO European page sizes [A0 - A4].

C:\> **SET HI_TYPE=29**
C:\> **SET HP_TYPE=7475,A,4**
C:\> **SET RD_TYPE=980,,6**

Hydrologic Engineering Center
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Addendum to HEC-HMS, Version 1.0, User's Manual and Software

Introduction

At the time of the Version 1.0 release, March 1998, some aspects of the software development and documentation were still underway. This addendum summarizes some current limitations of the software execution and provides information on technical methods not included in the previous HEC-1 documentation. The HEC-HMS technical reference manual is being prepared and will be released later this year. For the time being, please refer to the HEC-1 User's manual for technical reference. Up-to-date information on HEC-HMS execution, features, and limitations can be found on the HEC web site: www.hec.usace.army.mil

A. **Installation notes on HEC-HMS** are covered in User's Manual Chapter 2.

B. Notes on HEC-HMS Execution

1. **Printing Graphs.** We have encountered problems with printing graphs on computers running Windows 95; it works fine on computers running Windows NT. For users of HEC-DSS (HEC, 1995), graphs can be printed using DSPLAY.

2. **Printing/Capturing Screens.** The currently active screen can be copied to the Windows clipboard by pressing ALT + Print Screen. That screen can then be "pasted" into a document.

3. **Printing Tables to a File.** This capability is currently not operational in the Windows 95 or the NT systems. Tables can be sent directly to a printer, or they can be copied to the clip board as noted above for screens.

4. **Installation.** Due to constraints in the installation software used with HEC-HMS, installation can only be done automatically onto C drives. If another drive is selected, the program will be installed correctly, but the example data files, located in the HMSPROJ directory, will still be installed onto the C drive. The HMSPROJ folder will have to be manually moved from the C drive to the desired drive. The next release will be able to be installed onto any drive.

5. **Printing.** When printing tables or graphs from within HMS, output must be directed to a postscript printer.

6. **Video Display.** The video display resolution setting required by HEC-HMS is monitor dependent. 1024 by 768 works for most monitors, however experiment with different settings if you are not happy with the appearance.

7. Importing HEC-1 data files. Our beta testing revealed some deficiencies in the ability of HMS to import HEC-1 data files. In particular, the importation of rainfall data does not always work. We were not able to correct all of these deficiencies in time for Version 1.0, but will continue to work on this for future versions.

8. Managing Project folders. Renaming, copying, and deleting projects should be performed from within HMS. Performing such tasks outside of HMS can result in incompatibilities with the HMS file management structure. For the case when a project folder is being moved to a new computer, ensure that the newly copied project does not have a name that already exists in the HMS project list.

Another issue related to moving projects has to do with the use of DSS for observed data. If it is envisioned that a project will be moved around from machine to machine, it is best to keep the DSS observed data files in the project folder so that they go with the project. Alternatively, manual accounting of the DSS file locations on each machine will need to be performed.

C. Notes on HEC-HMS Computational Methods

These notes describe selected computational features of HEC-HMS not included in HEC-1 (HEC, 1990), and indicate variations from methods in HEC-1. For the time being, refer to the HEC-1 User's Manual and these notes for descriptions of technical capabilities. These notes will be superseded by a *Technical Reference Manual* that will contain detailed descriptions of all computational methods.

1. **Import of HEC-1 Data.** Data for use in HEC-HMS can be imported from an HEC-1 input file, as described in Chapter 3 of the *HEC-HMS User's Manual*. For example, consider the following HEC-1 file:

```
ID     EXAMPLE
ID
IT     15 27AUG67      1145       61
PG      A     2.39
PG      B
PI      0        0        0        0        0        0        0        0        0        0
PI      0        0        0      .10      .45     1.45      .73      .02      .80      .50
PI    .25      .05        0        0        0        0        0        0        0        0
KK SUB-1
PT      A        B
PW     .6       .4
PR      B
PW      1
BA   37.9
BF    57.     -.25   1.0025
UC      3        4
LU     .2       .4
ZZ
```

Importation of this file would cause the creation of a Basin Model that contains appropriate parameter data for the subbasin; a Precipitation Model with data for two gages and weighting factors associated with the subbasin; and Control Specifications with the start and end times for the simulation, and the computation interval.

2. **Gridded Rainfall Data**. HEC-HMS has capability to utilize gridded rainfall data via the ModClark method. The gridded rainfall data must exist as DSS records. The utility program gridUtil (HEC, 1995) can be used to create such records from radar-rainfall data.

3. **Baseflow**. Baseflow can be represented in HEC-HMS, as in HEC-1, with three parameters: starting baseflow, threshold discharge, and a rate-of-recession index. The rate-of-recession index (recession constant) in HEC-HMS is defined as the ratio of the current recession flow to the recession flow *1 day earlier*. The recession ratio RTIOR in HEC-1 is defined as the ratio of the current recession flow to the recession flow *1 hour later*. The following equation can be used to calculate a value for the HEC-HMS recession constant from a value for RTIOR:

$$Recession\ \ Constant = \frac{1}{(RTIOR)^{24}}$$

Section 9.2.3 of the *Handbook of Hydrology* (Maidment, 1993) shows the following to be typical values for the recession constant for basins ranging in size from 120 to 6500 mi^2:

Flow Component	Recession Constant
Groundwater	0.95
Interflow	0.8 - 0.9
Surface runoff	0.3 - 0.8

An alternative method in HEC-HMS permits specification of mean monthly baseflow (i.e., 12 values). This method is intended for use with continuous simulation.

4. **Deficit/Constant Loss Method**. A simple deficit/constant loss function can be used for continuous simulation. The function is the same as that used in the Interior Flood Hydrology program (HEC, 1992). The user specifies a soil moisture storage capacity which must be filled before rainfall excess can occur. The capacity is filled by rainfall, and depleted during rain-free periods at a rate based on user-specified mean-monthly values. When the capacity is filled, loss occurs at a user-specified constant rate. The method is essentially a continuous version of the Initial/Constant method whereby the initial loss "recovers" during rain-free periods.

5. **Unit Hydrograph.** The Clark method produces a unit hydrograph that theoretically has an infinite number of ordinates, because each ordinate on the tail of the unit hydrograph is obtained by multiplying the preceding ordinate by a constant fraction (less than one). In both HEC-HMS and HEC-1, the tail of the unit hydrograph is truncated when the volume represented by the unit hydrograph exceeds .995 in. In HEC-HMS, the ordinates are then adjusted to produce a volume

of 1 in., whereas in HEC-1 this adjustment is not made. Thus, slightly different results are produced by the two programs.

A user-defined time-area relationship cannot be specified in the beta version of HEC-HMS. The synthetic time-area relationship from HEC-1 is used.

6. **ModClark Method.** The ModClark method (Peters and Easton, 1996, and Kull and Feldman, 1998) provides a means to simulate runoff using gridded rainfall data. Rainfall and losses are tracked uniquely for each grid cell in a subbasin. Rainfall excess from each cell is lagged to the basin outlet and routed through a linear reservoir. The outflows from the linear reservoir are summed and baseflow is added to obtain a total-runoff hydrograph. A cell-parameter file must exist which contains, for each grid-cell in a subbasin, the cell's coordinates, area (within the subbasin) and travel-time index. Automated procedures are available for generating cell-parameter data from digital elevation models using ARC/INFO (HEC, 1996).

7. **Muskingum-Cunge Routing**

a. **Hydraulic properties for prismatic channels**

HEC-1 and HEC-HMS use different formulas for computing hydraulic properties. HEC-1 uses formulas based on the kinematic wave assumption. HEC-HMS uses the physical properties of the channel to compute hydraulic properties.

In HEC-1

Channel cross-sectional area, A, is computed from

$$A = \left(\frac{Q}{\alpha}\right)^{\frac{1}{m}}$$

Wave speed, c, is computed from

$$c = \alpha m A^{m-1}$$

where α and m are kinematic parameters based on channel shape.

In HEC-HMS

Area is computed using the formula for the area of a trapezoid

$$A = y(w+zy)$$

The ratio of wave speed, c, to flow velocity, v, is

$$\frac{c}{v} = \frac{10wzy + 16zy^2\sqrt{z^2+1} + 5w^2 + 6wy\sqrt{z^2+1}}{3(w+2zy)(w+2y\sqrt{z^2+1})}$$

for a trapezoidal channel with bottom width, w, side slope, z, and depth y. Velocity is computed using Manning's formula.

b. Hydraulic properties for 8-point cross-sections

In HEC-1
Discharge, area, top width, and wave speed are computed for 20 depths. During the routing, area, top width, and wave speed are interpolated from these tables for each discharge value.

In HMS
The depth for a given discharge is determined from the cross-section characteristics, then, area, top width, and wave speed are computed for that depth using the cross-section data.

c. Selecting Δt and Δx for routing

In HEC-1, Δt is set to be the lesser of the inflow hydrograph time interval, the travel time through the reach, and 1/20 of the time to peak inflow.

HEC-HMS does not use the time to peak inflow to determine Δt.

In both programs, Δt is adjusted so it divides the total simulation time into an integral number of intervals.

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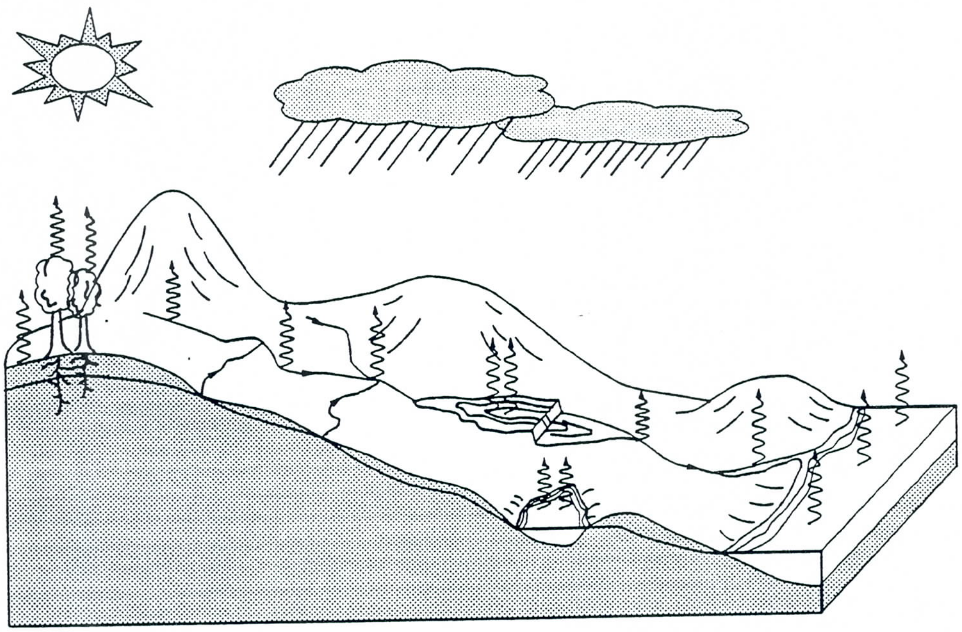
US Army Corps
of Engineers
Hydrologic Engineering Center

HEC-HMS
Hydrologic Modeling System



User's Manual

Version 1.0
March 1998

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HEC-HMS
Hydrologic Modeling System

User's Manual

Version 1.0
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Preface

The U.S. Army Corps of Engineers' Hydrologic Modeling System (HEC-HMS) is 'new-generation' software for precipitation-runoff simulation that will supersede the HEC-1 Flood Hydrograph Package. HEC-HMS is a significant advancement over HEC-1 in terms of both computer science and hydrologic engineering. It is a product of the Corps' Civil Works Hydrologic Engineering R&D Program.

HEC-HMS currently contains most of the watershed-runoff and routing capabilities of HEC-1. Snow accumulation and melt, flow-frequency curve analysis, and hydraulic features of dams capabilities are underway but not yet incorporated. The flood damage capabilities of HEC-1 will not be included; they are performed separately in the new Flood Damage Analysis, HEC-FDA, software.

Several important new capabilities are available in HEC-HMS: mainly, continuous hydrograph simulation over long periods of time, and spatially distributed runoff computation using a grid-cell depiction of the watershed. This initial continuous hydrograph simulation capability (termed 'deficit/constant') is a simple single-reservoir soil-moisture representation; more comprehensive soil moisture accounting is currently under development. This is the first version of HEC-HMS and we expect several new capabilities to evolve over the next few years.

HEC-HMS is comprised of a graphical user interface, integrated hydrologic analysis components, data storage and management capabilities, and graphics and reporting facilities. Development of HEC-HMS took place utilizing a mixture of programming languages (C, C++, and Fortran). The software is built for multi-platform usage, primarily PC's and workstations. The computational 'engine' and graphical user interface, GUI, are written in object-oriented C++. Hydrologic process algorithms (e.g., infiltration methods) are written in Fortran and have been incorporated into a library labeled *libHydro*. Although linked into a single executable, there are clear separations between the GUI, libraries, databases, and the main simulation engine. This design facilitates use of other components at later dates without having to revise the computational software.

In the spirit and requirements for the U.S.A. to use System International measurement units, all computations are performed in metric units. Input data and output results may be English or metric and are automatically converted if necessary.

HEC-HMS was developed by a team of HEC staff and consultants. The primary team was led by John Peters who designed the user interface and overall package, and wrote this User's Manual. Arthur Pabst, HEC, and Anthony Slocum, consultant, provided much essential input to the object-oriented design of the software. Slocum also wrote the code for the schematic representation of the basin model. William Charley developed most of the simulation engine and Paul Ely, consultant, developed the hydrologic algorithm library, *libHydro*, and later continued the simulation engine development. David Ford, consultant, provided recommendations for the scope and content of capabilities for the parameter optimization. The graphic user interface was developed by Elisabeth Pray; she also provided the computer science expertise that integrates all the components and builds the complete software package.

The final stages of the model development and testing team were led by Arlen Feldman with technical input from John Peters. Troy Nicolini led the beta testing team and assembled this first version of the software and documentation.

Several students from the nearby University of California at Davis, working as temporary employees at HEC, provided excellent assistance to the software development, testing, and documentation: Ken Sheppard, Jake Gusman, Dan Easton, William Scharffenberg III, Todd Bennett, and Cameron Ackerman.

HEC-HMS was developed under the HEC 'Next-Generation Software Development Project' led by the Director, Darryl Davis. Arlen Feldman, Chief of the Research Division, managed the overall project.

CHAPTER 1

Introduction

The Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) provides a variety of options for simulating precipitation-runoff processes. In addition to unit hydrograph and hydrologic routing options similar to those in HEC-1 (HEC, 1990), capabilities include a linear distributed-runoff transformation that can be applied with gridded (e.g., radar) rainfall data, a simple "moisture depletion" option that can be used for simulations over extended time periods, and a versatile parameter optimization option.

Future versions will have capability for continuous moisture accounting and snow accumulation/melt simulation.

This chapter discusses the features of HEC-HMS, provides a brief overview of its capabilities and summarizes the contents of this Manual.

Features

HEC-HMS is comprised of a graphical user interface (GUI), integrated hydrologic analysis components, data storage and management capabilities, and graphics and reporting facilities. The Data Storage System, HEC-DSS (HEC, 1994), is used for storage and retrieval of time series, paired-function, and gridded data, in a manner largely transparent to the user. Internal design features of HEC-HMS are described by Charley, et al., 1995.

The Graphical User Interface (GUI) provides a means for specification of watershed components, inputting data for the components and viewing of results.

The GUI has capability for schematic representation of a network of hydrologic elements (e.g., subbasins, routing reaches, junctions, etc.). You can configure the schematic by selecting and connecting icons that represent the elements. Once a schematic is developed, pop-up menus can be invoked from the element icons. A menu provides access to an editor for entering or editing data associated with the hydrologic element, and enables display of results of a simulation for that element.

The entering of data for a large number of hydrologic elements can be tedious if performed with the individual editors for each element. The GUI also contains global editors for entering or reviewing data of a given type (e.g., values for Green & Ampt parameters) for all applicable elements. You can also import data from an HEC-1 input file.

You can review simulation results with a variety of graphic and tabular displays, and transmit such displays to a printer.

Technical Capabilities

The basic framework for simulation of basin runoff is similar to that in HEC-1 (Peters, 1995). Hydrologic elements are arranged in a dendritic network, and computations are performed in an upstream-to-downstream sequence.

Computations are performed with SI (Système International d'Unites) units. However you can enter input and view output with units in the U.S. Customary system, and can readily convert input/results from one unit system to the other.

The execution of a simulation requires specification of three sets of data. The first, labeled Basin Model, contains parameter and connectivity data for hydrologic elements. Types of element are: subbasin, routing reach, junction, reservoir, source, sink and diversion. The second set, labeled Precipitation Model, consists of meteorological data and information required to process it. The model may represent historical or hypothetical conditions. The third set, labeled Control Specifications, specifies time-related information for a simulation. A Project can consist of a number of data sets of each type. A "run" is configured with one (each) Basin Model, Precipitation Model and Control Specifications.

Basin Model

Subbasin runoff can be computed in either a lumped or linear-distributed mode. In a lumped mode, precipitation and "losses" are spatially-averaged over a subbasin. In the linear-distributed mode, rainfall is specified on a gridded basis, and loss and excess are tracked separately for each grid cell in a subbasin. Excess is transformed to direct runoff with the Modified Clark method.

Losses. Options for calculating losses for event simulation include initial/constant, SCS Curve No., gridded SCS Curve Nos. and Green and Ampt. For continuous simulation, a simple deficit/constant loss function can be used. The user specifies a soil moisture storage capacity which must be filled before excess can occur. The capacity is filled by rainfall, and depleted during rain-free periods at a user-specified monthly-average depletion rate. When the capacity is filled, loss occurs at the specified constant rate. (It is planned to incorporate a more comprehensive soil moisture accounting option in future versions of HEC-HMS.)

Runoff Transformation. Transformation of precipitation excess to direct runoff can be achieved with unit hydrograph or kinematic wave methods. A unit hydrograph may be specified in tabular form, or in terms of parameters defined by Clark, Snyder or SCS methods. The kinematic wave method permits definition of two rectangular overland flow planes. Runoff from an overland flow plane may be routed through one or two collector channels and a main channel with kinematic wave or Muskingum Cunge methods.

A quasi-distributed treatment of subbasin runoff can be achieved with the Modified Clark method (Peters and Easton, 1996), which is based on the Clark conceptual runoff model (Clark, 1945). In the Modified Clark method, grid cells are superposed on the basin, and rainfall and losses are tracked uniquely for each cell. Rainfall excess from each cell is lagged to the basin outlet and routed through a linear reservoir. The outflows from the linear reservoir are summed and baseflow is added to obtain a total-runoff hydrograph.

Routing. Routing options include Muskingum, Modified Puls, Kinematic Wave and Muskingum-Cunge methods. The Kinematic Wave and Muskingum-Cunge methods may be invoked with standard geometric shapes (e.g., circle, trapezoid) or with cross sections defined with eight sets of X-Y coordinates and three Manning *n* values. Capability is also provided for routing through an uncontrolled reservoir, for which a relation between outflow and storage is required. If more sophisticated routing methods are required because of complex boundary conditions, hydrographs may be exported for use with software such as UNET (HEC, 1993) which provides a numerical solution to the one-dimensional St. Venant equations.

Diversion. A diversion can be specified in terms of a tabular relation between inflow and diverted flow. The diverted hydrograph can be treated as an inflow at a downstream location in the system network.

Precipitation Model

The precipitation model is the set of information required to define historical or hypothetical precipitation to be used in conjunction with a basin model. Types of hypothetical storm include frequency-based and the Corps of Engineers' Standard Project Storm (Corps of Engineers, 1952). HEC-HMS capabilities for the latter are applicable only for drainage areas up to 2600 km^2 east of the Rocky Mountains. Frequency-based storms require that the user provide rainfall depths for various durations, sources of which include Technical Paper 40 (National Weather Service, 1961) and NOAA Atlas 2 (National Weather Service, 1973).

Several options are available for specifying historical precipitation: (1) utilize cell-based precipitation as required for the Modified Clark method; (2) import previously determined spatially-averaged precipitation; (3) specify gages and associated weights (e.g., from Thiessen polygons); or (4) specify gages and their locations, and weights and locations of index nodes, to be used in an automated inverse distance-squared weighting. The latter method is useful in cases of missing data, as data from the next nearest gage is automatically used.

Control Specifications

Control specifications include the starting and ending dates for a simulation, and the time interval for computations.

Parameter Optimization

An optional capability is provided to enable automated estimation of values for selected subbasin and routing-reach parameters, provided that "observed" streamflow data is available. You can select from alternative objective functions and search methods, and impose constraints on parameter values. Parameters from any subbasin or routing reach upstream from the "target" location (for which the observed streamflow has been specified) can be included in an optimization.

User's Manual Overview

This manual provides instructions for application of HEC-HMS. The manual is organized as follows:

- Chapter 2 - installation instructions
- Chapter 3 - overview of procedures for working with HEC-HMS
- Chapter 4 - working with projects
- Chapter 5- entering and editing basin model data
- Chapter 6 - entering and editing precipitation model data
- Chapter 7 - entering and editing control specifications
- Chapter 8 - performing simulations
- Chapter 9 - example application
- Chapter 10 - parameter calibration

CHAPTER 2

Installing HEC-HMS

HEC-HMS can be used with Microsoft Windows 95 or NT, and X-Window, systems.

This chapter describes hardware and operating system requirements for HEC-HMS, and provides instructions for program installation.

Hardware/Operating System Requirements

PC Version (MS Windows)

- Any IBM or compatible PC with an 80386 processor or higher (a 80486 or higher is recommended).
- A hard disk with at least 15 megabytes of free space (20 megabytes or more is recommended).
- A 3 1/2" floppy drive.
- A minimum of 16 megabytes of RAM.
- A mouse.
- Color VGA or better video display (recommend running in Super VGA or higher).
- MS Windows 95; or MS Windows NT version 3.51 or later.

X-Window Version

- Sun workstation with Solaris 2.4 (or later) operating system.

Installation

PC Version (MS Windows)

Installation is accomplished with the program SETUP.EXE. When you run the Setup program, you will be asked to set a path for the program and data files. It is recommended that you choose the default, "\HEC\HMS".

To install the software, do the following:

1. Insert Disk 1 into the A (or B) drive.
2. Choose **Run** from the **Start** menu.
3. Type **A:SETUP** (or **B:SETUP** if disk 1 is in the B drive) and press **OK**.
4. Follow the setup instructions on the screen.

Upon completion of the installation, files will exist in directories (folders) as follows:

Directory	File(s)
C:\HEC\HMS	HEC-HMS executable and related files
C:\HMSPROJ	*projects.hms*, a list of HEC-HMS projects
C:\HMSPROJ\CASTRO	files associated with the project Castro
C:\HMSPROJ\TENK	files associated with the project Tenk

Initially, the list of HEC-HMS projects (in *projects.hms)* will contain references to two example projects, Castro and Tenk. From HEC-HMS you can open either project to explore their data sets, execute simulations and view results.

The Castro project contains data sets described in Chapter 9. The Tenk project contains data sets for the Illinois River Basin in northeastern Oklahoma and northwestern Arkansas. The approximately 4170 sq. km. (1600 sq. mi.) basin, which provides inflow to Tenkiller Lake, is divided into four subbasins. The ModClark method is used to simulate runoff using radar rainfall data.

X-Window Version

1. Make the directory **/usr/hec** if it does not already exist:

   mkdir /usr/hec

2. Change directory to /usr/hec:

   cd /usr/hec

3. Ftp to the site from which HEC-HMS will be retrieved.

4. Using the binary transfer mode, get **hms.tar.Z**. This is a compressed tar file containing all files necessary to execute HEC-HMS.

5. Extract the files from the hms.tar file:

   tar -xvf hms.tar

6. You now have the HEC-HMS executable and required binary files in **/usr/hec/bin**. Test data are located in **/usr/hec/testdata/hms.**

7. Add **/usr/hec/bin** to your path environment variable if it is not already there.

8. Change directory to the "working" directory. This is the directory to which project directories will normally be appended, and is commonly the users $HOME directory.

9. Execute HEC-HMS by typing

   hms &

   at the command prompt. The first time you execute HEC-HMS, a file named .vgalaxy.1.vr will be created in your home directory. This file will contain your preferences for such things as default methods, units, etc., and a list of the four projects you have opened most recently.

CHAPTER 3

Working With HEC-HMS - An Overview

In HEC-HMS terminology, a **Project** is a collection of data sets associated with a particular watershed or study. Types of data sets are **Basin Model**, **Precipitation Model** and **Control Specifications**. A **Run** consists of a specific combination (one each) of the three types. After execution of a run, you can view and print results in both tabular and graphical form. This chapter provides an introduction to use of the Graphical User Interface (GUI) to enter data, execute simulations and view results. Capability to import HEC-1 data is also discussed.

Starting HEC-HMS

Once HEC-HMS has been installed (see Chapter 2), start the program as follows:

From Microsoft Windows[1] -

double-click the HEC-HMS icon

From an X Window[1] -

at the prompt, type `hec-hms &`

When you first start HEC-HMS, you will see the main screen as shown in Figure 3.1. The main screen lists the data sets associated with a project and provides access to data editors, the simulation manager, and other components of HEC-HMS.

[1] See Chapter 4 regarding file directories for HEC-HMS data sets. For Microsoft Windows, HEC-HMS will normally be executed from a *working* directory, to which project subdirectories are appended. For UNIX systems, the *current* directory (from which HEC-HMS is executed) is treated as the working directory.

The main screen has the following menu-bar headings:

File File options are: New Project, Open Project, Save Project, Copy Project, Rename Project, Delete Project, and Import HEC-1 File. In addition, the four most recently opened projects are accessible from the list at the bottom of the File menu.

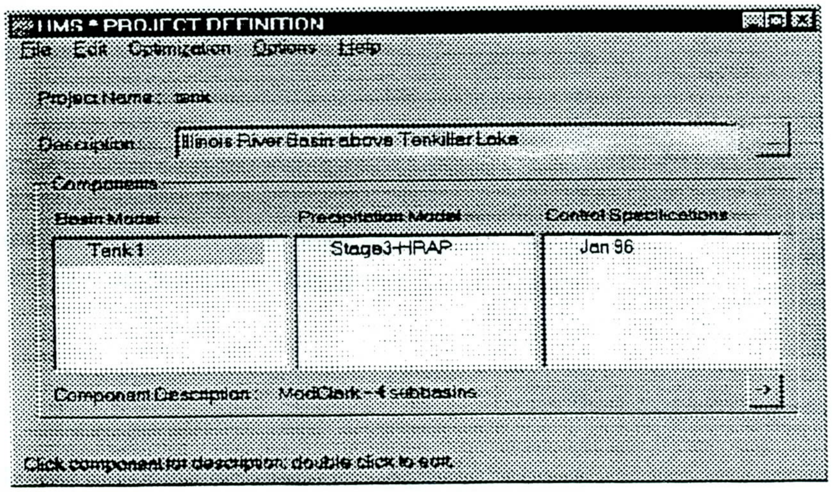


Figure 3.1 HEC-HMS Main Screen

Edit This option is used for initiating and accessing data sets. Data are categorized into three types: Basin Model, Precipitation Model and Control Specifications. Open, New and Delete options are available for each data type. The Gage Data option enables association of precipitation and discharge data with a project. The data may be entered manually, or existing Data Storage System (DSS) records may be referenced.

Optimization This option provides access to parameter optimization capabilities. See Chapter 10.

Options Options are: Setup (not yet functional) and Default Preferences. The Default Preferences option allows you to set default choices for the units system and for loss, transform and reach-routing methods. The choices will be the initial selections in data editors for new basin models.

Help This option provides on-line help and displays version information.

Data Storage

Figure 3.2 illustrates three locations where data for HEC-HMS can reside: (1) locally in the GUI, (2) in memory that is part of the computational "engine", and (3) in persistent storage such as in a database or a data file on disk. Generally data is transferred from a GUI screen to memory by pressing an **OK** or **Apply** button. **OK** causes the data to be stored in memory and then closes the screen. **Apply** causes the data to be stored in memory but leaves the screen open. The font color for newly-entered or modified values on a data-entry screen will generally be red until they are saved in memory, when the font color changes to black. Pressing **Cancel** will cause a screen to close without placing (or changing) any information in memory. A data set that is currently in memory is marked with a check mark (✓) on the PROJECT DEFINITION screen.

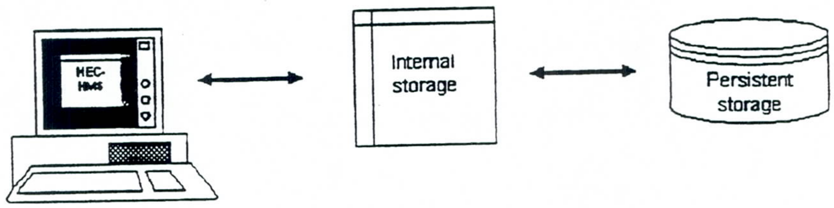


Figure 3.2 Data Storage

Saving data to persistent storage generally requires the selection of the **Save** option accessed from **File** on a menu bar. Individual data sets can be saved, or a global save of all data associated with a particular project can be effected. If you choose to open a new data set or project while an existing one which has been modified is in memory, you will be asked whether to save the existing set (to persistent storage) prior to opening the new one.

You can optionally set a switch that causes **OK** or **Apply** to automatically save data values on a screen to both memory and persistent storage. Data values preexisting in persistent storage will be overwritten with values from the screen. An advantage of this option is that with frequent incremental saving of information, there will generally be less loss of data in the case of a system or program failure. This option is invoked in **Default Preferences**, which is accessed from Options on the menu bar of the Project Definition screen. Future versions of HEC-HMS will likely contain automated backup capability to better provide for a more fail-safe operational environment.

A data set is automatically provided with a default name. It is generally advisable to override the name with a more descriptive name of your choosing. Also it is generally useful to exercise the option of providing, for future reference, descriptive information about the data set.

The bottom line of each screen is reserved for micro-help messages. More complete help is accessed by selecting **Help** on a menu bar.

Steps in Applying HEC-HMS

An application entails the following steps:

- Start a new project
- Enter Basin Model data
- Enter Precipitation Model data
- Enter Control Specifications
- Create and execute a run
- View results
- Exit program

Start a New Project

To institute a new project, go to **File** on the menu bar in the main (PROJECT DEFINITION) screen and select **New Project**. A NEW PROJECT screen will appear (Figure 3.3) which provides fields in which to enter the name and a description of the new project. The project name is used in HMS-controlled naming of files. It may consist of any alphabetic or numeric characters, and may include one or more embedded spaces.

The optional project description can have as many as 1024 characters. Long descriptions can be entered in a text screen accessed by pressing the button with ellipses (...) that follows the definition field. Press **OK** to accept the name and description of the new project and return to the PROJECT DEFINITION screen.

The directory where project files will be stored is by default a subdirectory to the working (or current) directory. You can override the default.

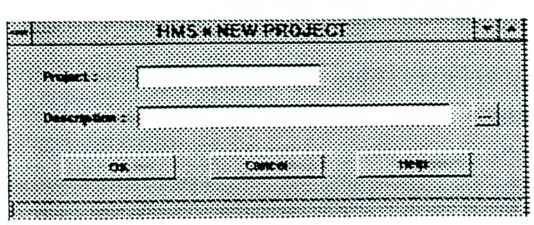


Figure 3.3 New Project

Enter Basin Model Data

Go to **Edit** on the menu bar in the main (PROJECT DEFINITION) screen and select **Basin Model** and **New**. This will bring up a NEW BASIN MODEL screen with "Basin-1" showing (and selected) as the Basin Model Name, as shown in Figure 3.4. You can edit or accept this name. A basin model description may optionally be entered. Press the **OK** button at the bottom of the screen to institute the new basin model and open a SCHEMATIC screen (Figure 3.5).

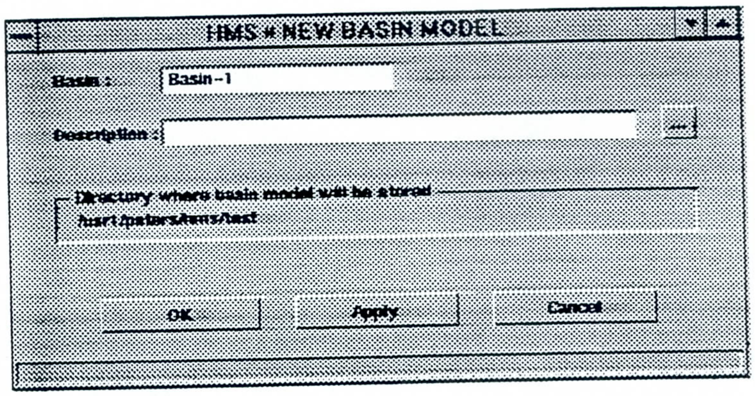


Figure 3.4 New Basin Model

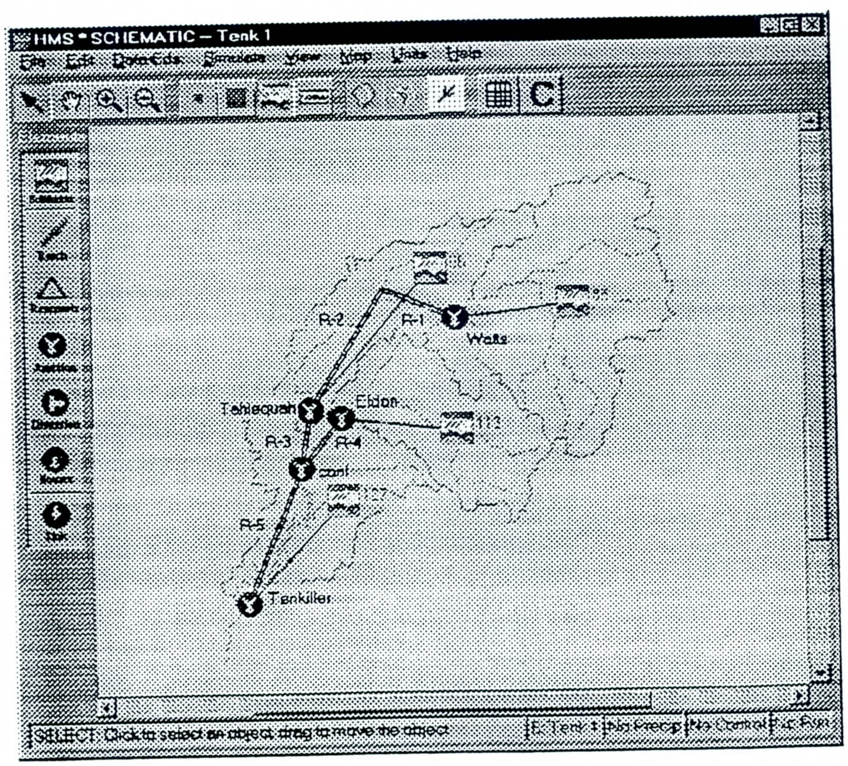


Figure 3.5 Basin Schematic

Schematic. A schematic representation of a basin network is created by dragging and dropping icons that represent hydrologic elements, and establishing connections between them. There are seven types of hydrologic elements: subbasin, river reach, junction, reservoir, source, sink and diversion. The icons are displayed on the element palette on the left side of the screen, as illustrated in Figure 3.5. After iconic representations of the hydrologic elements have been positioned on the schematic, an editor for a hydrologic element can be invoked by double clicking its icon. The editor enables specification of all basin model data required for that element.

An alternative to using an editor for a single element is to enter parameter data in global editors in which values for a particular data type (e.g., Clark unit hydrograph parameters) are entered for all hydrologic elements (e.g., subbasins) to which the type applies. To access a global editor, go to **Data-Eds.** on the menu bar and select the desired editor. Figure 3.6 illustrates the global editor for Clark Unit Hydrograph. To save the basin model, go to **File** on the menu bar and select **Save Basin Model**.

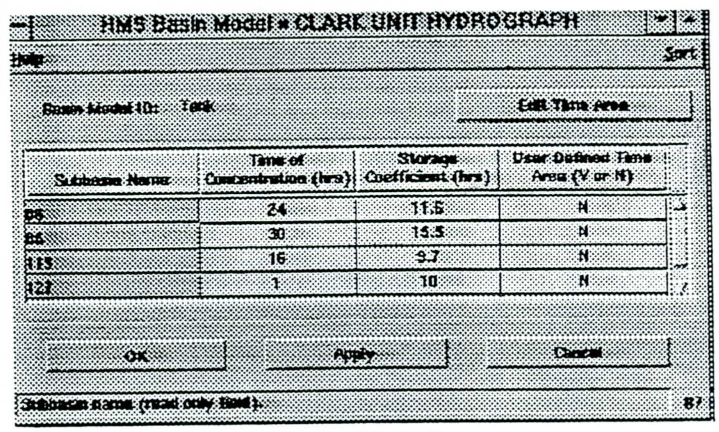


Figure 3.6 Global Editor for Clark Parameters

Enter Precipitation Model Data

Go to the **Edit** menu on the main (PROJECT DEFINITION) screen and select **Precipitation Model** and **New**. This will bring up the NEW PRECIPITATION MODEL screen with "Precip-1" showing (and selected) as the Precipitation Model Name. You can edit or accept this name. A precipitation model description may optionally be entered. Press the **OK** button to initiate the new precipitation model and open the METHOD SELECT screen. Select the desired method and press **OK**. A screen for the selected method will open. Figure 3.7 shows such a screen for FREQUENCY-BASED STORM. Enter data appropriate for the method. To save the precipitation model, go to **File** on the menu bar and select **Save**. Pressing the **OK** button will return you to the PROJECT DEFINITION screen.

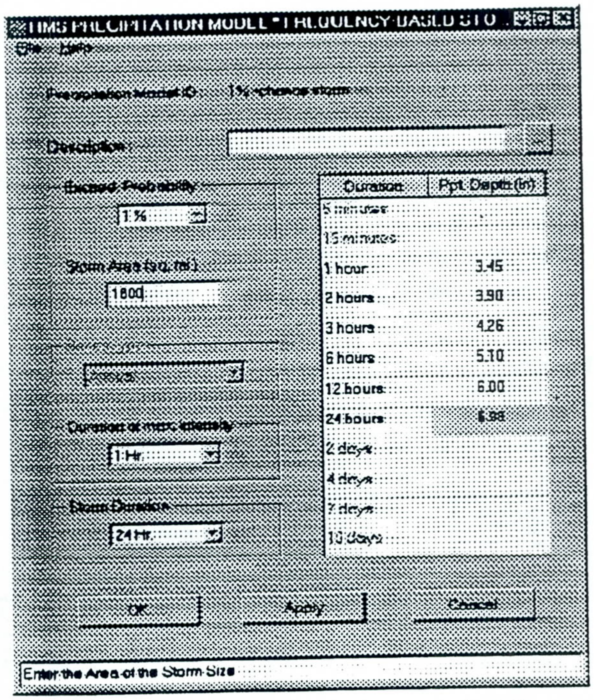


Figure 3.7 Frequency-Based Hypothetical Storm

Enter Control Specifications

Go to **Edit** on the menu bar in the main (PROJECT DEFINITION) screen and select **Control Specifications** and **New**. This will bring up the NEW CONTROL SPECIFICATIONS screen with "Control-1" showing (and selected) as the Control Specifications Name. You can edit or accept this name, and a description may optionally be entered. Press the **OK** button to open the CONTROL SPECIFICATIONS screen (Figure 3.8). Enter control data. To save the control specifications, go to **File** on the menu bar and select **Save**. Pressing the OK button near the bottom of the screen will close the SETUP screen and return to the PROJECT DEFINITION screen.

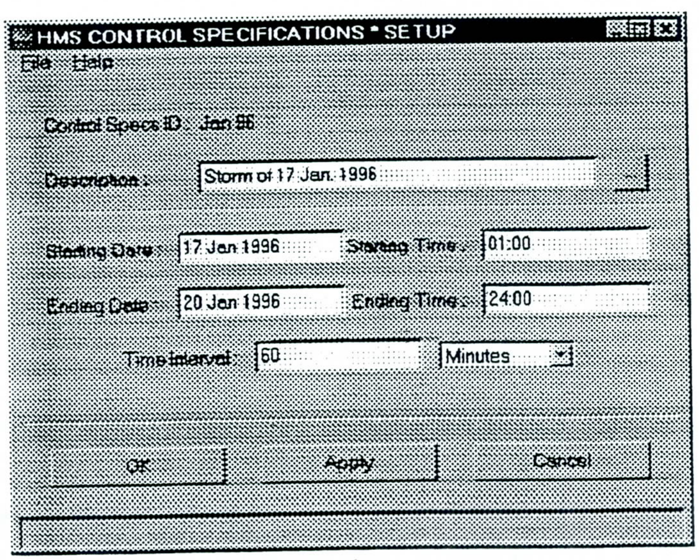


Figure 3.8 Control Specifications

Create and Execute a Run

Go to the **Simulate** menu on the SCHEMATIC screen and select **Simulation Manager** to bring up the SIMULATION MANAGER screen (Figure 3.9). Press the **Select Components** button to bring up the RUN CONFIGURATION screen (Figure 3.10). A run is configured by selecting one of each type of data set (Basin Model, Precipitation Model, Control Specifications). The Run I.D. can be edited or selected, and a run description can be optionally entered. Press the **Add** button, then **Close**. The run now appears in the SIMULATION MANAGER screen. Select the run, then press the **Compute** button. A COMPUTE screen will show the progress of the execution..

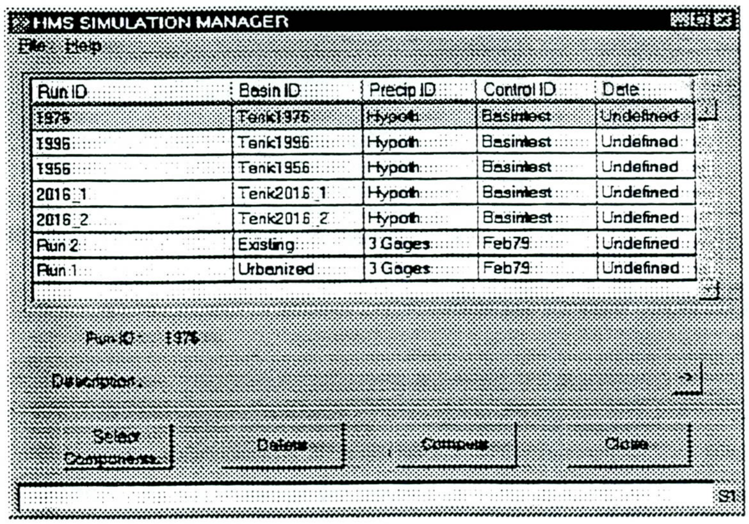


Figure 3.9 Simulation Manager

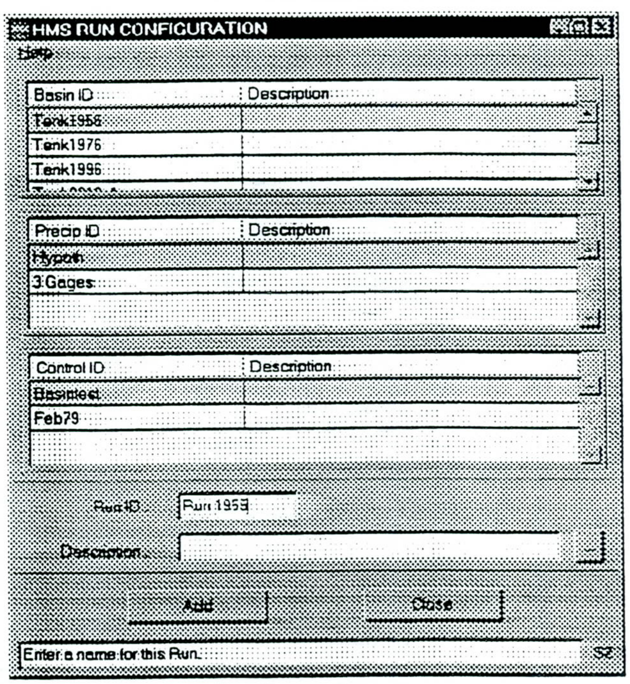


Figure 3.10 Run Configuration

View Results

Simulation results may be viewed in tabular or graphical form. Go to **View** on the SCHEMATIC screen menu bar and select **Summary Table**. A table summarizing results of the entire run, such as that shown in Figure 3.11, will appear. Access the pop-up menu for a hydrologic element by right-clicking the element icon. Select **View Results** to obtain a graphical display, such as that illustrated in Figure 3.12. Summary tables containing detailed results for an element are also available from the pop-up menu. Tables or graphs can be printed.

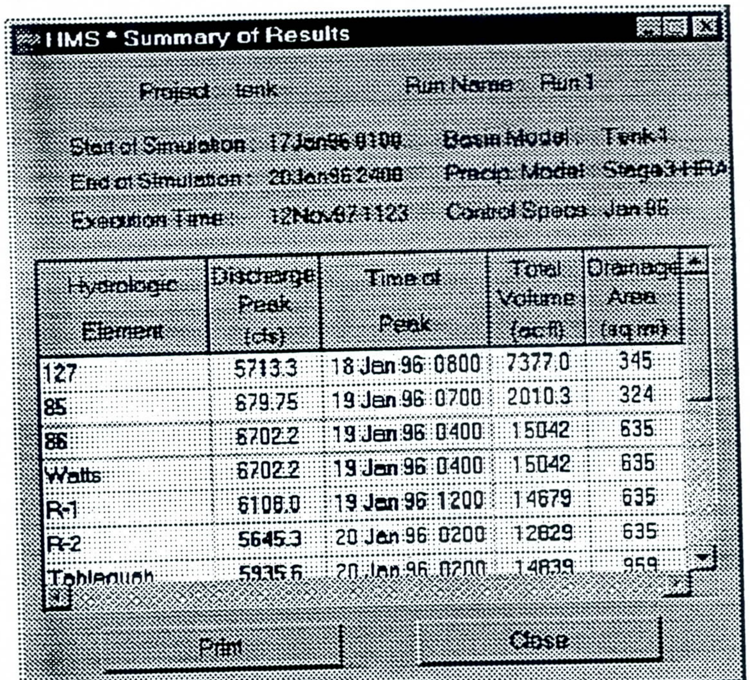


Figure 3.11 Summary Table

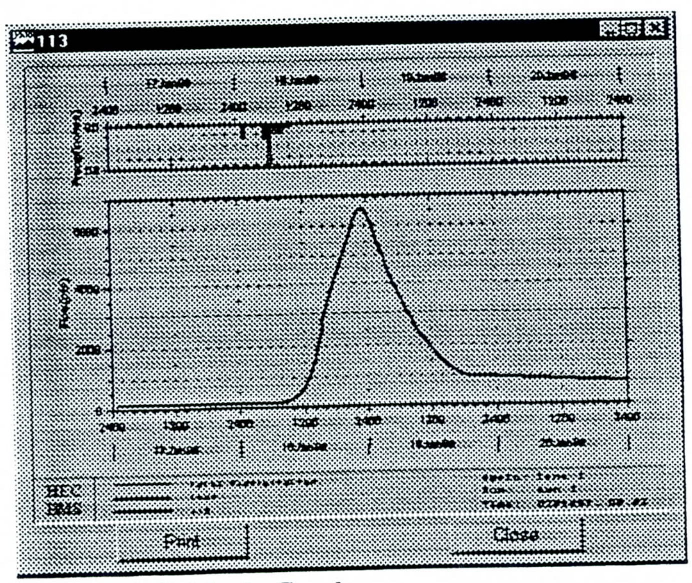


Figure 3.12 Subbasin Graph

Exit Program

In the SCHEMATIC screen, go to **File** and select **Close**. This will return you to the PROJECT DEFINITION screen, in which you can select **Save Project** under **File**. This will cause all data associated with the project to be saved to persistent storage (i.e., data files). Then select **Exit** under **File** to exit the program.

Importing HEC-1 Data

Data from an HEC-1 input file may be imported for use in HEC-HMS. The data is automatically partitioned into the three types of data set used by HEC-HMS: basin model, precipitation model and control specifications. To import data, select **Import HEC-1 File** from **File** on the menu bar in the main (PROJECT DEFINITION) screen. An IMPORT HEC-1 DATA screen (Figure 3.13) appears in which you can select an HEC-1 file and edit names of the generated data sets. Because not all HEC-1 options are available in HEC-HMS, editing of the imported data with various HEC-HMS editors may be required.

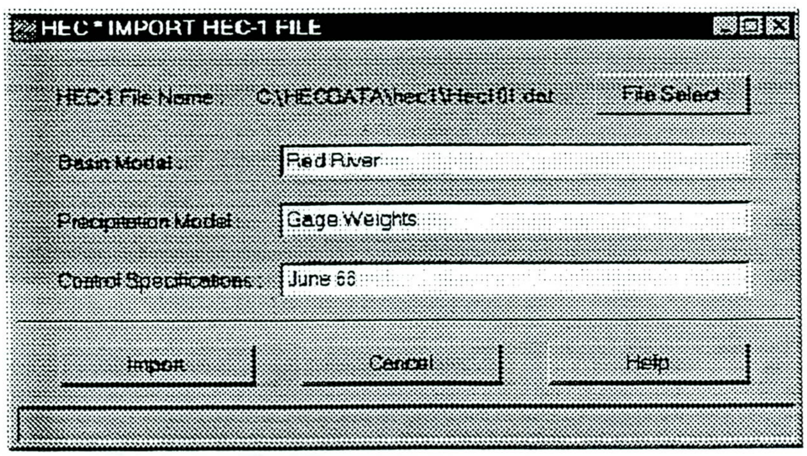


Figure 3.13 Import HEC-1 Data

CHAPTER 4

Working with Projects

The management of data files by HEC-HMS is largely done behind-the-scenes. That is, data and output files are automatically created and named based on information supplied by the user. Also, data stored in Data Storage System (DSS) files are automatically labeled.

A **project** is a collection of data sets associated with a particular watershed or study. This chapter describes how you work with projects, and how associated data files are developed, named and managed by HEC-HMS.

Gaged precipitation and discharge data for a project may be entered manually, or accessed as records in a DSS file. Procedures for entering or accessing such data are described.

Project Directories and Files

All files generated by HEC-HMS for a project are stored in a directory associated with that project. When a project directory is created by HEC-HMS, by default it is a subdirectory to the *working* directory (MS Windows) or *current* directory (UNIX). The default name for the directory is based on the project name. You are given the opportunity to override the default location and/or name of the project directory.

It is recommended (but not required) that each project be in a separate directory. Such an approach facilitates file management and archiving of files. Figure 4.1 illustrates a directory tree in which the working or current directory is *hmsproj*, and data for three projects named *Blue River*, *Green River* and *Ohio Tribs* are stored in their associated directories.

HEC-HMS maintains a list of projects and project descriptions in a file labeled **projects.hms**. This file is automatically placed in the working directory. On UNIX systems, it is placed in your home directory. The **projects.hms** file also contains settings for default methods and units.

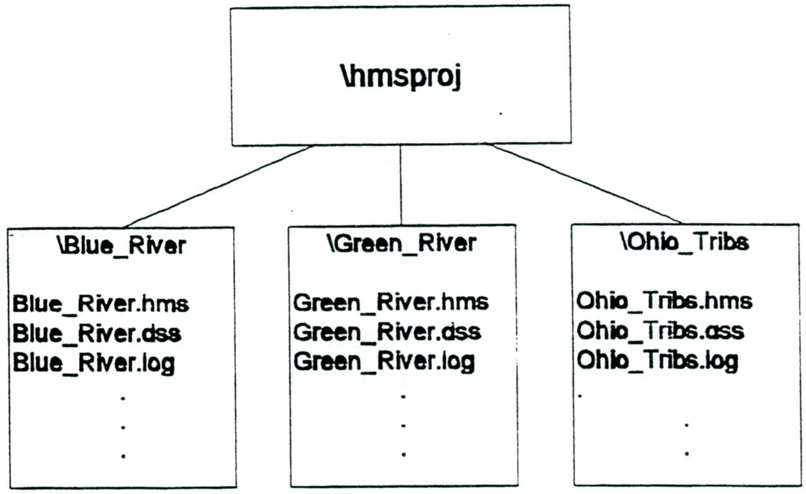


Figure 4.1 Project Directories

File Names Generated by HEC-HMS

The names that you specify for a project and data sets (e.g., basin models) are used in the automatic naming of associated files. For example, suppose that you have specified the project name *Blue River*. HEC-HMS creates a file in the project directory named "*Blue_River*.hms" that contains a list of data sets and their descriptions, and default method options, associated with the project. A DSS file, "*Blue_River*.dss", is created to contain time series and paired data for the project. Also a log file, "*Blue_River*.log", is created. When you configure a run (i.e., a combination of basin model, precipitation model and control specifications), the run name and references to its components are entered in the log file.

Similarly, if you name a basin model *urban2020*, the data file that contains values for hydrologic parameters and connectivity information is labeled "*urban2020*.basin". Precipitation model and Control Specification files will have extensions "precip" and "control", respectively.

Table 4.1 lists types of files associated with an HEC-HMS project.

Table 4.1 HEC-HMS Files

File Name	Contents
project-name.hms	List of models, model descriptions and project default method options.
project-name.dss	DSS file containing basin model data such as storage-outflow relationships, and simulation results (e.g., computed hydrographs).
project-name.run	List of runs, including most recent execution times.
basin-model-name.basin	Basin model data, including connectivity information.
precipitation-model-name.precip	Precipitation model data.
control-specifications-name.control	Control specifications.
run-name.log	Messages generated during execution of run *run-name*.

User-specified Files

In addition to the files named and controlled by HEC-HMS, user-specified files are commonly required for a simulation. Such files might contain, for example, observed precipitation or discharge, map coordinates, or characteristics of grid cells for application of the modClark method. You can locate such a file with a browser, or specify the file name directly. It is not necessary for the file to be located in the project directory.

DSS-File Pathnames

The project DSS file (e.g., "*Blue_River*.dss") can contain paired data, such as a relation between storage and discharge for a routing reach, and time series data, such as a calculated hydrograph. For simulation results, the F-part of a pathname is the run name. Thus results from different runs will have unique pathnames, making it possible to develop output displays of results from various runs.

Entering Gaged Data

Data from precipitation and streamflow gages are used for several purposes in HEC-HMS. Precipitation data is used to develop precipitation hyetographs for subbasins. Streamflow data is used to define discharge for a *source* hydrologic element, for optimization of basin model parameters, and for comparison with simulated streamflow. Gaged data may be entered manually or accessed as records in a DSS file. All gaged data associated with a project are entered via the **Gage Data** option on the **Edit** menu of the PROJECT DEFINITION screen. Gaged data must be entered prior to referencing such data in a Precipitation or Basin Model. The procedure for entering data is the same for precipitation or streamflow data. Precipitation data is used in the illustration that follows.

To enter data, select **Gage Data - Precipitation** from **Edit** on the menu bar of the PROJECT DEFINITION screen. This will open a PRECIPITATION GAGE LIST screen (Figure 4.2). If no precipitation gages have previously been entered, the NEW GAGE RECORD screen will also open (Figure 4.3). If data has previously been entered, select **Add Gage** from **Edit** on the menu bar of the PRECIPITATION GAGE LIST screen.

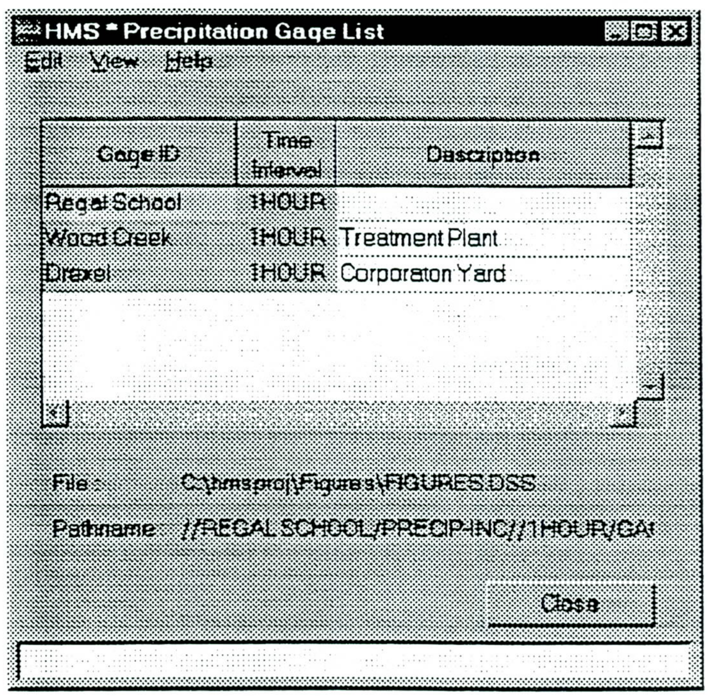


Figure 4.2 Precipitation Gage List

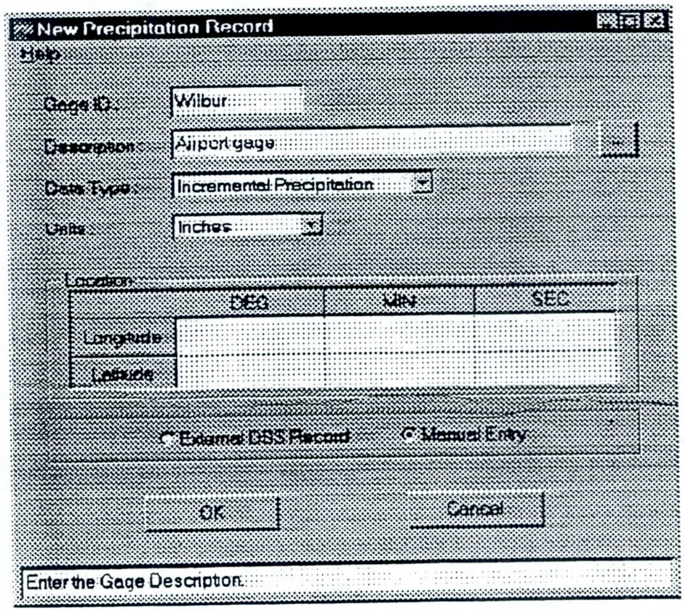


Figure 4.3 New Precipitation Record

In the NEW GAGE RECORD screen, enter a name for the gage, and (optionally) a description. Select the data type and units. Latitude and longitude data are required if the gage is to be used with the Inverse Distance Weighting method for defining subbasin hyetographs; otherwise the gage location is not required. Select whether the data will be referenced in an external DSS file, or entered manually. Click **OK**. The screen that opens next depends on the source of the data.

For data from an external DSS file, the DSS PATHNAME SELECT screen (Figure 4.4) will open. Specify the external DSS file, or use the File Browser to select the file. The filters can optionally be used to specify pathname "parts" to obtain a subset of pathnames when the **Generate Catalog** button is pressed. Generate a catalog and select the pathname of the desired record. Press **OK** or **Apply**. The Gage ID will be added to the list on the PRECIPITATION GAGE LIST screen. A gage description can optionally be entered.

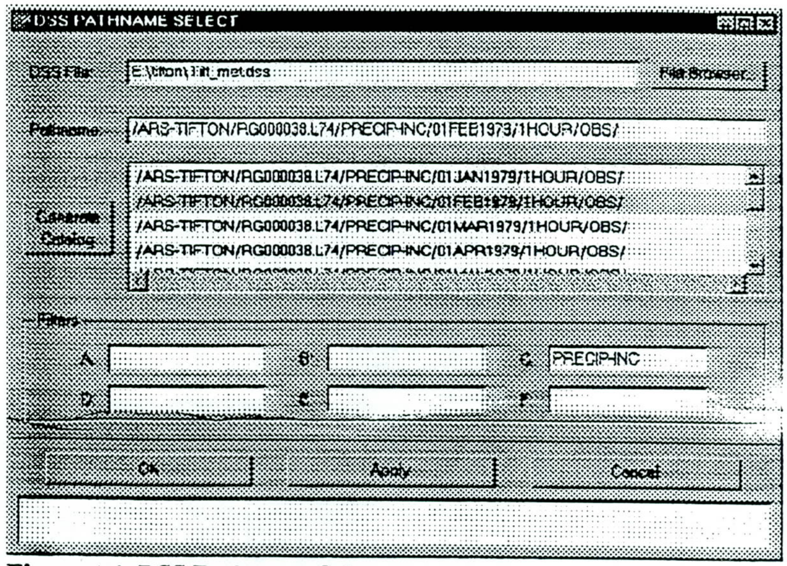


Figure 4.4 DSS Pathname Select

If data for the new gage record is to be entered manually, the screen that opens from the NEW GAGE RECORD screen (Figure 4.3), is the TIME PARAMETERS FOR MANUAL DATA ENTRY screen (Figure 4.5).

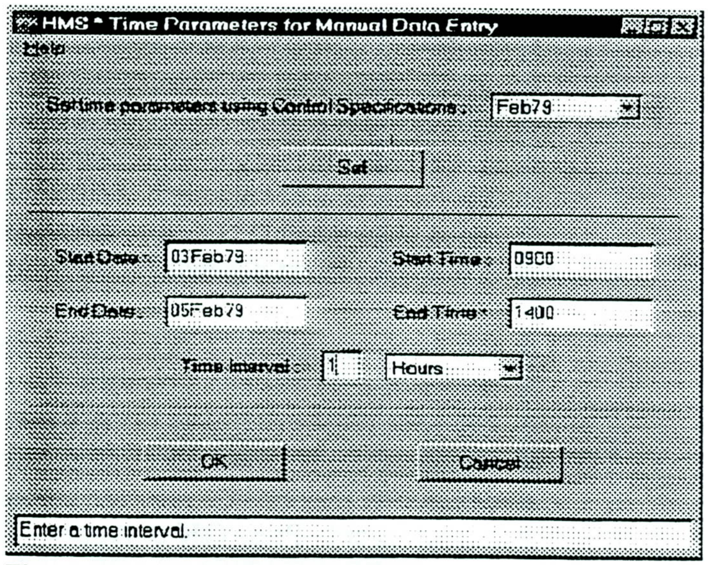


Figure 4.5 Time Parameters for Manual Data Entry

This screen is used to set the starting and ending dates and times, and a time interval, for the data. If desired, the time information can be automatically retrieved from an existing Control Specifications by selecting a Control Specifications from the list box, and pressing SET. The time information obtained by this means can be edited. The time information can be entered directly if it is not acquired from an existing Control Specifications. Click **OK**, and the DATA EDITOR screen (Figure 4.6) opens. Enter your data values on this screen.

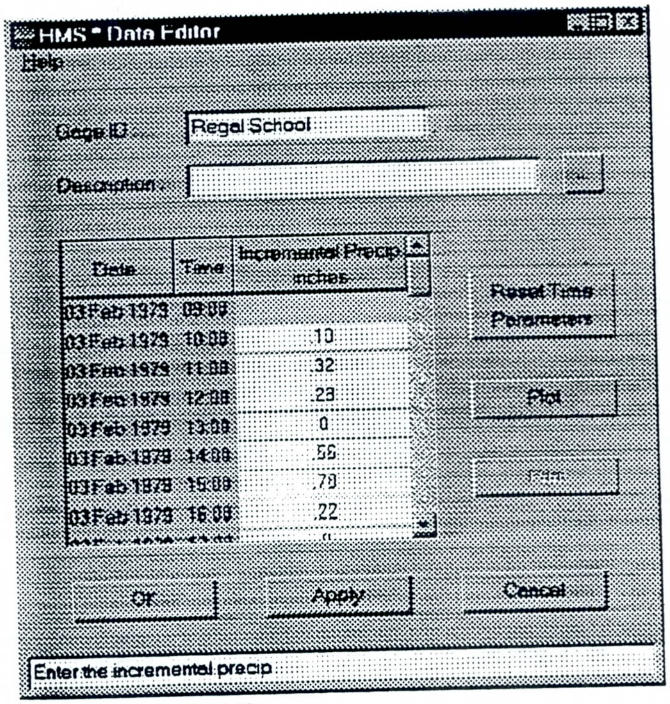


Figure 4.6 Data Editor

HEC-HMS maintains lists of precipitation and discharge gages for which data has been entered. You will select from these lists when establishing Precipitation or Basin models that utilize the data.

Editing Previously-Entered Gaged Data

Gaged data that was previously manually entered may be edited. Select **Gage Data - Precipitation** from **Edit** on the menu bar of the PROJECT DEFINITION screen. This will open a PRECIPITATION GAGE LIST screen (Figure 4.2). Select the gage for which data is to be edited. Select **Gage Data** from **Edit** on the menu bar. This will open the SELECT TIME WINDOW screen (Figure 4.7), which shows time windows for which data have previously been entered. Select a time window, or press the **New Time Window** button to access the TIME PARAMETERS FOR MANUAL DATA ENTRY screen (Figure 4.5). Once a time window has been selected or a new one has been set, the DATA EDITOR screen (Figure 4.6) will open to permit editing of previously-entered data, or to enter new data. Data from external DSS records cannot be manually edited from within HEC-HMS.

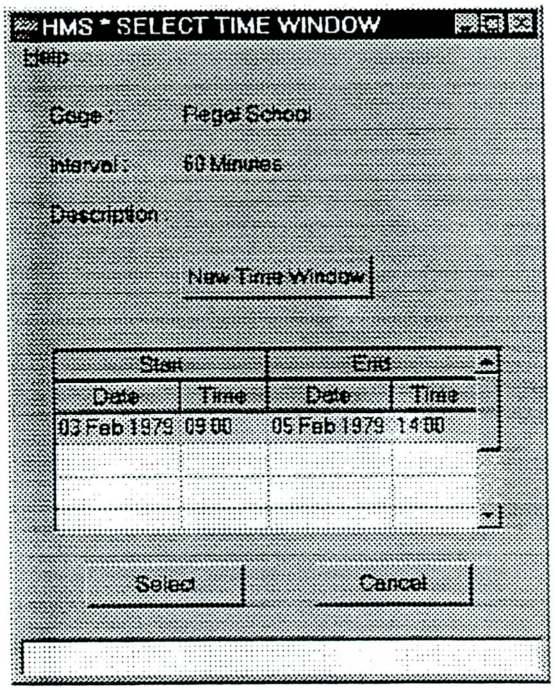


Figure 4.7 Select Time Window

Managing Projects

Projects are managed with options accessed from the **File** menu of the main (PROJECT DEFINITION) window. The options are as follows (Table 4.2):

Table 4.2 Project Definition

File menu command	Description
New Project	Closes the current project, prompting you to save any changes. Prompts for the name and description of the new project. Permits specification of the directory where project files will be stored.
Open Project	Closes the current project, prompting you to save any changes. Provides a list from which to select an existing project. Permits opening a project that is not currently on the project list, and optionally adding the project to the list.
Save Project	Saves all new project files and updates all project files affected by additions or
Copy Project	Copies all files associated with the current project to the specified project directory. File names of the new files will reflect the specified (new) project name, as appropriate. Permits adding the project to the project list.
Rename Project	Similar to Copy Project, except that files are renamed rather than copied. The project name in the project list is changed to the new name.
Delete Project	Three levels of delete are possible: (1) the current project is removed from the project list (2) in addition to level (1), all project files except the "log" and "dss" files are deleted (3) in addition to levels (1) and (2), the project "log" and "dss" files are deleted
Import HEC-1 File	Prompts for HEC-1 file to be imported. Data from the file is used to generate a basin model, a precipitation model and control specifications. Allows editing of default names for the generated data sets and makes the sets part of the current project.

CHAPTER 5

Entering and Editing Basin Model Data

This chapter describes how you can enter and edit basin model data. Such data includes specification of the hydrologic elements comprised by the basin model, information on how the hydrologic elements are connected, and values of parameters for the hydrologic elements. The capability to configure a basin model by "dragging and dropping" icons on a schematic display is described, as is the use of single-element and global data editors.

Getting Started

To initiate a new basin model, select **Basin Model - New** from **Edit** on the menu bar of the main (PROJECT DEFINITION) screen. This will open the NEW BASIN MODEL screen (Figure 5.1). You can edit or accept the default model name that appears. A model description may optionally be entered. Press the **OK** button to institute the new model and open the SCHEMATIC screen (Figure 5.2).

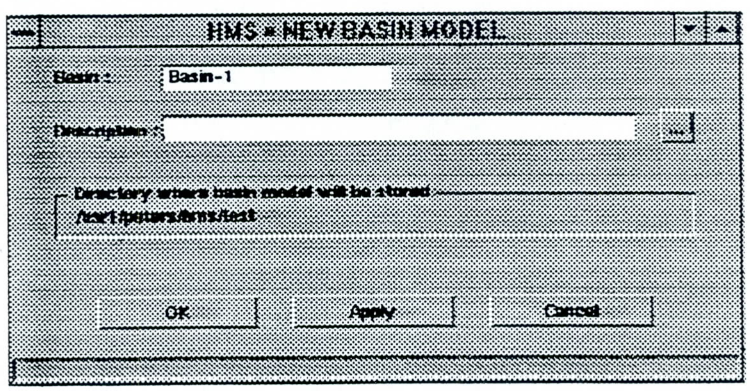


Figure 5.1 New Basin Model

Schematic Screen

The SCHEMATIC screen will generally be central to your application of HEC-HMS, because from this screen you can: (1) configure a basin model by dragging and dropping icons that represent hydrologic elements, (2) invoke data editors, (3) manage (e.g., save, rename, delete, etc.) basin models, (4) access the Simulation Manager, and (5) view simulation results. A background map can be displayed to provide a spatial context for a basin model.

Components of the SCHEMATIC screen (Figure 5.2) include menu and tool bars at the top of the screen, an element palette on the left side, and the display area. Menu bar options enable basin model management (under **File**), hydrologic element creation and management (under **Edit**), access to"global" data editors (under **Data-Eds.**), access to the Simulation Manager.(under **Simulate**), access to displays of simulation results (under **View**), access to map controls (under **Map**), and access to a units switch (under **Units**).

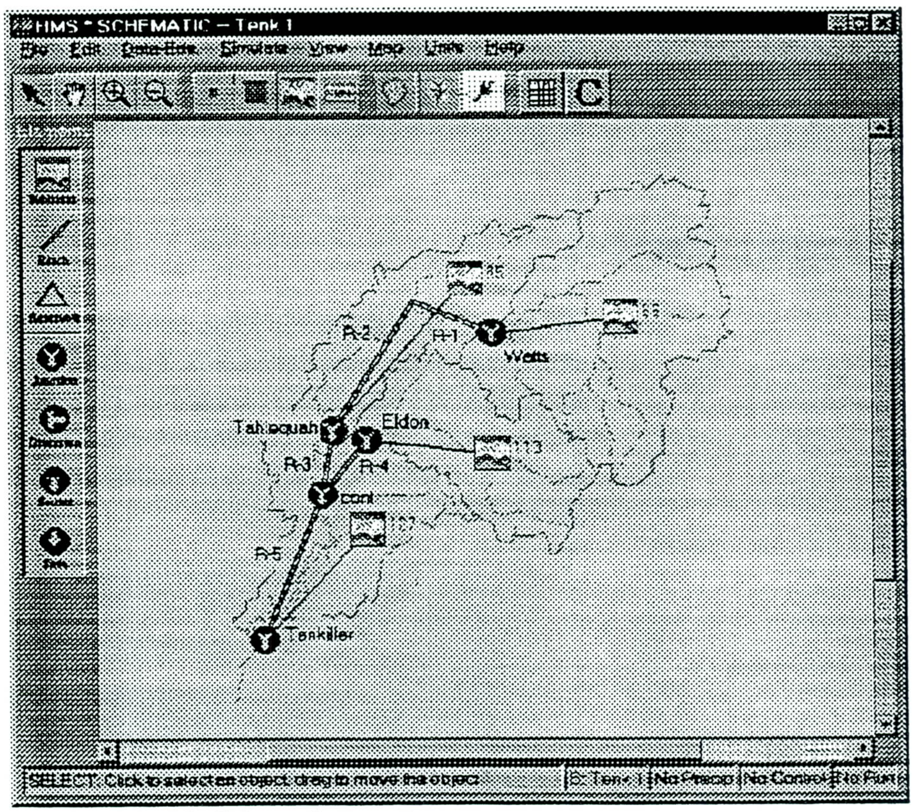


Figure 5.2 Basin Schematic

The first four buttons on the left end of the tool bar control the mode of the display portion of the SCHEMATIC screen. If the first (arrow) button is depressed, the *select* mode is chosen by which a hydrologic element can be selected by a click of the left mouse button. The second (grab hand) button sets the *navigation* mode and changes the cursor to a hand. In this mode, you can reposition a display by dragging it. The last two modes are *zoom-up* (plus sign) and *zoom-down* (minus sign). With these modes, use the left mouse button to define a rectangular area on the screen. In the zoom-up mode, the portion of the display within the rectangle will be magnified to fill the view area. In the zoom-down mode, the display will be reduced to the size of the rectangle. In either mode, a double-click of the left mouse button will reset the display to its original size.

The second set of four buttons (from the left) controls the icon style by which hydrologic elements are represented. These include *small* symbols, *large* symbols, *standard* icons and *names* only.

The third set of buttons (from the left) contains three off-on switches that control map displays. With these buttons you can turn off or on the display of watershed *boundaries* and *streams* (if a map file is used), and directional *arrows* on element connections.

The second-to-last button on the far right of the tool bar provides access to a summary-of-results *table* that becomes available at the conclusion of a simulation. The button on the far right enables execution of a run when run components are in memory.

Hydrologic Elements

A basin model consists of hydrologic elements, of which there are seven types: subbasin, river reach, junction, reservoir, diversion, source and sink. The development of a basin model requires the specification of such elements and data that controls their "behavior". You can generally choose from alternative computational methods (e.g., routing methods for a river reach) to define such behavior.

Functionality of hydrologic elements is as follows:

Subbasin. A subbasin is conceptually an element that produces a discharge hydrograph at its outlet. Its properties include area and percent imperviousness. The discharge hydrograph is based on subtracting "losses" from input precipitation, transforming the resulting precipitation excess to direct runoff at the outlet, and adding baseflow. If the modClark transform is used (with gridded rainfall), it is also necessary to specify characteristics of subbasin grid cells.

River reach. A river reach is conceptually a linear element that has a "known" inflow hydrograph at its upstream end and produces an outflow hydrograph at its downstream end. Data requirements vary from a single parameter for the simplest routing method to coordinates defining a representative cross section and channel properties for more complex methods.

Junction. A junction is a location where two or more inflow hydrographs are added together to produce an outflow hydrograph.

Reservoir. A reservoir is similar to a routing reach in that there is a "known" inflow hydrograph to the reservoir, and the reservoir element produces an outflow hydrograph. In the current version of HEC-HMS, capability only exists for routing through an uncontrolled reservoir, for which there is a monotonically increasing relationship between reservoir storage and outflow.

Diversion. A diversion is an element for which a portion of the inflow to the element is diverted out, and the remainder passes through. The diversion is based on a user-specified relationship between inflow and diverted flow. The diverted flow can be brought back into the basin network at a hydrologic element that is computationally downstream from the point of diversion.

Source. A source is an element with which a discharge hydrograph is imported into the basin network. The element might be used to import an observed hydrograph, or a hydrograph generated in a prior simulation. Data for a source must be entered via **Gage Data - Discharge**, which is accessed from **Edit** on the menu bar of the PROJECT DEFINITION screen.

Sink. A sink is an element for which there is an inflow but no outflow.

Connecting Hydrologic Elements

Part of the information required for a hydrologic element is the name of the downstream element to which it is connected. This information is implicit in the connections established on the basin schematic. When two or more elements are connected to the same downstream element, contributions from the upstream elements will be combined prior to performing computations for the downstream element. You have two alternatives for dealing with such connections, as illustrated in Figure 5.3.

The first is to insert a junction between the upstream elements (subbasins, in this case) and the downstream element. The second alternative is simply to connect the upstream elements to the downstream element. Simulation results will be the same for the two alternatives; the use of a junction element only affects availability of information for output displays. When a junction element is used, a graph will be produced automatically that shows the inflow hydrographs and the hydrograph of combined flow. Also an entry for the junction will appear in tabular summaries of simulation results. If a junction element is not used, the graph and table entry will not be generated. The combined inflow, however, will be shown for the downstream element.

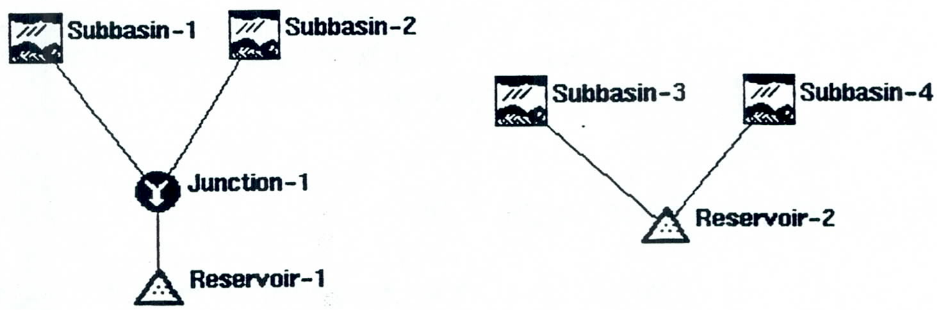


Figure 5.3 Connections With and Without a Junction

Creating a Basin Schematic

Figure 5.2 shows the SCHEMATIC screen, primary uses of which are to configure a basin model with icons that represent hydrologic elements; access data editors; and access displays of simulation results. Prior to creation of a basin schematic, it is useful to set default computation methods so that as hydrologic elements are created, the user-selected methods will be the first to appear in element editors. Select **Basin Model Attributes** from **File** on the menu bar of the SCHEMATIC screen. On the BASIN MODEL ATTRIBUTES screen, select the desired default methods.

To configure a basin model, select an element from the palette on the left edge of the SCHEMATIC screen. With the left mouse button depressed, drag an image of the icon to the desired location on the schematic background and release the mouse button. Repeat this procedure for other basin elements.

Establish flow links between elements with one of the following methods:

(1) Click an element icon with the right mouse button and select **Connect Downstream**. Place the mouse cursor, which has changed to a cross, over the element for the "downstream" end of the connection, and click the left mouse button.

(2) A river reach icon can be connected by dragging its "handles" onto the elements to which it is to be connected. First select the river reach icon by clicking it with the left mouse button. The reach handles (small squares at either end) will be highlighted. Drag the handle at the upper end over the icon for the element that will produce inflow to the reach. Drag the opposite handle over the icon for the element that will receive reach outflow.

(3) The diverted flow from a diversion can be linked to any element that is downstream (computationally) from the diversion. Establish thediversion link with **Connect Diversion**, which is an option on the pop-up menu for diversion icons. (The pop-up menu is obtained by right-clicking the diversion icon.)

Data Entry for Hydrologic Elements

Two types of editors are provided for data entry: single element and global. Both are accessed from the basin schematic.

Use of a Single-Element Editor

You can access a single-element editor by double-clicking the left mouse button with the cursor placed over an element icon. The editor can be used to enter all data associated with the element. Figure 5.4 shows an editor for a subbasin. This editor contains a "notebook" (having the appearance of a set of file folders), with "folders" for entering loss rate, transform and baseflow data.

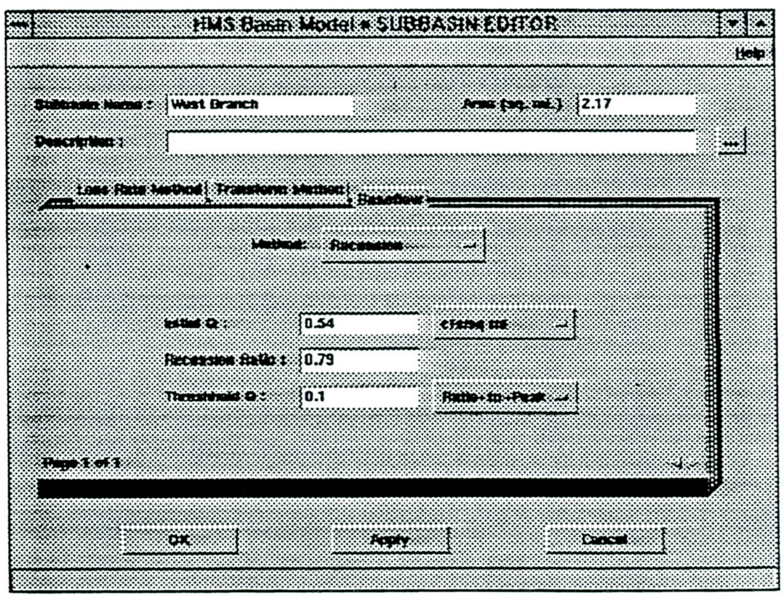


Figure 5.4 Subbasin Editor

When an editor is first accessed, a default name for the element (e.g., "Subbasin-1") is provided. You can accept the default name or provide a different one. You can also optionally provide an element description. Where alternative computational methods are available, the method that first appears is the default method associated with the basin model. However, any one of the available methods can be selected. Default methods are set on the BASIN MODEL ATTRIBUTES screen, which is accessed from **Basin Model Attributes** under **File** on the menu bar of the SCHEMATIC screen. Project-level method defaults are set on the PROJECT DEFAULTS screen, which is accessed from **Default Preferences** under **Options** on the PROJECT DEFINITION screen. Defaults set here control the initial settings for new basin models that become part of the project.

Use of Global Editors

A global editor provides capability to input or edit data of a specific type for all hydrologic elements to which the type applies. For example, the **Subbasin Area/Baseflow** editor would contain entries for all subbasins in the basin model. Similarly, the **Muskingum Routing** editor (Figure 5.5) would contain entries for all river reaches for which the Muskingum routing method has been specified. The global editors are intended to facilitate data entry and to provide a means for comparing data values across elements. The global editors are accessed from **Data-Eds.** on the menu bar of the SCHEMATIC screen.

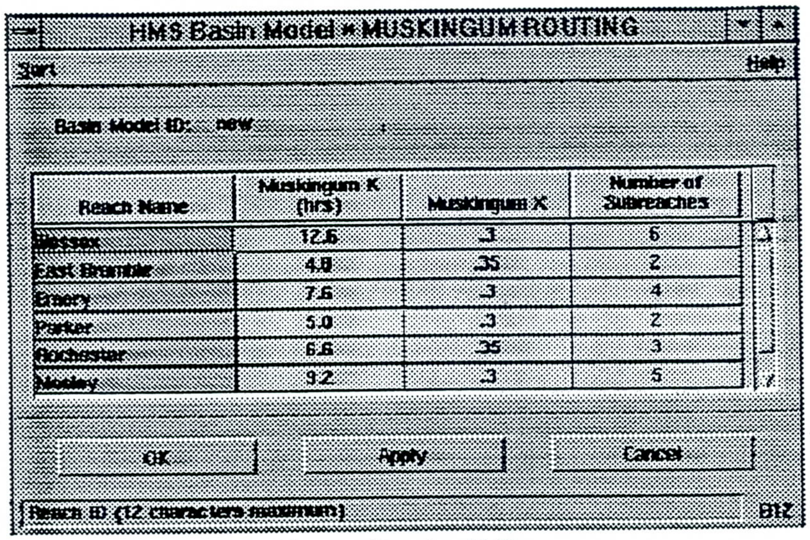


Figure 5.5 Muskingum Routing Editor

Observed Hydrograph

Observed-hydrograph data can be associated with a hydrologic element to enable tabular and graphical comparisons with simulated data. The data must first be incorporated in the project, which is accomplished by accessing **Gage Data - Discharge** from **Edit** on the PROJECT DEFINITION screen (see "Entering Gaged Data" in Chapter 4).

To establish an association of an observed hydrograph with a hydrologic element, select the element on the SCHEMATIC screen, and with the right mouse button, select **Observed Flow**. An OBSERVED FLOW screen will be displayed, from which you can select the gage i.d. corresponding to the observed hydrograph. When an association with an observed hydrograph has been made, the observed data are shown in both tabular and graphical displays of computational results for the element. The observed hydrograph can also be used for parameter optimization (see Chapter 10).

Basin Map

The basin schematic illustrated in Figure 5.2 includes a map background showing basin boundaries and the stream system. Use of a map background is optional. A map background is associated with a basin model by use of the **Basin Model Attributes** option under **File** on the menu bar. A map file is a text file that contains boundary and stream coordinates. Appendix B contains information on the content and creation of such a file. You can use toolbar buttons to toggle (on or off) basin boundaries and the stream delineation.

Basin Model File Options

Basin model data can be saved to persistent storage (i.e., a basin model file) by selecting **Save** from **File** on the menu bar in the SCHEMATIC screen, or by saving a project in the main (PROJECT DEFINITION) screen. The various options under **File** in the SCHEMATIC screen are as follows (Table 5.1):

Table 5.1 File Options

File menu command	**Description**
New	Closes the current basin model, prompting you to save any changes. Prompts for the name and description of the new basin model. Permits specification of the directory where the basin model file will be stored.
Open	Closes the current basin model, prompting you to save any changes. Provides a list from which to select an existing basin model. Permits opening a basin model that is not part of the current project.
Save	Saves all data for the current basin model.
Save As	Saves a copy of the current basin model with a new name.
Rename	Renames current basin model.
Delete	Deletes current basin model. Removes reference to the basin model from the list of basin models.

CHAPTER 6

Entering and Editing Precipitation Model Data

This chapter describes how you can enter and edit data to define the precipitation input for a watershed. The several options for defining precipitation include capability to process "point" data from gages, gridded data such as is obtained from radar, and generalized data associated with frequency-based or Standard Project design storms.

Getting Started

To initiate a new precipitation model, select **Precipitation Model - New** from **Edit** on the menu bar of the main (PROJECT DEFINITION) screen. This will open the NEW PRECIPITATION MODEL screen (Figure 6.1). You can edit or accept the default model name. A model description may optionally be entered. Press **OK** to institute the new model. The METHOD SELECT screen (Figure 6.2) will open. Select the desired method and press **OK**. A screen for the selected method will open.

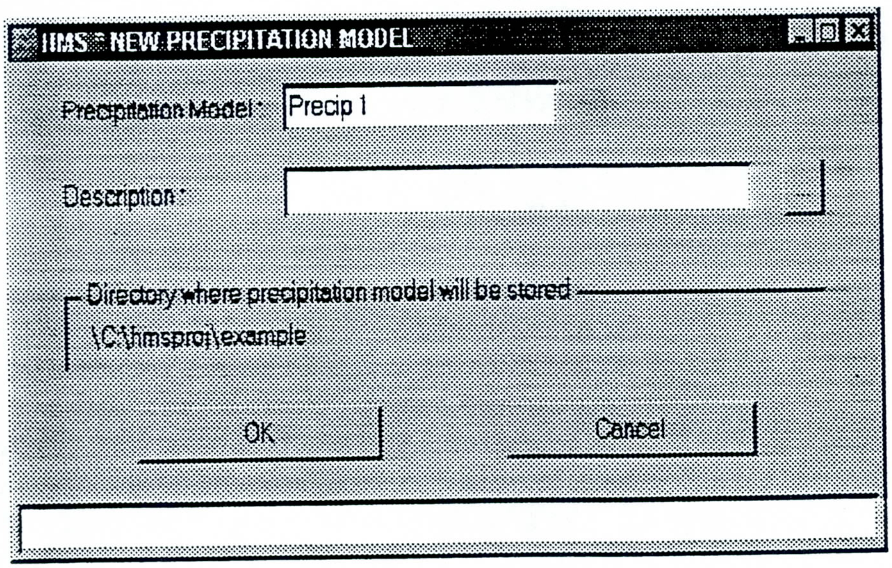


Figure 6.1 New Precipitation Model

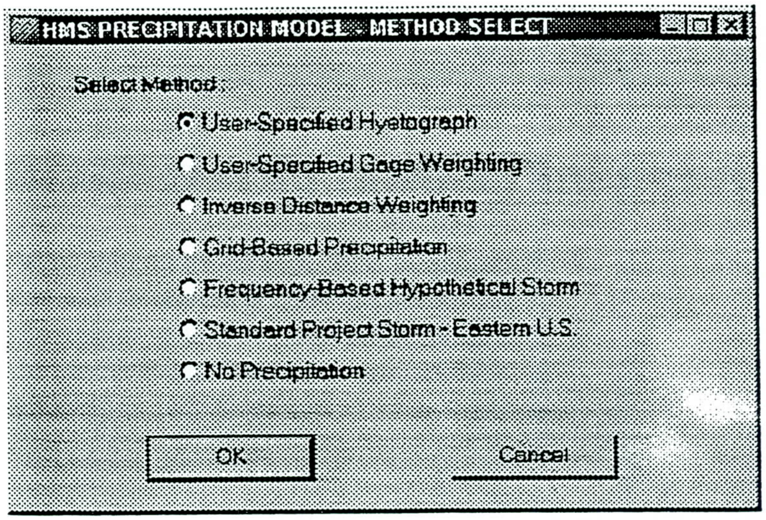


Figure 6.2 Method Select

Methods

The function of a precipitation model is to produce precipitation hyetographs for each subbasin in a basin model. You can use any one of the six methods listed in Figure 6.2 and described in the following sections. For some applications, precipitation data is not required. For example, a basin model could consist of a source and a river reach or reservoir. The method labeled "No Precipitation" should be used to define a precipitation model in this case.

User-Specified Hyetograph

Gaged or previously-calculated precipitation hyetographs may be utilized for runoff simulation. Figure 6.3 illustrates the USER-SPECIFIED HYETOGRAPH screen. Subbasins are added from the basin model by using the **Add** button. "Gage" ID's are then entered from a drop-down list that appears once you select the gage field. **Precipitation data must have been previously entered prior to referencing this data in the USER-SPECIFIED HYETOGRAPH screen** (see Entering Gage Data, Chapter 4).

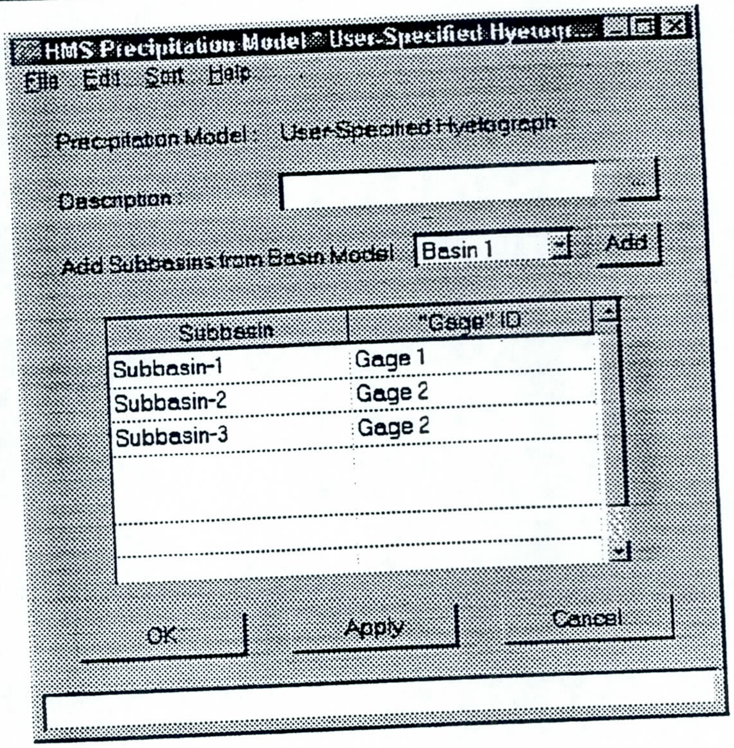


Figure 6.3 User-Specified Hyetograph

User-Specified Gage Weights

With this option, weighting factors (Thiessen-type) are specified for gaged precipitation to calculate spatially-averaged precipitation for subbasins. Figure 6.4 shows the USER-SPECIFIED GAGE WEIGHTS screen which contains a "notebook" with three sections. The first section, labeled *Gages*, provides for specification of a gage ID, gage type, total storm depth, and index precipitation for each precipitation gage (both recording and non-recording).

The second section, *Subbasins*, provides for the addition of subbasins to the precipitation model, and allows for specification of index precipitation for each subbasin. The optional specification of index precipitation for subbasins and precipitation gages enables adjustment for bias in gage-precipitation values. The third section, *Weights*, specifies both the total-storm weight and temporal-distribution weight for each gage.

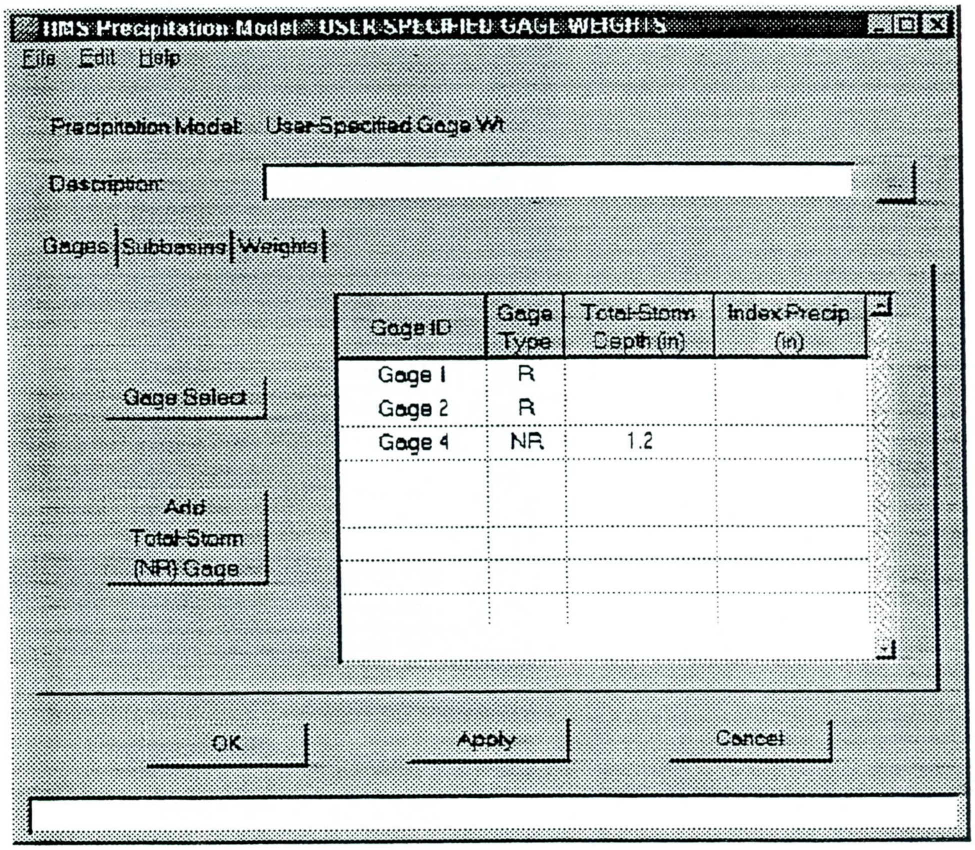


Figure 6.4 User-Specified Gage Weights (*Gages*)

Gages for total storm precipitation (i.e. non-recording gages) can be entered in the *Gages* section by selecting the **Add Total-Storm (NR) Gage** button and entering a gage name and appropriate storm depth. Non-Recording gages entered in this way can only be accessed by the current precipitation model. Recording gage ID's are obtained by selecting them from the GAGE SELECTION LIST, which is accessed by clicking the **Gage Select** button. A total-storm depth is not normally entered for recording gages, but can optionally be added. When total-storm depth is specified for recording gages, the individual precipitation values will be scaled so that the total-storm rainfall will equal the specified amount. **Recording precipitation gage data must have been previously entered before it can be referenced via the Gage Select button** (see Entering Gaged Data, Chapter 4). The gage type for both recording and non-recording gages is entered automatically.

In the *Subbasins* section (Figure 6.5) the subbasin names are entered and the number of gages associated with each subbasin is shown. Subbasins are added from the basin model by clicking the **Add** button. **The addition of subbasins from a basin model must be done before the subbasins can be referenced in the *Weights* section.**

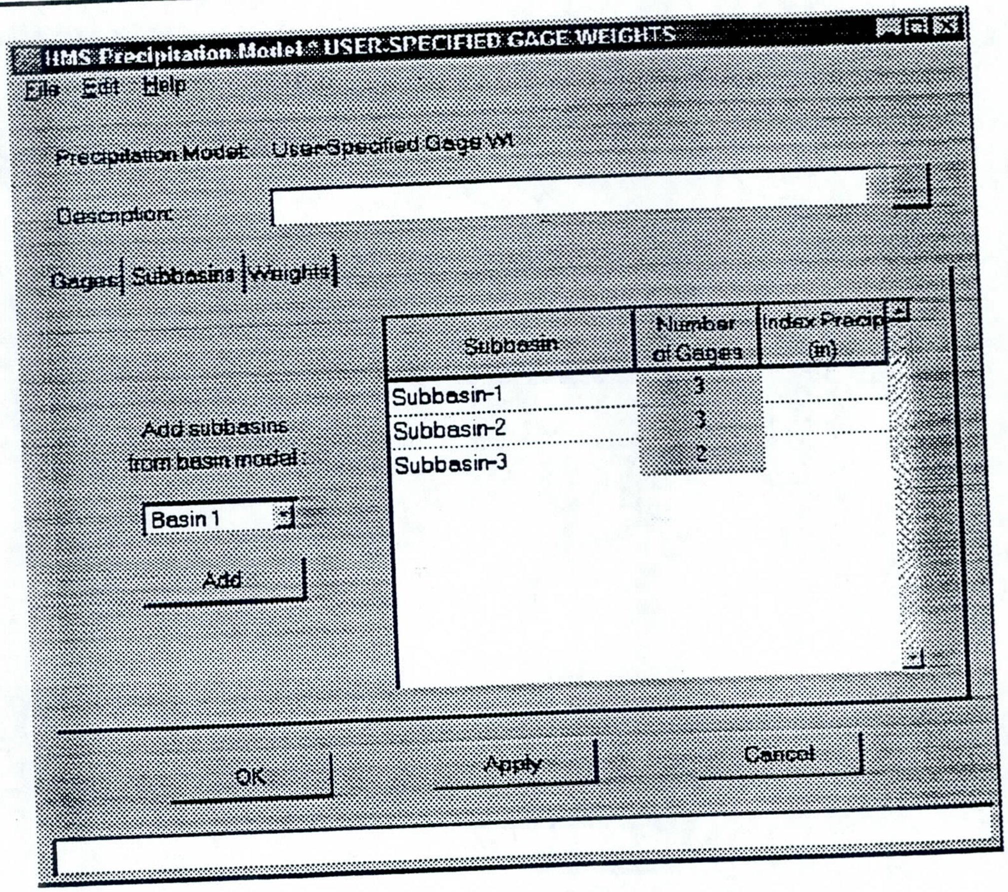


Figure 6.5 User-Specified Gage Weights (Subbasins)

Index precipitation (e.g., normal annual) amounts can optionally be entered for both precipitation gages and subbasins. If such data is entered, it will be used to apply a bias adjustment to gage precipitation.

The *Weights* section (Figure 6.6) displays information for a single subbasin at a time. A drop-down list allows selection of a subbasin that has previously been specified in the *Subbasins* section. Gage ID, type and associated weight, are entered in the table. When a gage ID field is selected, a drop-down list appears that shows the gages previously entered in the *Gages* section. The gage type is either "R" for recording, or "NR" for non-recording, and is entered automatically. The Total Storm Gage Weight is applicable to both recording and non-recording gages, whereas the Temporal Distribution Gage Weight applies only to recording gages. The weights of each type are normalized to sum to 1 if the entered values do not do so.

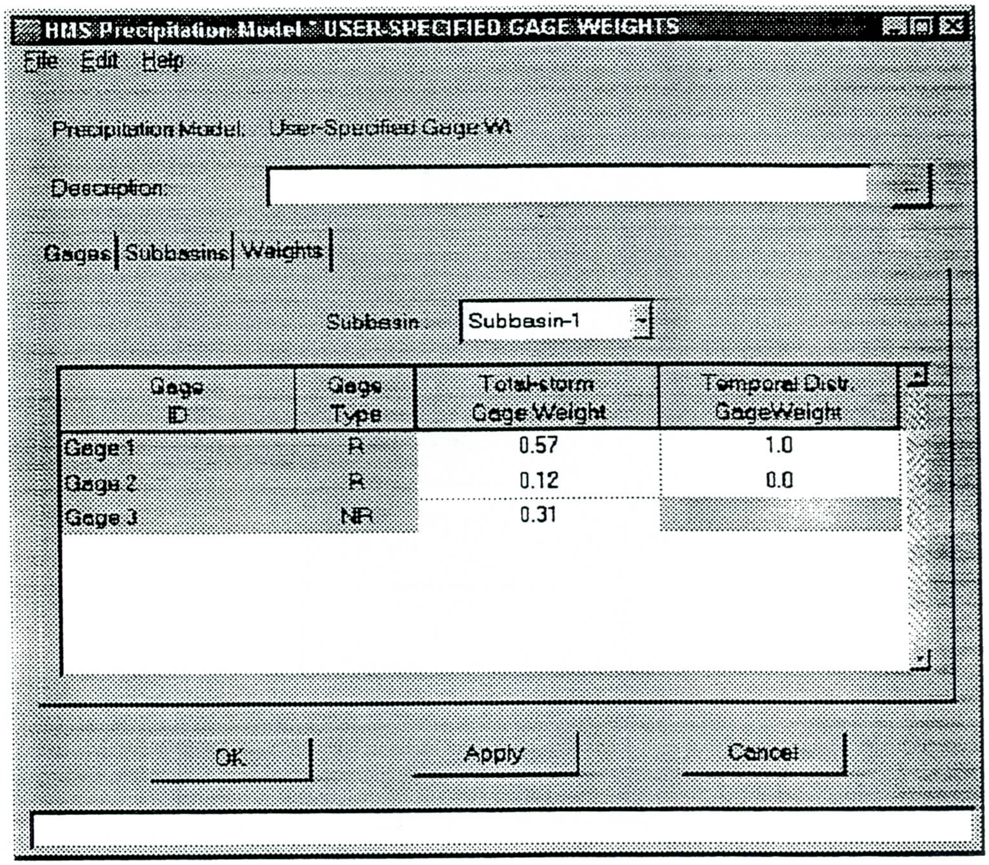


Figure 6.6 User-Specified Gage Weights (*Weights*)

Inverse-Distance Weighting

This option provides for automated determination of weighting factors for gaged precipitation based on inverse distance-squared weighting (HEC, 1989). The factors may vary from time interval to time interval depending on the availability of gaged data. Figure 6.7 shows the INVERSE-DISTANCE WEIGHTING screen, which contains a "notebook" with three sections. The first, *Gages*, provides for the specification of gage ID, gage type, latitude and longitude, and index precipitation. The second section, *Subbasins*, assigns subbasin names from the basin model. The *Subbasin Nodes* section allows for defining nodes, weights and longitude/ latitude for these nodes, and index precipitation.

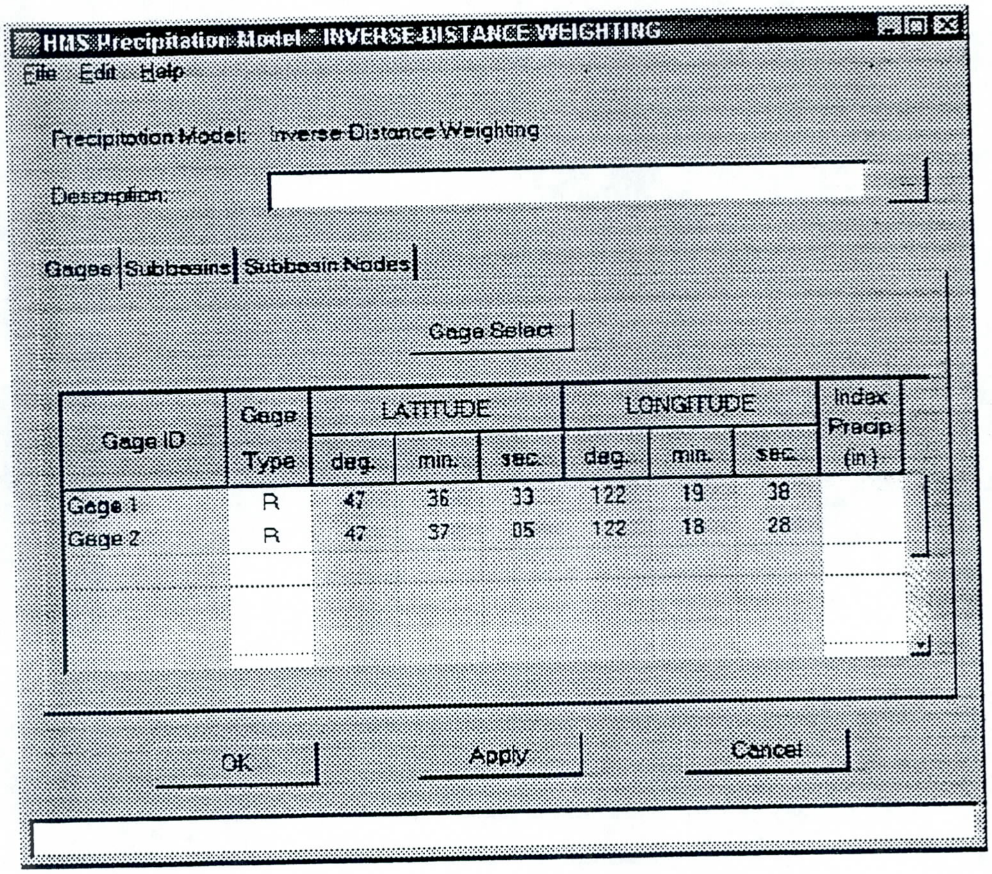


Figure 6.7 Inverse-Distance Weighting (*Gages*)

The gage ID, latitude, and longitude are entered automatically in the Gages section when gages are selected from the list accessed with the **Gage Select** button. **Gage data must have been previously entered prior to referencing them in the INVERSE-DISTANCE WEIGHTING screen** (see Entering Gage Data, Chapter 4). The gage type can be toggled between recording (R) and non-recording (NR) by clicking in the Gage Type field.

The *Subbasins* section is where subbasin names are entered and where the number of subbasin nodes are shown. The **Add** button is provided to enable subbasins previously specified for a basin model to be entered in the Subbasin Name column. **Subbasin names must be entered in the *Subbasins* section before they can be referenced in the *Subbasin Nodes* section.**

The *Subbasins Nodes* section (Figure 6.8) displays information for a single subbasin at a time. A drop-down list enables selection of a subbasin that has previously been specified in the *Subbasins* section. A subbasin node is created by entering a node identifier in the Node field. Enter the weight to be applied to the node, and the node's latitude and longitude. Also, you can optionally enter an index precipitation.

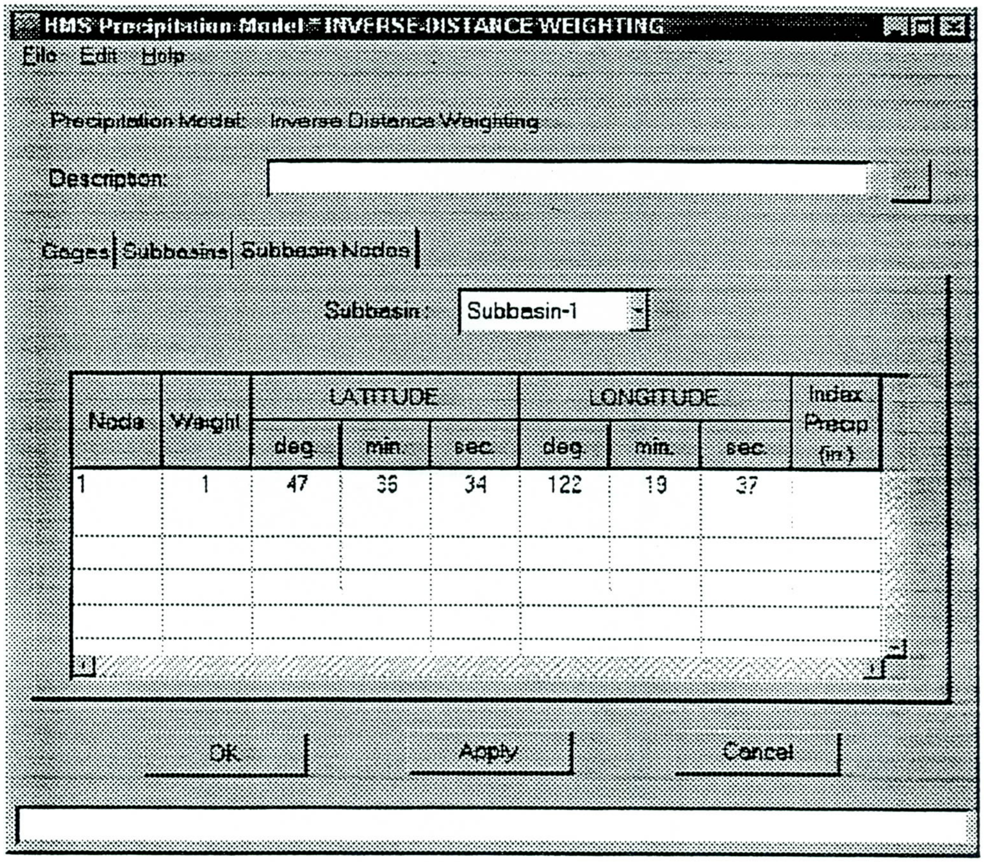


Figure 6.8 Inverse-Distance Weighting (*Subbasin Nodes*)

Gridded Precipitation

This option enables specification of information required for retrieving gridded (e.g., radar-based) precipitation data from a DSS file. The GRIDDED PRECIPITATION screen is shown in Figure 6.9. The **Browser** button accesses a file browser with which the DSS file can be selected. A DSS record contains gridded data for an array of grid cells for a single time interval.

It is required that all cells associated with a basin model be contained in the same DSS record (for a given time interval), and that pathnames be consistent. Therefore, it is only necessary to specify one set of A-, B- , C- and F-parts of a pathname. The C-part will generally be "PRECIP". You can choose whether or not to automatically replace missing data with zero values. If you choose not to replace missing values, a simulation will terminate when missing data is encountered. A time shift may be specified if computations are to be performed on a local time scale (rather than Universal Coordinated Time associated with radar-based precipitation).

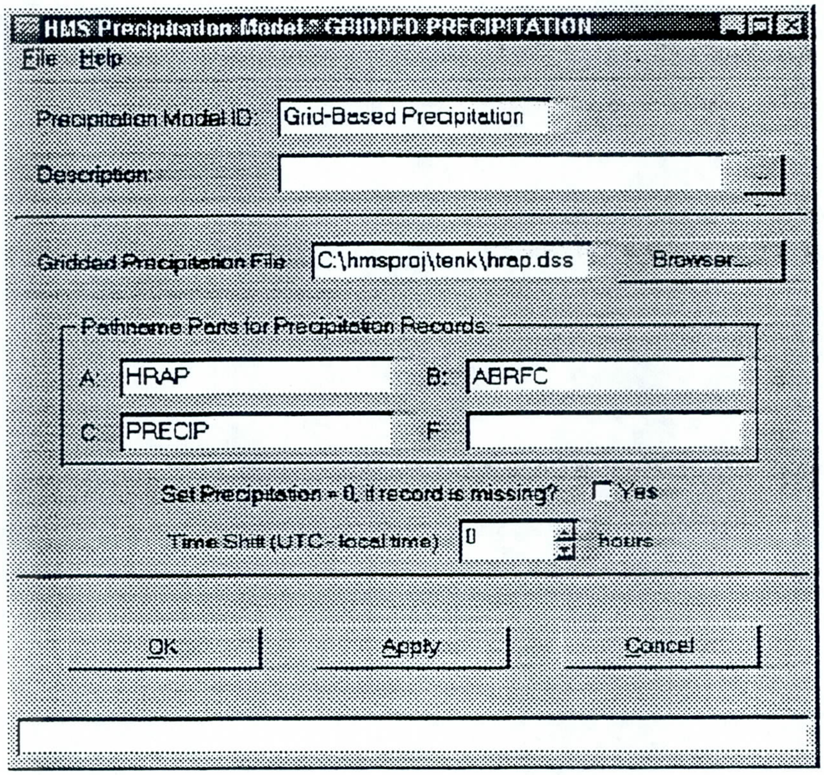


Figure 6.9 Gridded Precipitation

Frequency-Based Design Storm

This option provides capability to generate subbasin precipitation based on frequency-based criteria such as are contained in NWS Technical Paper 40 (National Weather Service, 1961) and NOAA Atlas 2 (National Weather Service, 1973). The FREQUENCY-BASED STORM screen is shown in Figure 6.10. Required input are the storm frequency, storm size (if different from subbasin areas), annual or partial duration series, storm duration, duration of the peak precipitation intensity (generally the time interval to be used for simulation), and precipitation depths for various durations.

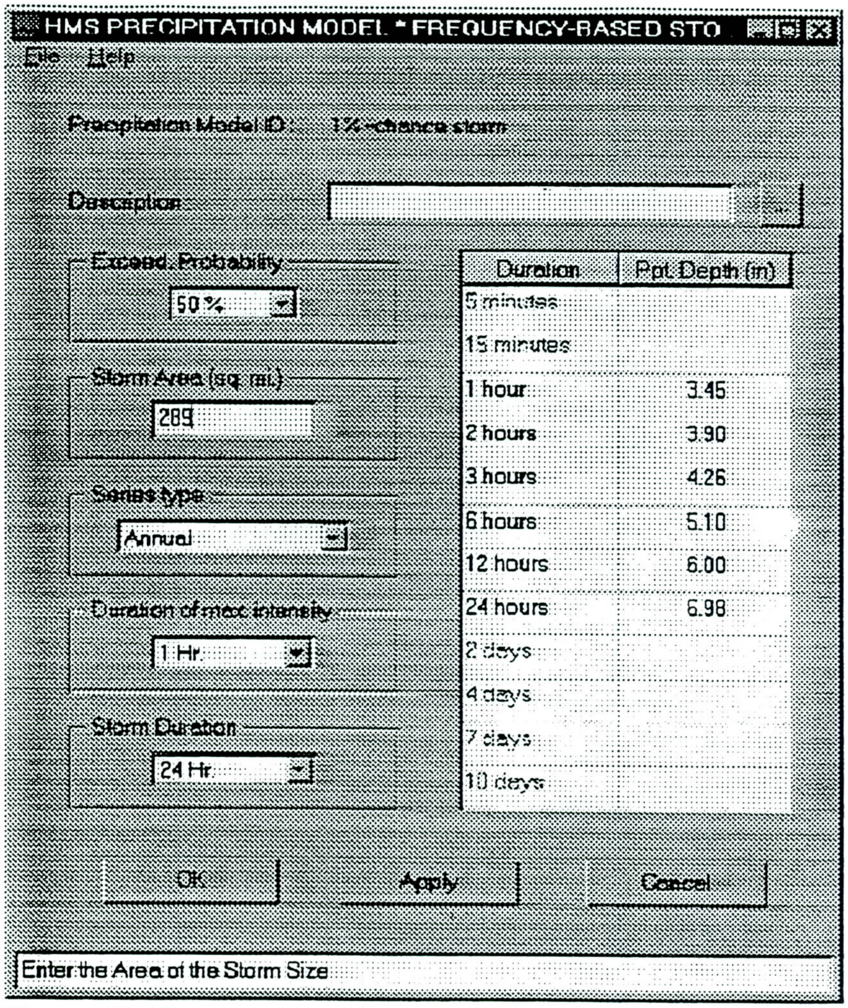


Figure 6.10 Frequency-Based Storm

Standard Project Storm - Eastern U.S.

This option provides capability to generate a Standard Project Storm using Corps of Engineers' criteria for the eastern United States (Corps of Engineers, 1965). Figure 6.11 shows the STANDARD PROJECT STORM screen. Required values are index precipitation, storm size, type of temporal distribution, and a transposition factor for each subbasin.

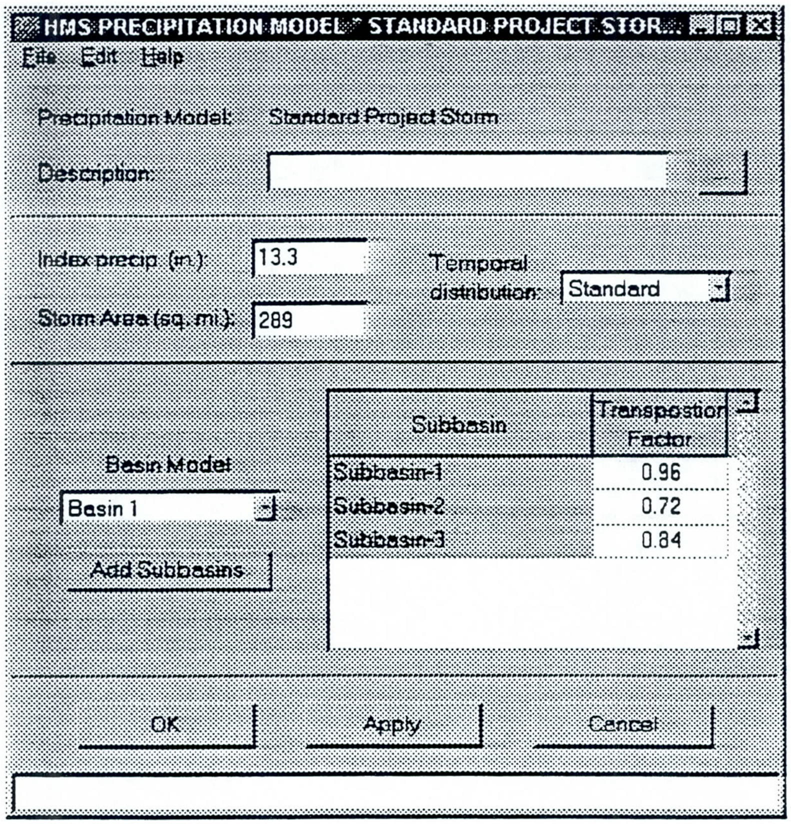


Figure 6.11 Standard Project Storm

Precipitation Model File Options

Precipitation model data are saved to persistent storage (i.e., a precipitation model file) by selecting **Save** from **File** on the menu bar in the various precipitation model screens, or when a project is saved in the main (PROJECT DEFINITION) screen. The various options under **File** in the precipitation model screens are as follows (Table 6.1):

Table 6.1 Precipitation Model File Options

File menu command	Description
New	Initiates a new precipitation model.
Open	Opens an existing precipitation model.
Save	Saves all data for the current precipitation model.
Save As	Saves current precipitation model with a new name (without deleting an existing model).
Rename	Renames (and saves) current precipitation model.
Delete	Deletes current precipitation model. Removes reference to the precipitation model from the list of precipitation models.

CHAPTER 7

Entering and Editing Control Specifications

This chapter describes how you can enter and edit control specifications, which are required along with a basin model and precipitation model to comprise a simulation run.

Getting Started

To initiate new control specifications, select **Control Specifications - New** from **Edit** on the menu bar of the main (PROJECT DEFINITION) screen. This will open the NEW CONTROL SPECIFICATIONS screen (Figure 7.1). You can edit or accept the default name. A description may optionally be entered. Press **OK** to institute the new control specifications. The CONTROL SPECIFICATIONS screen (Figure 7.2) will open.

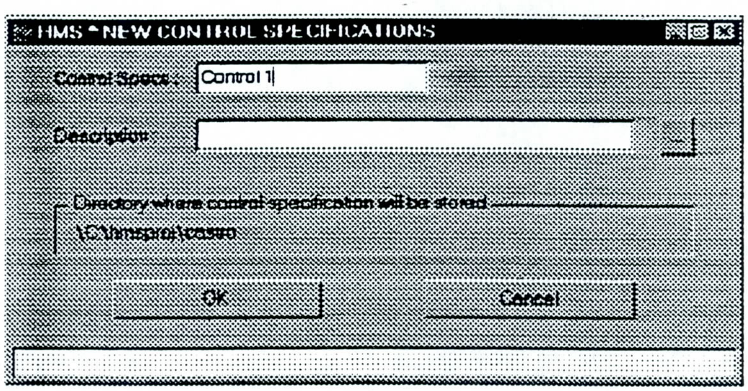


Figure 7.1 New Control Specifications

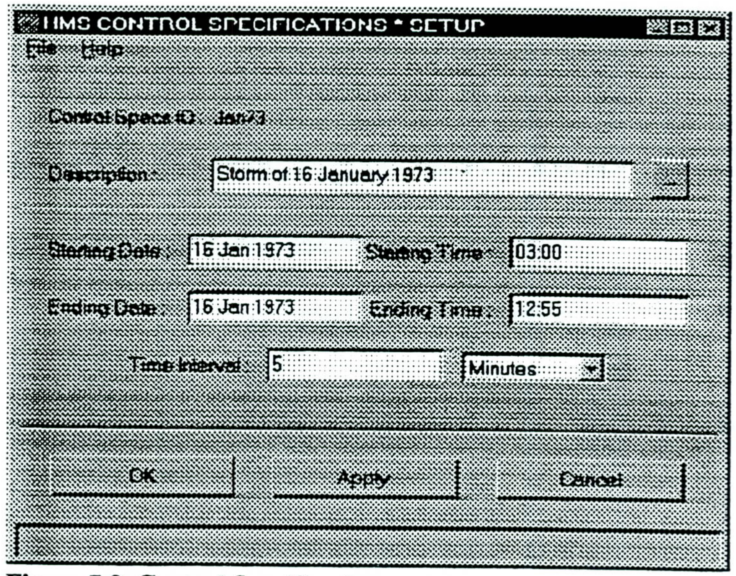


Figure 7.2 Control Specifications

Control Specifications

The function of control specifications is to set the starting and ending dates and times, and the time (computation) interval. Future versions of HEC-HMS will provide capabilities to specify output alternatives and initial values of state variables, such as soil moisture levels or reservoir storage.

A variety of styles are available for entering starting and ending dates. The month designation is not case sensitive. Months may be specified with the first three characters of the month name. The following are examples of valid entries for dates:

01Mar72
1 March 1972
March 1, 1972

Time is specified as a four-digit number representing 24-hour clock time. A colon after the first two digits is optional. The following are examples of valid entries for times:

0100
13:30

File Options

Control specifications are saved to persistent storage (i.e., a control specifications file) by selecting **Save** from **File** on the menu bar of the CONTROL SPECIFICATIONS screen, or when a project is saved in the main (PROJECT DEFINITION) screen. The various options under **File** in the CONTROL SPECIFICATIONS screen are shown in table 7.1:

Table 7.1 Control Specifications File Options

File menu command	Description
New	Provides access to NEW CONTROL SPECIFICATIONS screen.
Open	Provides selection list for opening a different control specifications.
Save	Saves the current control specifications.
Save As	Saves current control specifications with a new name (without deleting an existing control specifications).
Rename	Renames (and saves) current control specifications.
Delete	Deletes current control specifications. Removes reference to the control specifications from the list of control specifications.

CHAPTER 8

Performing Simulations

This chapter describes how you can create and execute a simulation *run*, and view results.

Simulation Manager

A *run* consists of a basin model, a precipitation model, and control specifications. It is created with the Simulation Manager, which is accessed by choosing **Simulation Manager** from **Simulate** on the menu bar of the SCHEMATIC screen. Figure 8.1 shows the SIMULATION MANAGER screen.

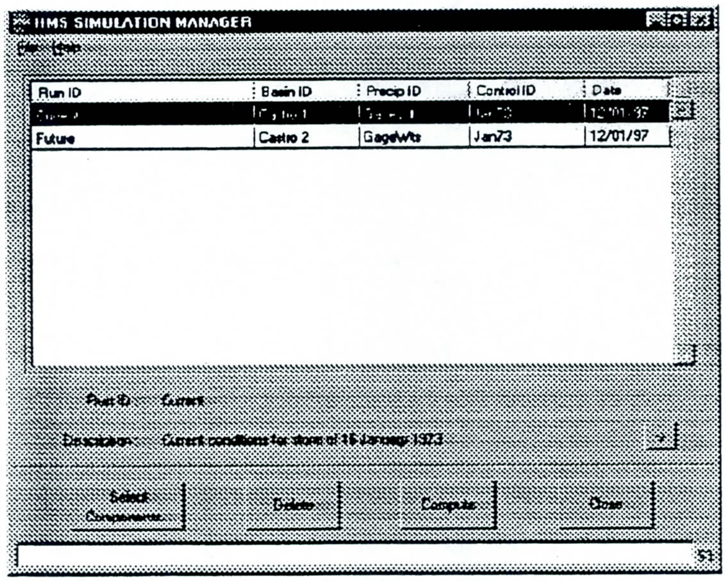


Figure 8.1 Simulation Manager Screen

The SIMULATION MANAGER screen lists the names of existing runs and their components, and the most recent date that the run was executed. To create a new run and add it to the displayed list, press the **Select Components** button on the lower left. This will open a RUN CONFIGURATION screen, as shown in Figure 8.2. The RUN CONFIGURATION screen may also be accessed directly from the **Simulate** menu.

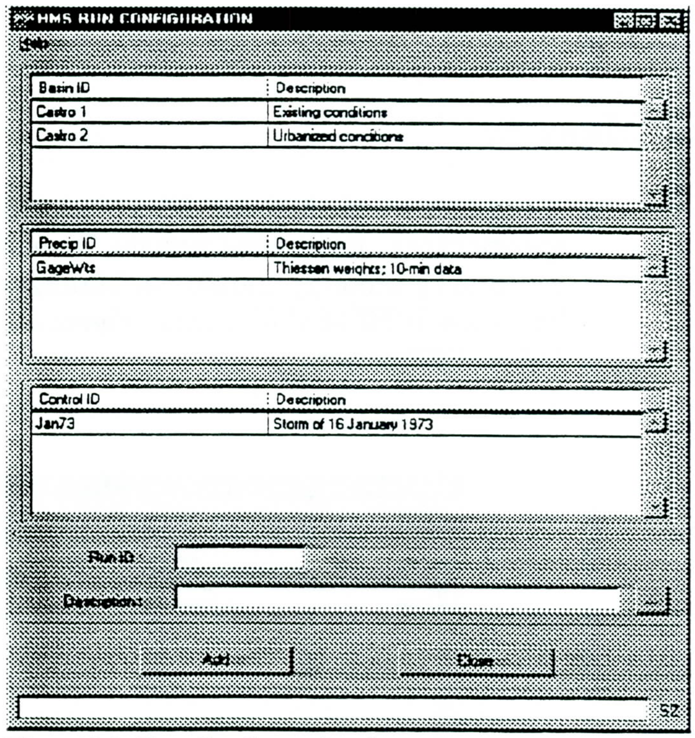


Figure 8.2 Run Configuration Screen

The RUN CONFIGURATION screen lists all basin models, precipitation models, and control specifications that are associated with the current project. To create a run, select one of each type of data set with the left mouse button. The default Run ID can be edited or accepted, and an optional description can be entered. Press the **Add** button to add the Run to the list of runs in the SIMULATION MANAGER screen. Repeat this procedure to create additional runs, if desired, and press the **Close** button to exit the screen.

To delete a run, select it in the SIMULATION MANAGER screen and press **Delete**. Deleting a run removes its identity and configuration from the SIMULATION MANAGER, but does not delete any of the constituent components.

To execute a run, select it in the SIMULATION MANAGER screen and press **Compute**. Additional runs may be executed before exiting the SIMULATION MANAGER. To exit the SIMULATION MANAGER, press the **Close** button.

Simulations may also be performed directly from the SCHEMATIC screen. The name of the *active run* appears on the lower right corner of the SCHEMATIC screen, and inside the brackets following **Compute** on the **Simulate** menu. The active run may be computed by selecting **Compute <RUN ID>** from the **Simulate** menu. The active run may also be computed by pressing the button on the far right of the toolbar.

A list of the four most recently executed runs appears on the bottom of the **Simulate** menu. You can make one of these runs become the active run by clicking on it. The corresponding basin model is displayed on the SCHEMATIC screen, and the run can be executed from the **Simulate** menu, or by pressing the **Compute** button on the toolbar.

If *none* is shown as the active run in the bottom right corner of the SCHEMATIC, or there is no run id shown after **Compute** on the **Simulate** menu, the user must select a run to be the active run before simulation can be performed directly from the SCHEMATIC. Executing a run from the SIMULATION MANAGER will cause that run to become the active run. If more than one run is executed in the SIMULATION MANAGER, then the last run to be executed will be the active run.

Viewing Results

The results of the active run can be viewed and printed in tabular or graphical form. Three types of tabular data are available: (1) a master summary table with a single line of information for each hydrologic element, (2) an element summary table with information tailored to the element type, and (3) an element time series table that shows results for each time interval. A graphical display is available for each element type.

To view tabular or graphical displays of results, return to (or open) the SCHEMATIC screen. You can access the master summary table from **View** on the menu bar, or with a button (second from right) on the toolbar. Figure 8.3 shows a master summary table. Individual-element summary and time-series tables are accessed with **View Results : Summary Table** and **View Results : Time Series** from the pop-up menu for an element. Figure 8.4 shows a summary table for a junction for which an observed hydrograph is available. Figure 8.5 shows a time-series table for a subbasin. Graphical displays are similarly accessed with **View Results : Graph**. Figure 8.6 shows a graphical display for a subbasin.

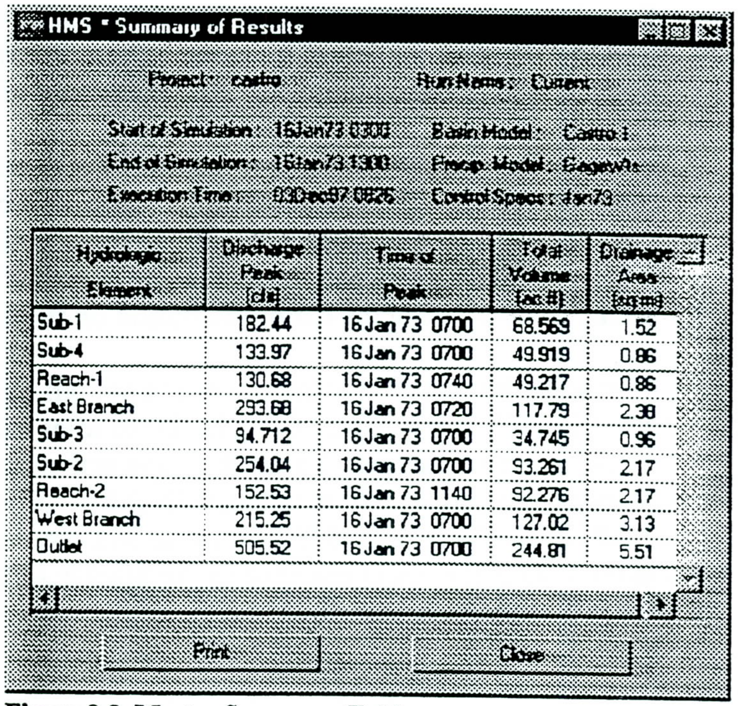


Figure 8.3 Master Summary Table

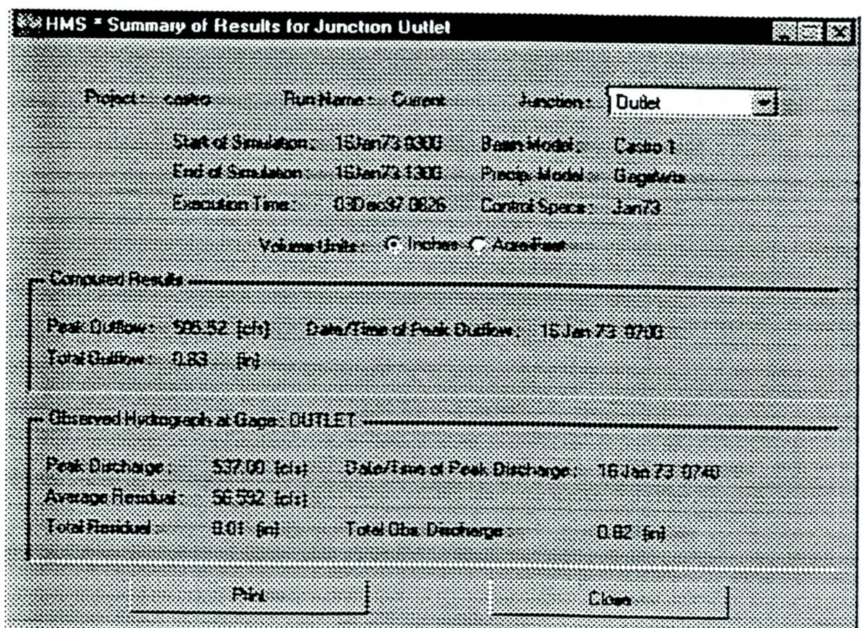


Figure 8.4 Junction Element Summary Table

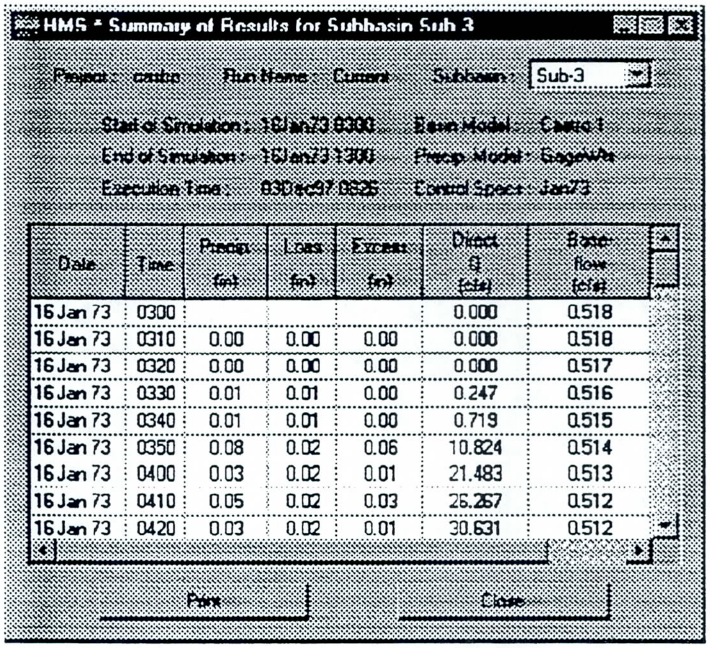


Figure 8.5 Subbasin Element Time Series Table

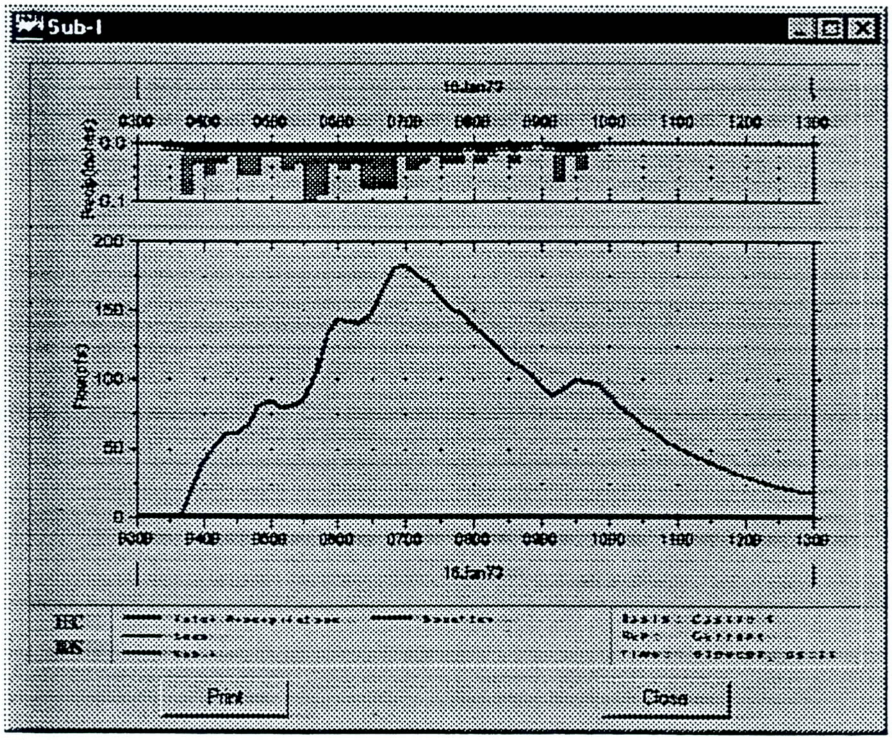


Figure 8.6 Subbasin Element Graph

CHAPTER 9

Example Application

Chapter 3 provides an overview of steps involved in a typical application of HEC-HMS. This chapter illustrates application of these steps.

Problem

Data for this example are for the 5.51 sq. mi. Castro Valley basin located in northern California. Figure 9.1 shows boundaries of the four subbasins which comprise the basin. Data from three precipitation gages (located at Proctor School, Sidney School, and the Fire Dept.) are for a storm which occurred on January 16, 1973. The purpose of the analysis is to determine the effects of anticipated future urbanization on the runoff response to the January 1973 storm. Application of HEC-HMS will involve creating a project, entering gaged data, creating basin and precipitation models, setting control specifications, creating and executing runs, and viewing results.

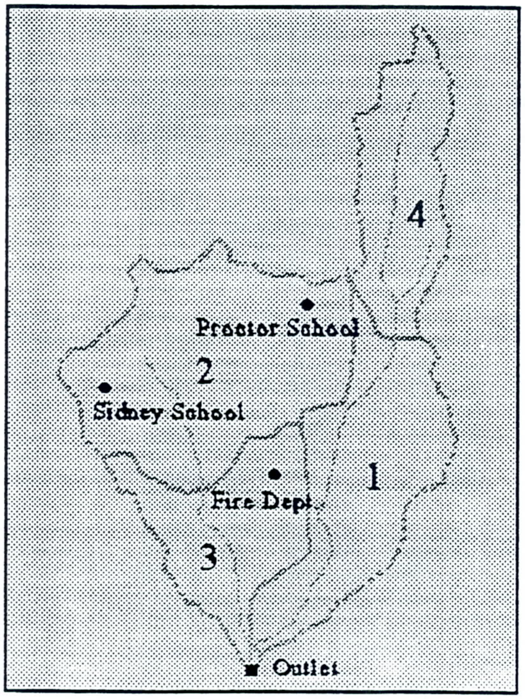


Figure 9.1 Castro Valley Creek Basin

Data for each of the four subbasins are listed in Table 9.1. The data include the subbasin area, percent imperviousness, and values for parameters that define losses, the runoff transform and baseflow.Routing criteria for the river reaches are listed in Tables 9.2 (a) and (b).

Table 9.1 Subbasin Characteristics/Parameters

Subbasin		Loss Rates			Transform		Baseflow		
I.D.	Area	Imperviousness	Initial Loss	Constant Loss Rate	Snyder r t_p	Snyder C_p	Initial Q	Threshold Q	Recession Constant*
	sq. mi.	%	*in.*	*in./hr.*	*hr.*		*c.f.s./sq. mi.*	*ratio to peak*	
1	1.52	8	0.02	0.14	0.28	0.16	0.54	0.1	0.79
2	2.17	10	0.02	0.14	0.20	0.16	0.54	0.1	0.79
3	0.96	15	0.02	0.14	0.17	0.16	0.54	0.1	0.79
4	0.86	2	0.02	0.14	0.20	0.16	0.54	0.1	0.79

*Ratio of baseflow discharge to baseflow discharge one day earlier

Table 9.2 (a) Routing Criteria

Reach	From	To	Method	Subreaches (5 min. time step)	Routing Parameters
1	Subbasin 4	Castro Valley Creek Outlet	Muskingum	7	travel time = 0.6 hrs. x = 0.2
2	Subbasin 2	Castro Valley Creek Outlet	Modified Puls	4	initial cond.: outflow = inflow outflow vs. storage below

Table 9.2 (b) Outflow vs. Storage for Reach 2

Storage (ac.ft.)	0	0.2	0.5	0.8	1	1.5	2.7	4.5	750	5000
Outflow (c.f.s.)	0	2	10	20	30	50	80	120	1500	3000

Table 9.3 shows Thiessen-polygon weights for total-storm rainfall for the four subbasins. Total-storm rainfalls measured by the Proctor School and Sidney School gages were 1.92 in. and 1.37 in., respectively. Storm rainfall is to be distributed in time using the temporal pattern of incremental rainfall from the Fire Dept. gage. For this example, precipitation data for the Fire Dept. gage is available in the DSS file *Castro.dss* with the pathname

/CASTRO VALLEY /FIRE DEPT./PRECIP-INC/16JAN1973/10MIN/OBS/

Table 9.3 Total-storm Gage Weights

Subbasin	Proctor School Gage	Fire Dept. Gage	Sidney School Gage
1	0.2	0.8	
2	0.33	0.33	0.33
3		0.8	0.2
4	1		

Creating the Project

To create the project, select **New Project** from **File** on the main (PROJECT DEFINITION) screen. Specify the name and description of the project in the NEW PROJECT screen (Figure 9.2). Enter `Castro` for the project name and `Castro Valley urban study` for the description. By default, files related to the new project will be stored in a directory labeled "Castro", a subdirectory to the working or current directory. Select **OK**. The project name and description are added to the project list (projects.hms).

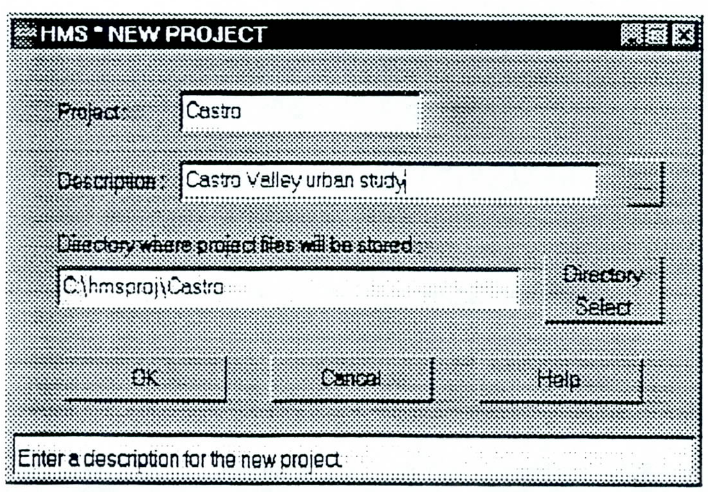


Figure 9.2 New Project

Setting Project Defaults

To set the defaults for the new project to the desired unit system and computational methods, select **Default Preferences** from **Options** on the PROJECT DEFINITION screen. Select **English**, **Initial/Constant**, **Snyder UH**, and **Muskingum** as shown in Figure 9.3. Select **OK** to save the defaults.

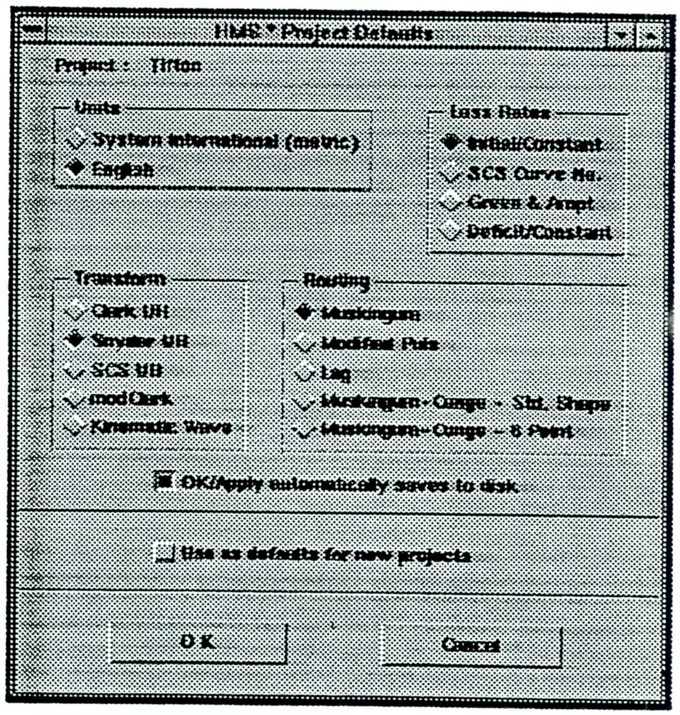


Figure 9.3 Project Defaults

Entering Gage Data

Two sets of gaged data will be entered. The first set is incremental precipitation for the Fire Dept. gage; the second is an "observed" discharge hydrograph for the basin outlet. Select **Edit - Gage Data - Precipitation** on the menu bar of the PROJECT DEFINITION screen. On the NEW PRECIPITATION RECORD screen, enter `Fire Dept.` for the Gage I.D., and select **External DSS Record** as the data source (Figure 9.4). Click **OK**. A DSS PATHNAME SELECT screen opens. Select the file and pathname for the precipitation record (Figure 9.5). Click **OK**. The gage is entered on the PRECIPITATION GAGE LIST (Figure 9.6). You can optionally enter descriptive information for the gage. Press **Close** to exit this screen.

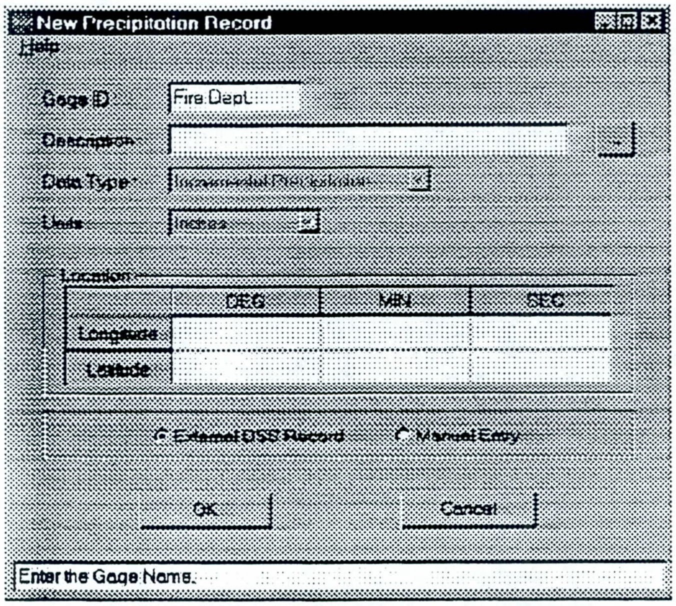


Figure 9.4 New Precipitation Record

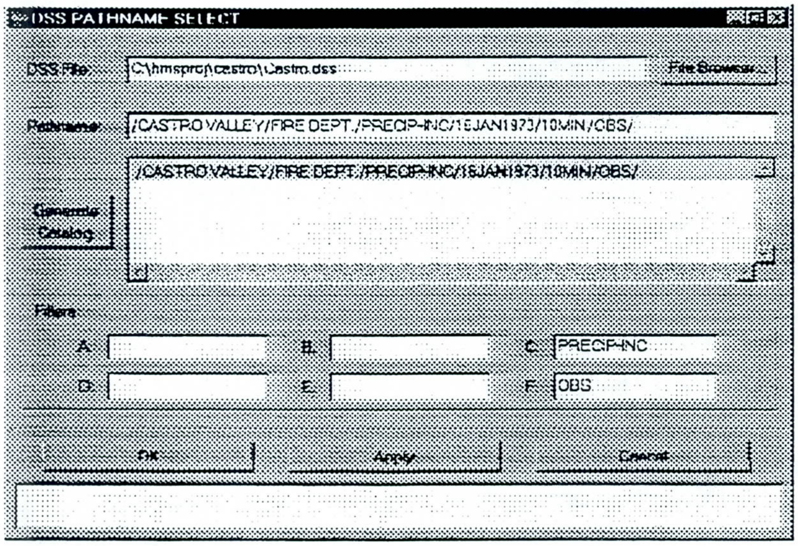


Figure 9.5 File/Pathname Select

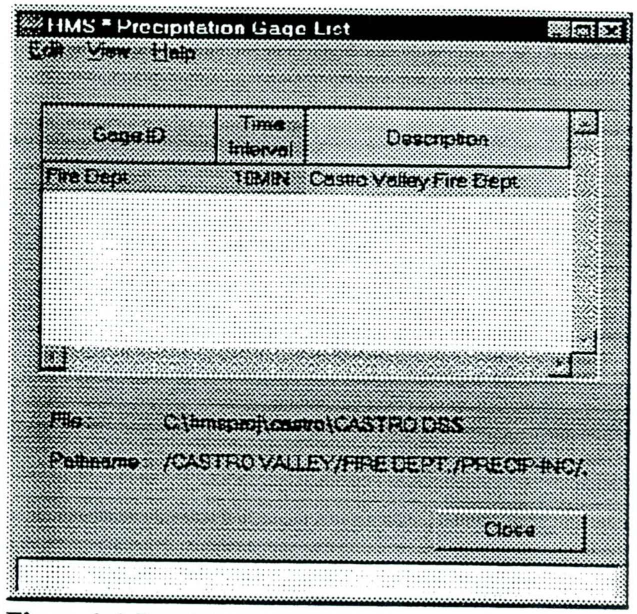


Figure 9.6 Precipitation Gage List

The observed discharge data may be entered in the same manner, starting with **Edit - Gage Data - Discharge** on the PROJECT DEFINITION screen. The discharge data for the Castro Valley outlet is in the *Castro.dss* file; the pathname is:

/CASTRO VALLEY/OUTLET/FLOW/16JAN1973/10MIN/OBS/

Creating the Basin Model

To create a basin model, select **Basin Model - New** from Edit on the PROJECT DEFINITION screen. Enter `Castro 1` for the basin name and `Existing conditions` for the description, and press **OK**, which opens the SCHEMATIC screen.

Setting the Map File

A map file for the Castro basin has been developed in the format described in Appendix B. To associate this map file with the new basin model, select **Basin Model Attributes** from **File** on the SCHEMATIC screen. Click **File Select** and use the file browser to find and select the Castro map file (Castro.map). The BASIN MODEL ATTRIBUTES screen is illustrated in Figure 9.7.

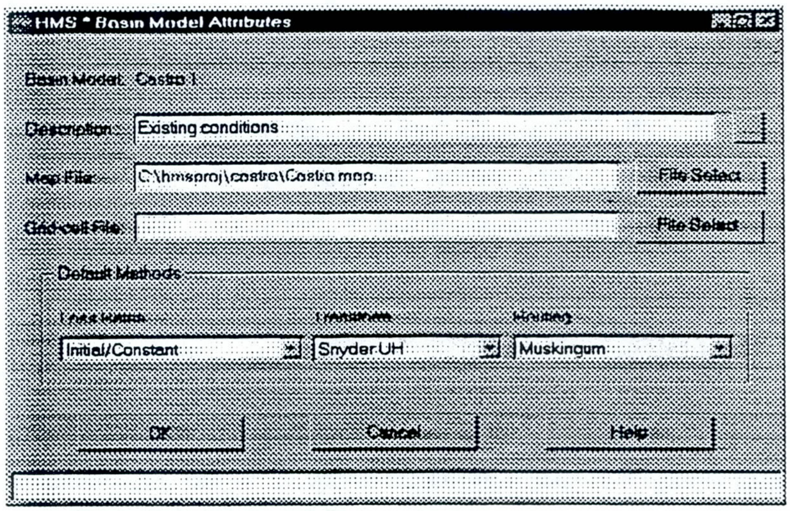


Figure 9.7 Basin Model Attributes

Creating the Basin Schematic

The Castro Valley basin will be represented with four subbasins, two routing reaches, and three junctions. The following steps describe how to set-up the Castro Valley basin schematic shown in Figure 9.8:

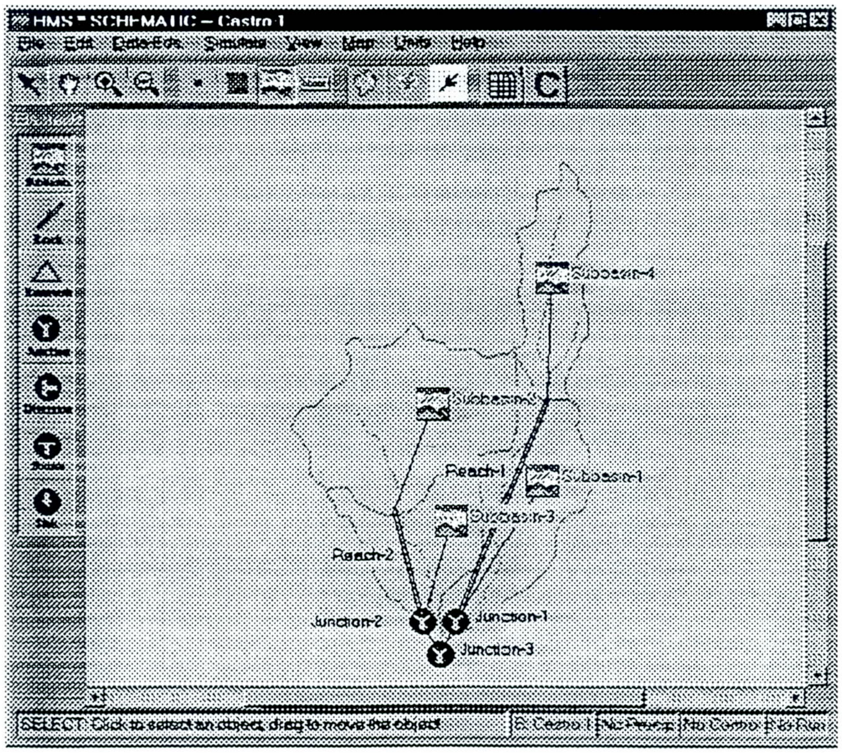


Figure 9.8 Castro Valley Schematic

1. Click the **Subbasin** icon in the element palette on the left side of the screen, then drag and drop the icon (with default name "Subbasin-1") onto the map where the Castro Valley Subbasin 1 is located (see Figures 9.1 and 9.8). Repeat this procedure for the other three subbasins.

2. Click the **Junction** icon and drag it to a position near, but upstream from, the outlet of Subbasin 1 (see Figure 9.8). Repeat this procedure to position a Junction-2 icon upstream of the outlet of Subbasin 3. Position a third junction at the outlet of the basin. With the right mouse button, click the Junction-1 icon and select **Connect Downstream**. Move the cursor (cross-hairs) over Junction-3 and click the left mouse button. Repeat this procedure to connect Junction-2 to Junction-3.

3. Click the **Reach** icon and drag it to a position anywhere in the clear area to the right of the right side of the Castro Valley Basin. With the right mouse button, click the Subbasin-4 icon and select **Connect Downstream**. Move the cursor over Reach-1 and click the left mouse button. The selected (highlighted) Reach-1 icon has blue *handles* at each end. Drag the upstream handle to a position at the outlet of Subbasin-4. Drag the downstream handle over the Junction-1 icon, which establishes the connection between Reach-1 and Junction-1. You can reposition an element label by selecting it and dragging it to the desired location.

4. In a similar manner, position a Reach-2 icon anywhere in the clear area to the left of the left side of the Castro Valley Basin. With the right mouse button, click the Subbasin-2 icon and select **Connect Downstream**. Move the cursor over Reach-2 and click the left mouse button. Drag the upstream handle of the Reach-2 icon to a position at the outlet of Subbasin-2, and the downstream handle over the Junction-2 icon.

5. With the right mouse button, click the Subbasin-1 icon and select **Connect Downstream**. Move the cursor over Junction-1 and click the left mouse button. In a similar manner, connect Subbasin-3 to Junction-2.

6. Select **Save Basin Model** from **File** on the menu bar of the SCHEMATIC screen.

Entering Basin Model Data

Subbasins. From **Data-Eds.** on the menu bar of the SCHEMATIC screen, select **Subbasin Area/Base Flow**. Enter the drainage areas and baseflow data from Table 9.1 (see Figure 9.9). In a similar manner, access the editors for **Loss Rate - Initial/Constant** and **Transform - Snyder**, and enter the data from Table 9.1. An alternative means for entering subbasin data is to use an individual-element editor, which is accessed by double-clicking a subbasin icon.

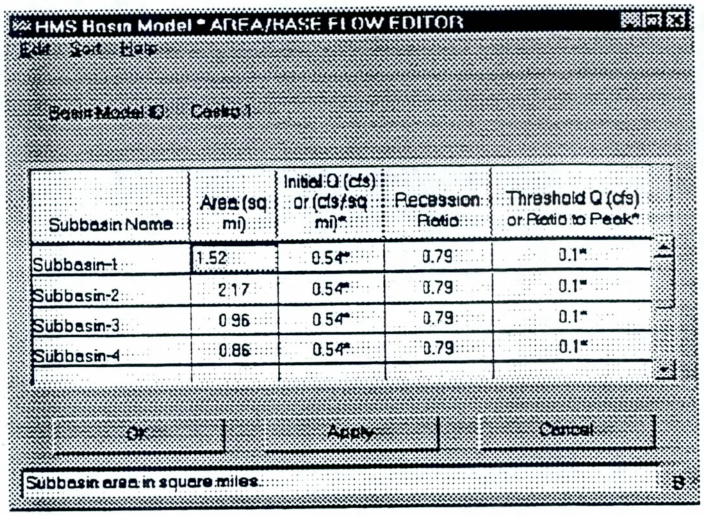


Figure 9.9 Area/Baseflow Editor

Junctions. Double click the icon for Junction-1 to bring up its editor. Change the junction name to "East Branch". Similarly, change the names of Junction-2 and Junction-3 to "West Branch" and "Outlet", respectively.

Reaches. Double click the icon for Reach-1. The editor is opened with the default method, Muskingum, selected. Enter the values for Muskingum K and x, and the number of subreaches (see Table 9.2a and Figure 9.10). Choose **OK** to save the data in memory. Double click the icon for Reach-2 to open its editor. Press the **Routing Method** button and select Modified Puls. Enter the data given in Tables 9.2b. Select **OK** to save the data and return to the SCHEMATIC screen. A message appears, stating: "Route Method has changed ...Data will be lost for old Route method." Press **OK**.

Basin Outlet. To associate the observed discharge hydrograph with the Outlet junction, right click its icon to open a pop-up menu, and select **Observed Flow**. The Gage selection list will have one entry, which is the name of the gage (Outlet) for which data was previously entered. Select this gage and press **OK**.

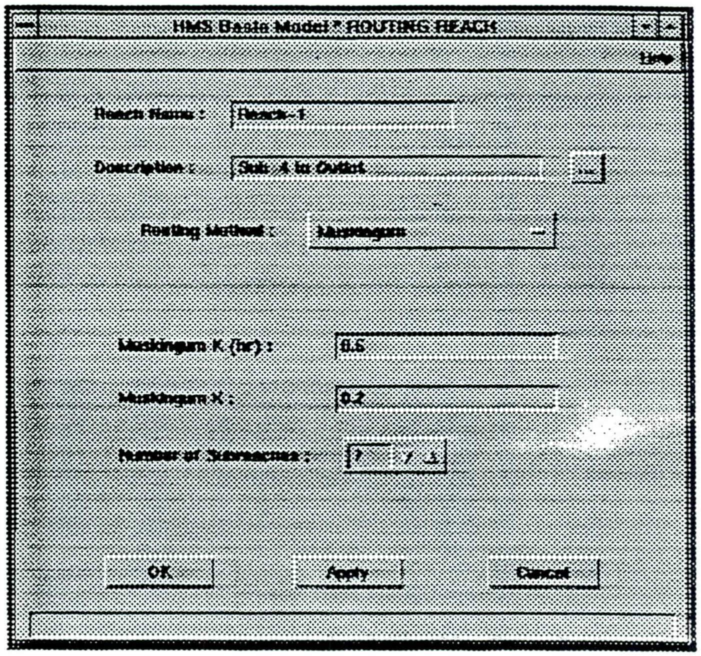


Figure 9.10 Routing Reach Editor for Reach-1

The basin model is now complete. Select **Save Basin Model** from **File** on the menu bar of the SCHEMATIC screen. You can close the SCHEMATIC screen by selecting **Close** from **File** on the menu bar, or you may choose to leave it open for later use in viewing simulation results. The SCHEMATIC screen will appear whenever a basin model is opened from the PROJECT DEFINITION screen.

Creating the Precipitation Model

To create the precipitation model, select **Precipitation Model - New** from **Edit** on the PROJECT DEFINITION screen. Enter `GageWts` for the precipitation model name and `Thiessen weights;10-min data` for the description. Press **OK**, which opens the PRECIPITATION MODEL -- METHOD SELECT screen. Choose **User-Specified Gage Weighting** and press **OK**, which opens the USER-SPECIFIED GAGE WEIGHTS screen. The following steps describe how to enter the precipitation model data using this screen:

1. First displayed is the *Gages* page (Figure 9.11). Click the **Gage Select** button to bring up a list of precipitation gages for which data has previously been entered. In this case there is only one gage on the list, the Fire Dept. gage. Select this gage, and click **Add**, then **Close.** The gage is entered on the *Gages* table and an R is entered in the second column of the table to indicate that this is a recording gage. Press the **Total-Storm (NR) Gage** button to add the

Proctor School gage to the table. The NR indicates that this is a non-recording gage. Enter a total-storm depth of 1.92 in. for this gage. In a similar manner, enter Sydney School as a second non-recording gage, for which the total-storm depth is 1.37 in. Press **Apply** to save the data to memory.

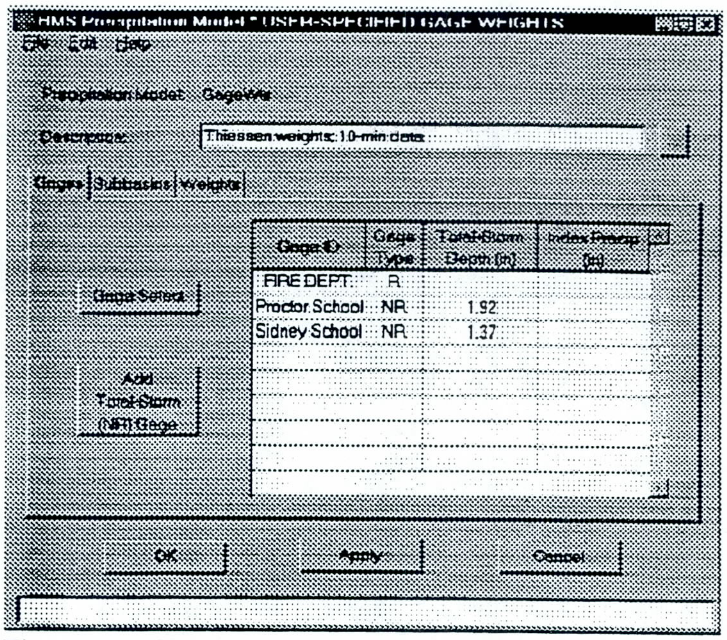


Figure 9.11 Gages

2. Select the *Subbasins* page (Figure 9.12). Select Castro 1 for the basin model from which subbasins are to be added to the precipitation model, and press the **Add** button. Click **OK** on the confirmation dialog screen to add the four subbasins to the table.

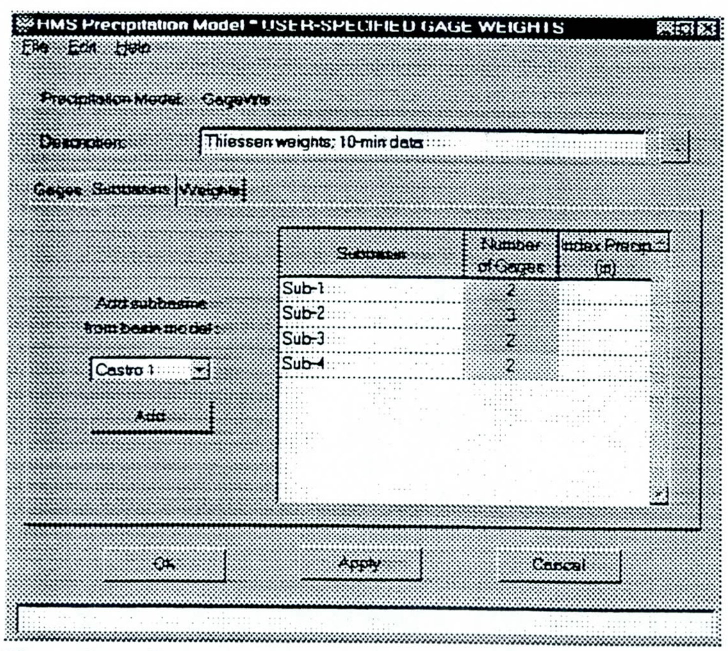


Figure 9.12 Subbasins

3. Select the *Weights* page (Figure 9.13). At the top of the page is a selection list for selecting a subbasin. Gage weights must be entered for each subbasin in the precipitation model. Select Sub-1. Select the first column of the first row of the table to obtain a selection list of gages. From this list, select Proctor School. Enter a total-storm weight of `0.2` (see Table 9.3). In the first column of the second row, select FIRE DEPT. Enter the total-storm and temporal-distribution weights from Table 9.3. Repeat this data-entry procedure for the remaining subbasins. The precipitation model is now complete. Press **OK** to close the USER-SPECIFIED GAGE WEIGHTS screen.

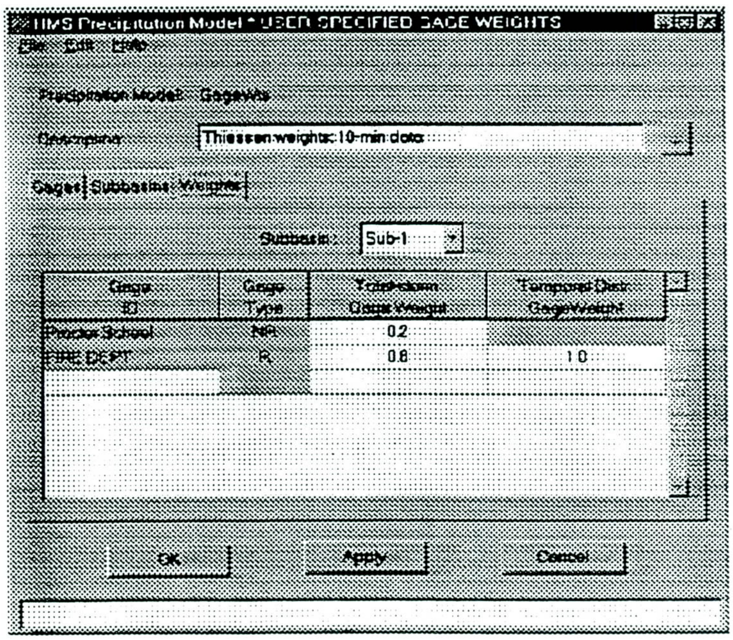


Figure 9.13 Weights

Entering Control Specifications

Select **Control Specifications - New** from **Edit** on the PROJECT DEFINITION screen. Enter `Jan73` for the Control Specs name and `Storm of 16 January 1973` for the description. Press **OK** to open the CONTROL SPECIFICATIONS--SETUP screen (Figure 9.14).

Enter `16Jan73` for both the Starting and Ending Dates, `0300` for the Starting Time, and `1255` for the Ending Time. For the Time Interval, select **Minutes** (if necessary) using the Minutes/Hours toggle button, and enter 5 for the value. Press **OK** to return to the main screen.

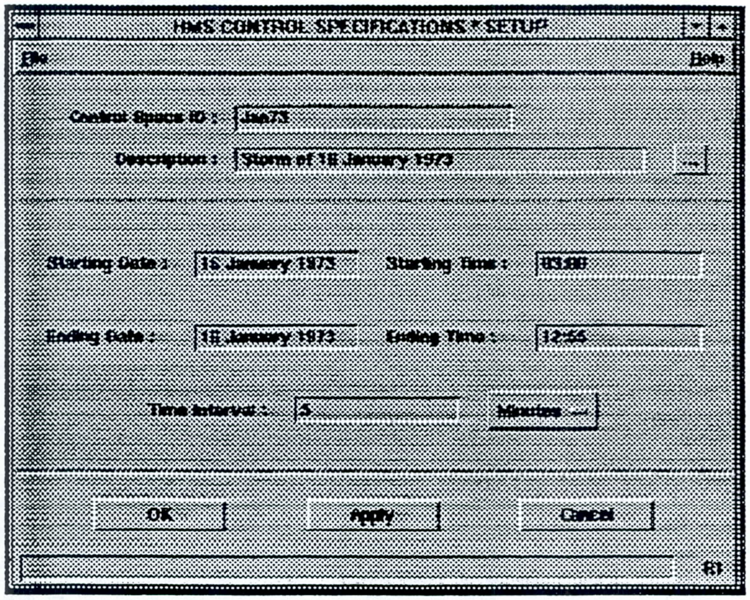


Figure 9.14 Control Specifications

The control specifications, precipitation model, and basin model are now complete. Select **Save Project** from **File** on the PROJECT DEFINITION screen to ensure that all the data is saved to disk.

Creating and Executing a Run

The main screen now lists a basin model (Castro 1), a precipitation model (GageWts), and control specifications (Jan73). Double-click Castro 1 to bring up the SCHEMATIC screen. Select **Simulation Manager** from **Simulate** (on the menu bar) to open the SIMULATION MANAGER screen. Press the **Select Components** button to configure a simulation run. Select Castro 1, GageWts, and Jan73 (see Figure 9.15). Keep the default name Run_1, and type `Existing conditions; 16Jan73 storm` for the description. Press **Add**, then **Close** to return to the SIMULATION MANAGER. Select Run_1, then press **Compute** to execute the run. A "Compute" screen monitors simulation progress. Select **Close** on both the COMPUTE and SIMULATION MANAGER screens and return to the SCHEMATIC screen.

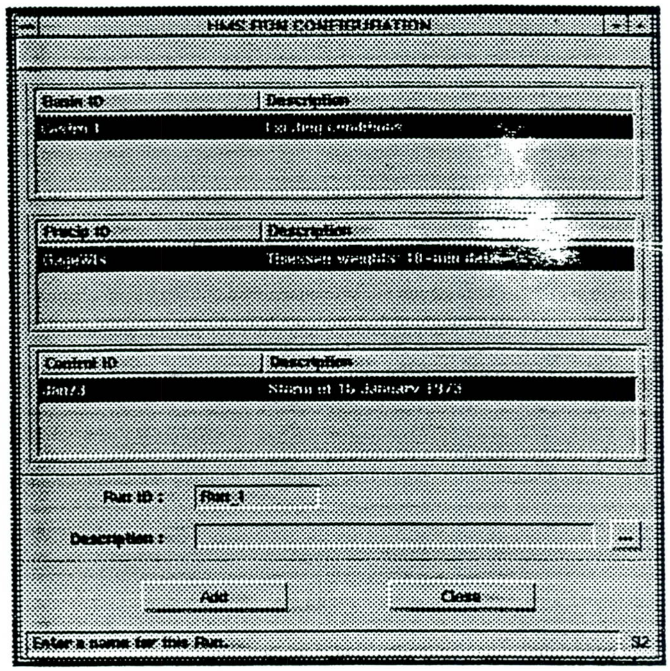


Figure 9.15 Run Configuration

Viewing Results

In the SCHEMATIC screen, press the table icon (second from right on the tool bar) to view a tabular summary of results (see Figure 9.16). Print the table or make a note of the simulated peak discharges for Sub-1, the East Branch junction, and the Outlet. Close the screen. With the right mouse button, click the Outlet junction and select **View Results - Graph**. The simulated and observed hydrographs at the Outlet are graphically displayed, along with the East and West Branch hydrographs (see Figure 9.17).

In addition to graphical displays, simulation results (for each element) can be viewed in a tabular format. With the right mouse button, select Sub-1 and **View Results - Time-Series Table** (see Figure 9.18). This table provides information for each time step of the simulation period. Notice that a button in the upper left corner provides access to Time-Series Tables for the other subbasins. An element Summary Table can be accessed with **View Results:Summary Table** (using the right mouse button). Figure 9.19 shows a Summary Table for Sub-1.

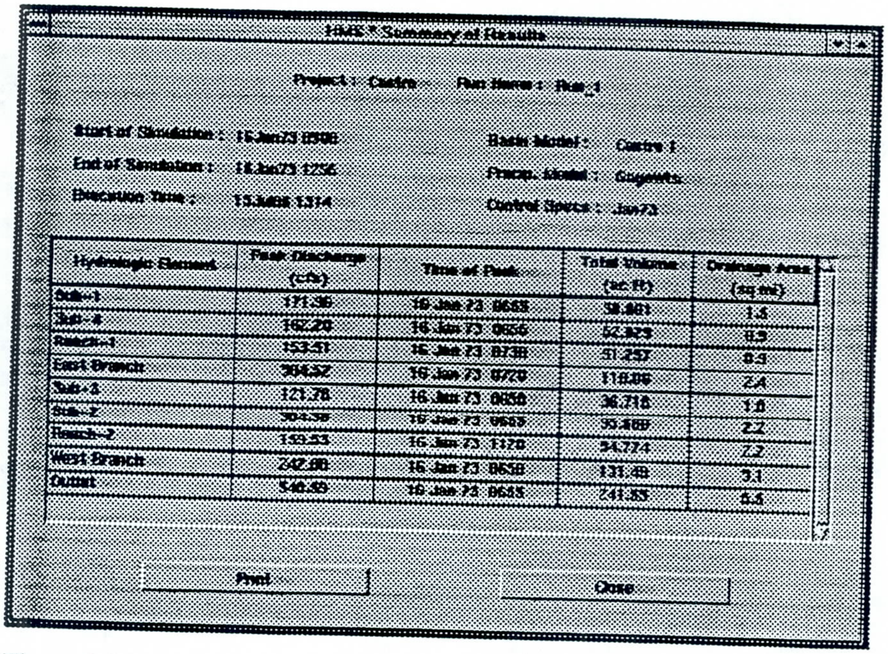


Figure 9.16 Summary of Results

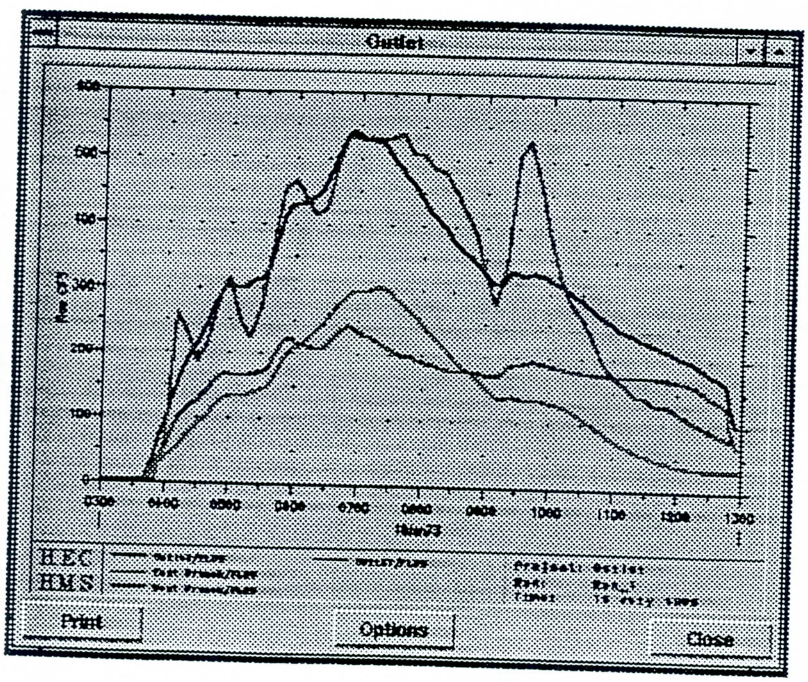
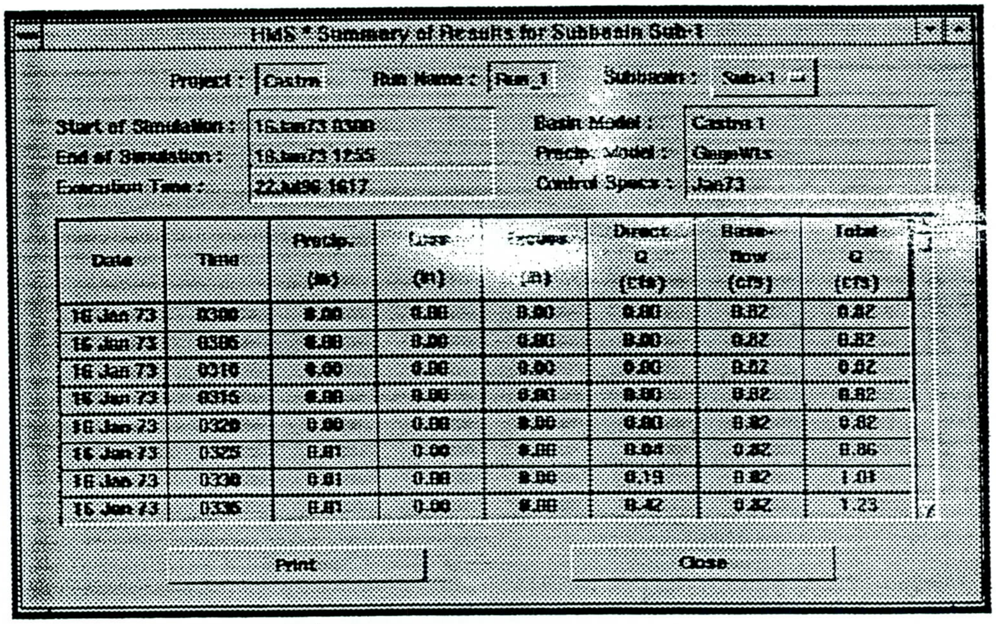


Figure 9.17 Outlet Hydrograph



Date	Time	Precip. (in)	Loss (in)	Excess (in)	Direct Q (cfs)	Base-flow (cfs)	Total Q (cfs)
16 Jan 73	0300	0.00	0.00	0.00	0.00	0.82	0.82
16 Jan 73	0305	0.00	0.00	0.00	0.00	0.82	0.82
16 Jan 73	0310	0.00	0.00	0.00	0.00	0.82	0.82
16 Jan 73	0315	0.00	0.00	0.00	0.00	0.82	0.82
16 Jan 73	0320	0.00	0.00	0.00	0.00	0.82	0.82
16 Jan 73	0325	0.01	0.00	0.00	0.04	0.82	0.86
16 Jan 73	0330	0.01	0.00	0.00	0.19	0.82	1.01
16 Jan 73	0335	0.01	0.00	0.00	0.42	0.82	1.23

Figure 9.18 Time Series for Sub-1

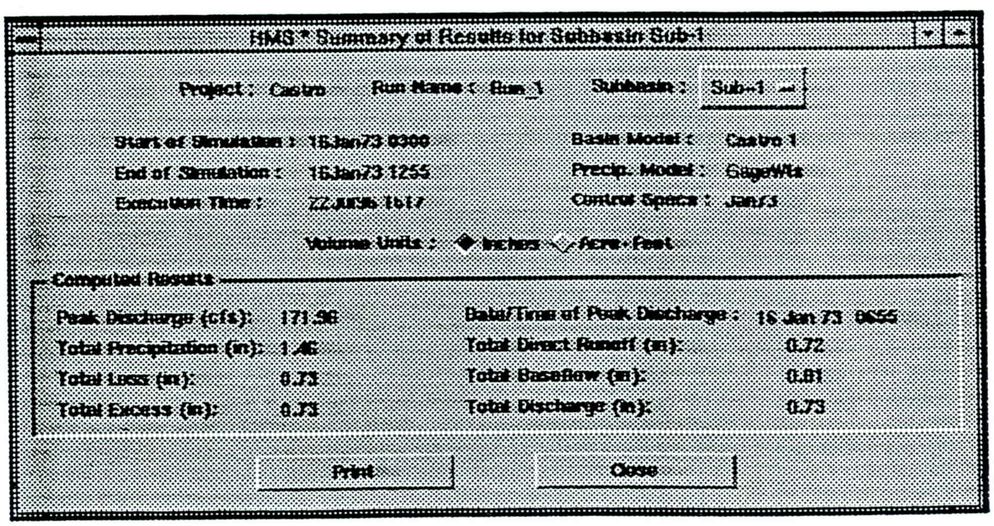


Figure 9.19 Summary of Results for Sub-1

Simulation with Future Urbanization

Consider now how the Castro Valley basin response would change given the effects of future urbanization in Subbasin 1. The precipitation model and control specifications remain the same, but a modified basin model is created to reflect the anticipated changes to the basin.

Creating the Modified Basin Model

In the SCHEMATIC screen, select **File - Save Basin Model As**. Type `Castro 2` for the name of the new basin model, and press **OK**. Double-click the Sub-1 icon to bring up its editor. Change the value of imperviousness from 8 to 17 percent, and the Snyder t_p from 0.28 to 0.19 (Figure 9.20), then press **OK**. Select **File - Save** to save this basin model to disk.

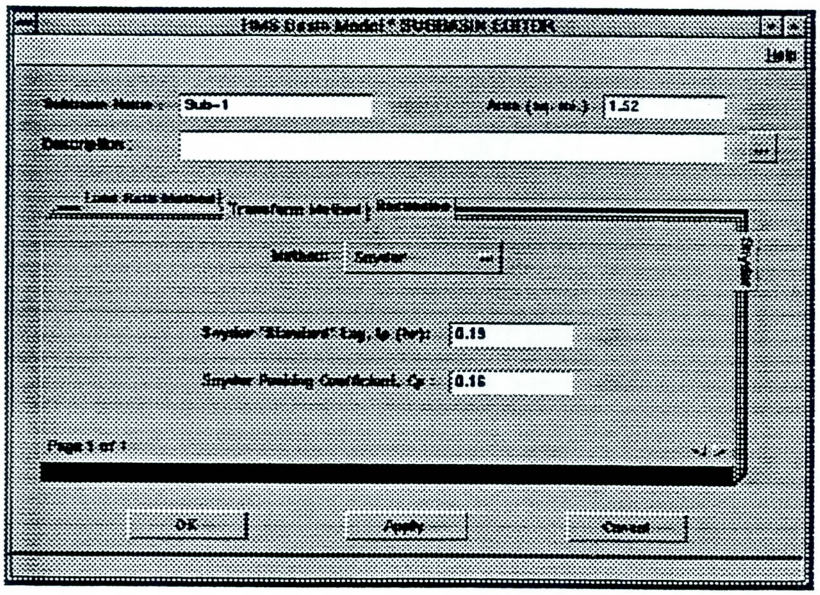


Figure 9.20 Subbasin Editor for Sub-1

Urbanized Simulation Run

Select **Simulation Manager** from **Simulate**, which opens the SIMULATION MANAGER screen. Press the **Select Components** button to configure a simulation run. Click on Castro 2, GageWts, and Jan73. Keep the default name Run_2, and type `Urbanized conditions; 16Jan73 storm` for the description. Press **Add**, then **Close** to return to the SIMULATION MANAGER screen. Click on Run_2, then press

Compute to execute the run. Select **Close** on both the COMPUTE and SIMULATION MANAGER screens and return to the SCHEMATIC screen.

Press the table icon on the tool bar to view a tabular summary of results (Figure 9.21). Compare the peak discharges under urbanized conditions for Sub-1, the East Branch junction, and the Outlet with the values previously obtained for existing basin conditions (Table 9.4). Close the screen. To view results graphically, open the pop-up menu for the Outlet junction and select **View Results - Graph**.

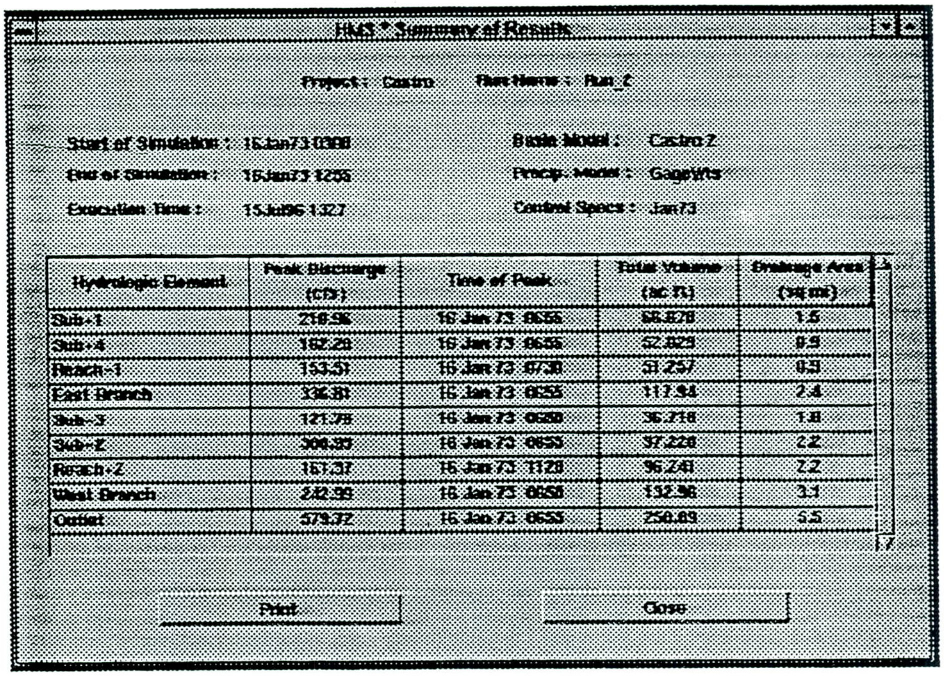


Figure 9.21 Summary of Results – Urbanized Case

Table 9.4 Peak Discharges (cfs); Existing vs. Urbanized Conditions

	Subbasin 1	East Branch Jct.	Outlet
Existing conditions	172	305	541
Urbanized conditions	211	337	580
% increase due to urbanization	23	10	7

Close the SCHEMATIC. In the PROJECT DEFINITION screen, select **Save Project** from **File**. This example project is now complete. Choose **New Project** or **Open Project** from **File** to work with another project, or select **Exit** to quit HEC-HMS.

CHAPTER 10

Parameter Calibration

HEC-HMS provides capabilities for automated estimation of the values for selected runoff parameters for situations in which observed precipitation and discharge data are available.

This chapter describes the conceptual framework for parameter estimation and provides information on the objective functions, search methods, constraints, etc., that are used.

Framework for Parameter Estimation

Parameter estimation is achieved by automated adjustment of the values for selected parameters to produce an *optimal fit* of a computed hydrograph to an observed hydrograph at a target location. The selected parameters may be associated with losses, runoff transformation, baseflow or routing for any subbasin or reach upstream from the target location.

The quantitative measure of optimal fit is the *objective function*, which is based on the degree of variation between the computed and observed hydrographs, and is equal to zero if the hydrographs match exactly. The key to automated parameter estimation is a *search procedure* for adjusting the selected parameters to produce an optimal fit; that is, to minimize the magnitude of the objective function. Constraints are imposed on parameter values to insure that unreasonable values are not utilized.

Figure 10.1 illustrates basic characteristics of the optimization methodology. Initial values for all parameters are required at the start of optimization. A hydrograph is computed at the target location (for which an observed hydrograph has been specified), and the value of the objective function is calculated. The search procedure adjusts values for the selected parameters (i.e., the parameters being optimized), and a new computed hydrograph and objective function are obtained. This cycle is followed until little improvement in the objective function is achieved, and the search is ended.

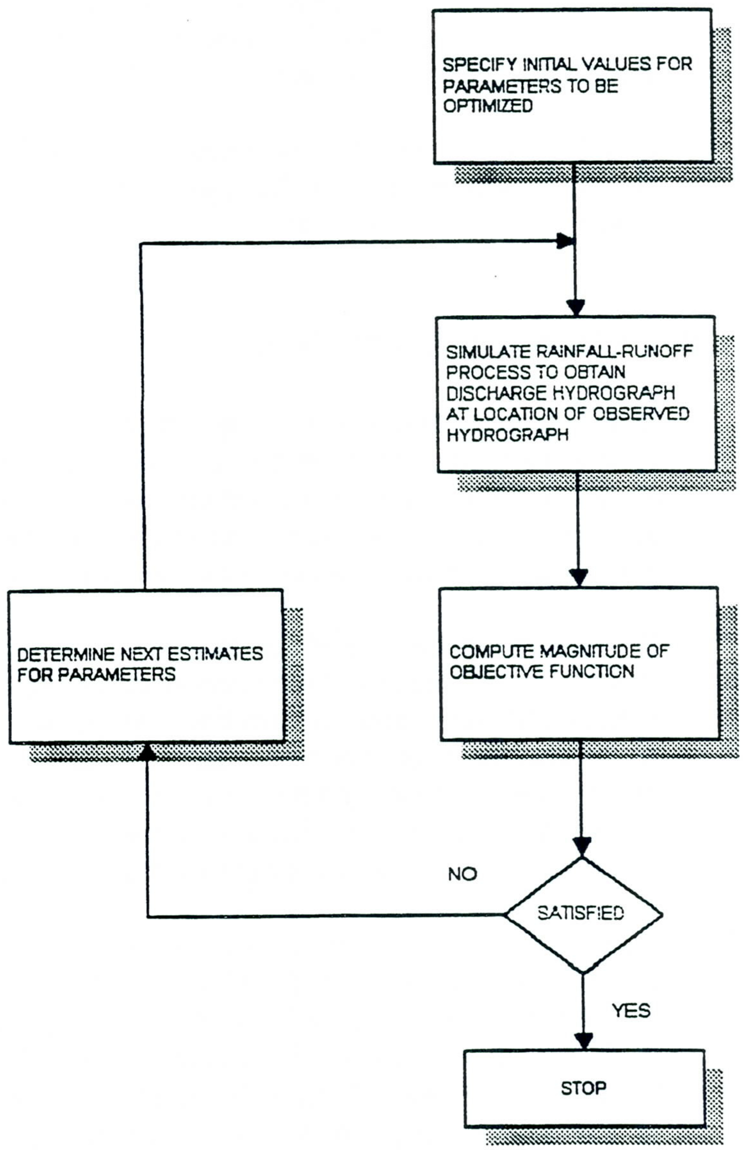


Figure 10.1 Framework for Optimization

Objective Function

You can choose from four objective-function definitions for measuring the goodness of fit of a computed hydrograph to an observed hydrograph. The default function is the HEC-1 objective function.

HEC-1 Objective Function

The following equations define the objective function used in HEC-1 (HEC, 1990).

$$Z = \sqrt{\frac{\sum_{i=1}^{n} (Q_O(t) - Q_S(t))^2 \frac{(Q_O(t) + Q_A)}{2Q_A}}{n}} \qquad (10\text{-}1)$$

$$Q_A = \frac{1}{n}\sum_{i=1}^{n} Q_O \qquad (10\text{-}2)$$

where Z is the objective function, $Q_O(t)$ is observed discharge at time t, $Q_S(t)$ is simulated discharge at time t, Q_A is the average observed flow, i is an integer counter for hydrograph ordinates, and n is the total number of ordinates used to define the objective function.

The expression $\frac{Q_o(t) + Q_A}{2Q_A}$ in Equation 10-1 is a weighting function that gives greater weight to discharge deviations associated with higher flows.

Sum of Squared Residuals

The following equation expresses the objective function simply as the sum of squared differences between the observed and simulated discharges.

$$Z = \sum_{i=1}^{n} (Q_O(t) - Q_S(t))^2 \qquad (10\text{-}3)$$

The terms are as defined for the HEC-1 objective function.

Sum of Absolute Residuals

The following equation expresses the objective function as the sum of the absolute differences between the observed and simulated discharges, and thus gives equal weight to all differences.

$$Z = \sum_{i=1}^{n} \left| Q_O(t) - Q_S(t) \right| \tag{10-4}$$

The terms are as defined for the HEC-1 objective function.

Percent Error in Peak Flow

The objective function defined by the following equation considers only the peak observed and simulated flows. It does not account for timing or volume differences between the observed and simulated hydrographs. where $Q_O(peak)$ and $Q_S(peak)$ are peak discharges of the observed and simulated hydrographs, respectively.

$$Z = 100 \left| \frac{Q_O(peak) - Q_S(peak)}{Q_O(peak)} \right| \tag{10-5}$$

Search Methods

HEC-HMS has two methods for adjusting the selected parameters to obtain an optimal fit. The Univariate Gradient Method (UG) varies the magnitude of one parameter at a time while holding the magnitude of the remaining selected parameters constant. The Nelder and Mead Method (N&M) changes the magnitude of all selected parameters in each iteration. The search process takes longer than with the UG, but may produce a more nearly optimal fit. Appendix C describes the technical bases for the two search methods.

When the value of only a single parameter is to be optimized, the UG is used automatically.

Initial Values and Constraints

As indicated in Figure 10.1, initial values for parameters are required at the start of an optimization. The default values are those specified in the basin model. However, you can override any default value.

Hard constraints limit the range of values that a parameter may have. Such constraints are used to keep the magnitude of a variable within reasonable limits, or to preclude values that cause instabilities or errors in computations. For example, negative loss rates are not allowed. When a search method attempts to use a value outside the range of hard constraints, the value is changed to the constraining value. Values for hard constraints are listed in Table 10.1.

You can specify *soft constraints* to keep parameter values to within tighter limits than those defined with hard constraints. When a search procedure adopts a value outside of the range of soft constraints, the value is used, but the objective function is multiplied by a Penalty Factor, defined as follows:

$$PenaltyFactor = 2\,|\,value - constraint\,|$$

Objective Function Sensitivity

To aid in evaluation of results, a measure of the sensitivity of the objective function to the optimized value of a parameter is displayed. Values of the objective function are computed for parameter values of 0.995 and 1.005 times the optimal value, with all other parameters held at their optimal values. The sensitivity measure is the percent change in the value of the objective function resulting from the 1% increase in the value of the parameter. If a parameter value obtained by multiplying by 0.995 or 1.005 exceeds a hard constraint, the parameter value is set to the constraint, and the constrained value is used to calculate the sensitivity measure.

Table 10.1 Constraints

Parameter	Minimum Constraint	Maximum Constraint
Initial Loss	0 mm	500 mm
Constant Loss Rate	0 mm/hr	300 mm/hr
SCS Initial Abstraction	0 mm	500 mm
SCS Curve Number	1	100
Moisture Deficit	0	1
Hydraulic Conductivity	0 mm/mm	250 mm/mm
Wetting Front Suction	0 mm	1000 mm
Initial Deficit	0 mm	500 mm
Maximum Deficit	0 mm	500 mm
Deficit Recovery Factor	0.1	5
Time of Concentration	0.1 hr	500 hr
Clark Storage Coefficient	0 hr	150 hr
Snyder Lag	0.1 hr	500 hr
Snyder Cp	0.1	1.0
SCS Lag	0.1 min	30000 min
Manning's n	0	1
Initial Baseflow	0 m3/s	100000 m3/s
Recession Factor	0.00001	1
Flow To Peak Ratio	0	1
Muskingum K	0.1 hr	150 hr
Muskingum x	0	0.6
Number of Steps	1	100
n-value Factor	0.01	10
Lag (routing)	0 min	30000 min

Program Use

Parameter optimization can be performed with parameters for any subbasins or routing reaches that are upstream from a location for which an observed hydrograph has been specified. Steps involved in optimization are as follows:

(1) Enter gaged data to be used for optimization using the data entry capabilities accessed by selecting **Edit - Gage Data** on the menu bar of the PROJECT DEFINITION screen.

(2) For the basin model to be used for optimization, associate an observed hydrograph with the hydrologic element at which the objective function will be evaluated; this is accomplished by means of the **Observed Flow** option accessed from the pop-up menu for the hydrologic element on the SCHEMATIC screen.

(3) From the PROJECT DEFINITION screen, select **Optimization - Optimizer Control** from the menu bar. This will open the OPTIMIZER CONTROL screen, which is illustrated in Figure 10.2. From the menu bar on this screen, select **Simulate - Optimizer Run Configuration** to open the OPTIMIZER RUN CONFIGURATION screen, which is illustrated in Figure 10.3. On this screen, select (one each) a basin model, precipitation model and control specifications which will be used for optimization. The default run i.d. can be edited, and a description can optionally be entered. Press the **Add** button to adopt this configuration. Additional optimization runs can be configured in the same manner. Press **Close** to exit the OPTIMIZER RUN CONFIGURATION screen.

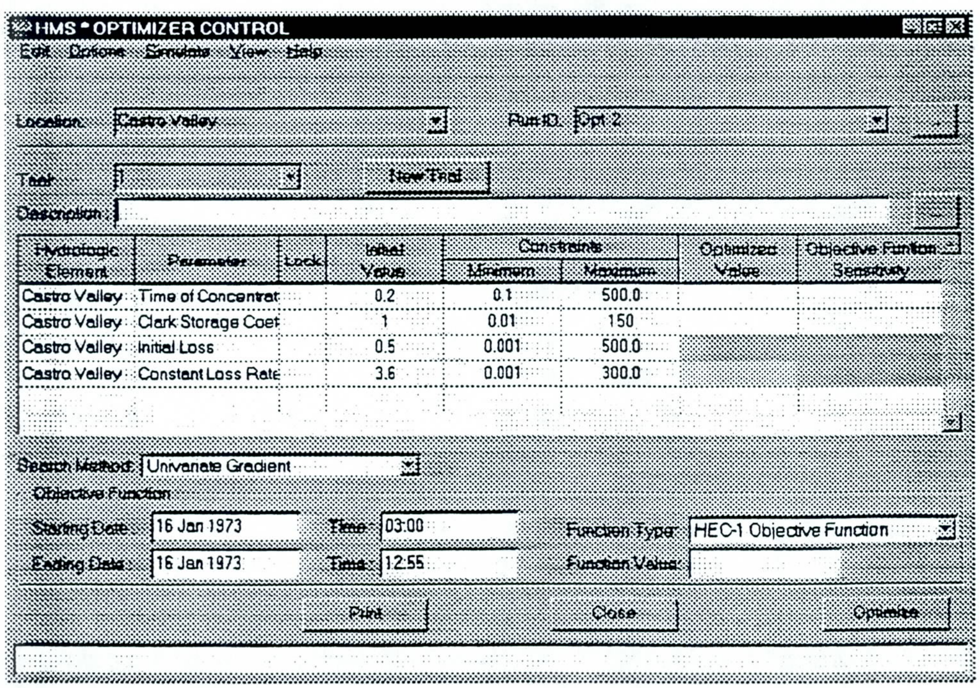


Figure 10.2 Optimizer Control

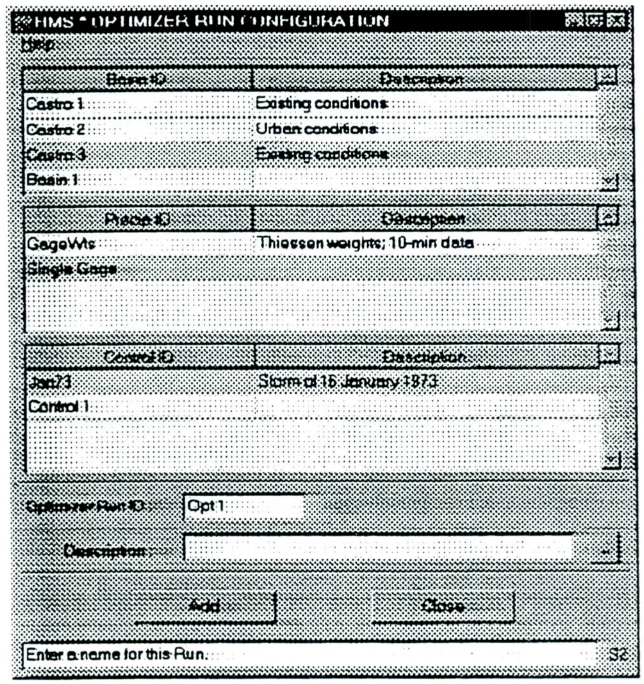


Figure 10.3 Optimizer Run Configuration

(4) On the OPTIMIZER CONTROL screen, select the run to be used for optimization using the Run I.D. selection list (upper right). Select the location at which the objective function will be evaluated from the Location selection list (upper left). The Location list shows all locations (for the current basin model) for which observed hydrographs have been specified. The Trial box shows a trial number to be associated with the optimization. The Run I.D., Location and Trial No. together control the labeling of optimization results. If several different optimization runs are to be made for the same Run I.D. and Location, the Trial No. can be incremented so that results from one trial do not overwrite results of a previous trial. A description can be entered for each trial.

(5) After the Run I.D., Location and Trial have been set, select (click) the first field in the Hydrologic Element column of the table to activate a selection list of all subbasins and routing reaches that are at, and upstream from, the location at which the objective function will be evaluated. Select the subbasin or routing reach for which a parameter value is to be optimized. In the next (Parameter) column, select the parameter to be optimized from the selection list of available parameters. When the parameter is selected, the value of that parameter from the basin model is shown as the *initial value.* Likewise, default values for *constraints* are shown. The initial and constraint values may be overridden. Select additional parameters for optimization in subsequent rows of the table as desired. The Lock field may be clicked if it is desired to preclude optimization of a parameter for a given trial. The *search method* and *objective function* type can be selected using the selection lists provided.

The time window shown at the bottom of the screen is the period over which the objective function will be evaluated. If it is desired to reduce the window from that specified in the control specifications, the time window settings can be edited. After desired characteristics of the optimization run have been set, click the **Optimize** button (lower right corner of screen). An OPTIMIZER COMPUTE screen will show progress of the execution.

(6) Following completion of an optimization, optimized values are displayed in the table, and the final value of the objective function is shown (below the objective function type). Also, values for *Objective Function Sensitivity* are shown in the last column of the table. A number of displays can be accessed from the **View** menu. A table showing OPTIMIZER RESULTS is illustrated in Figure 10.4. HYDROGRAPH, SCATTER and DIFFERENCE plots are available (Figures 10.5-10.7). A SCHEMATIC of the portion of the basin model upstream from the location where the objective function is evaluated is accessed from **Optimizer Schematic**, the last item on the **View** menu. The schematic provides access to summary tables and graphs for any associated hydrologic elements. Finally, the OPTIMIZER TRIAL LOG, accessed from the **View** menu, provides a means for comparing results of various trials, and for setting the value of a parameter in the basin model. (See Figure 10.8.)

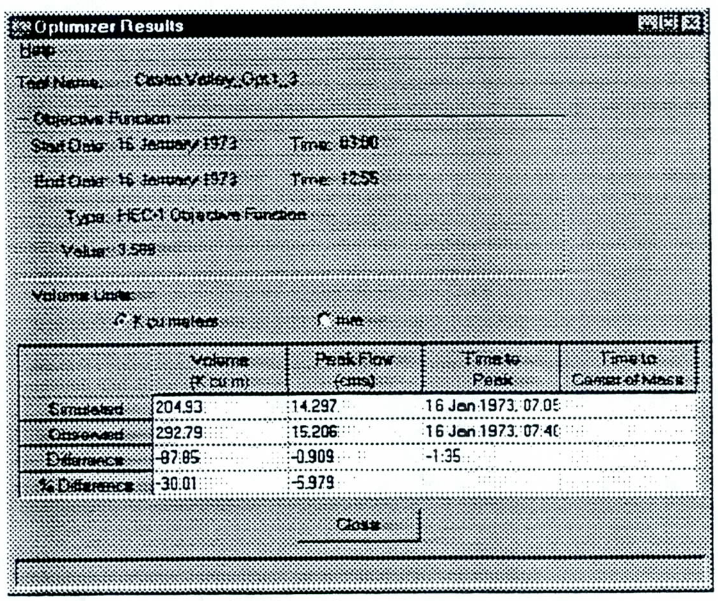


Figure 10.4 Optimizer Results

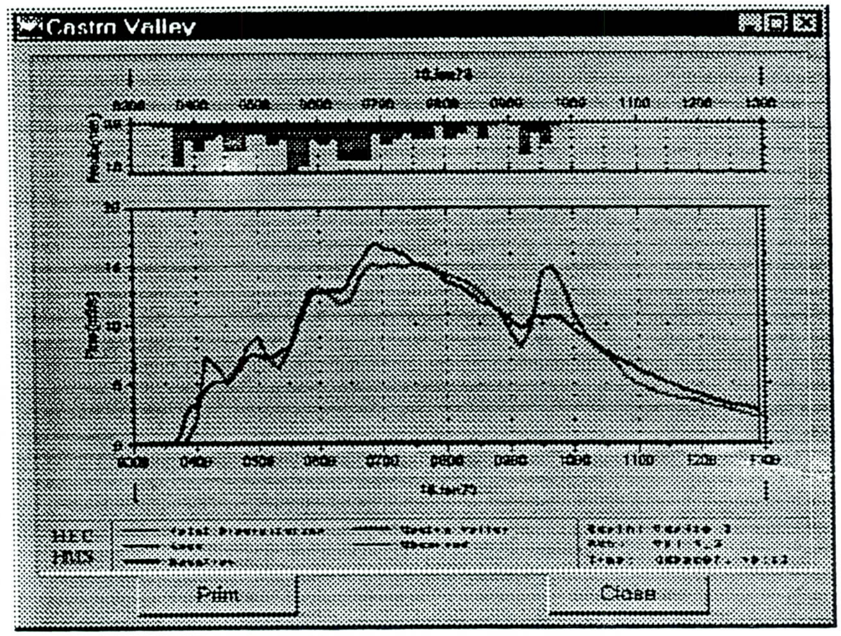


Figure 10.5 Hydrograph Plot

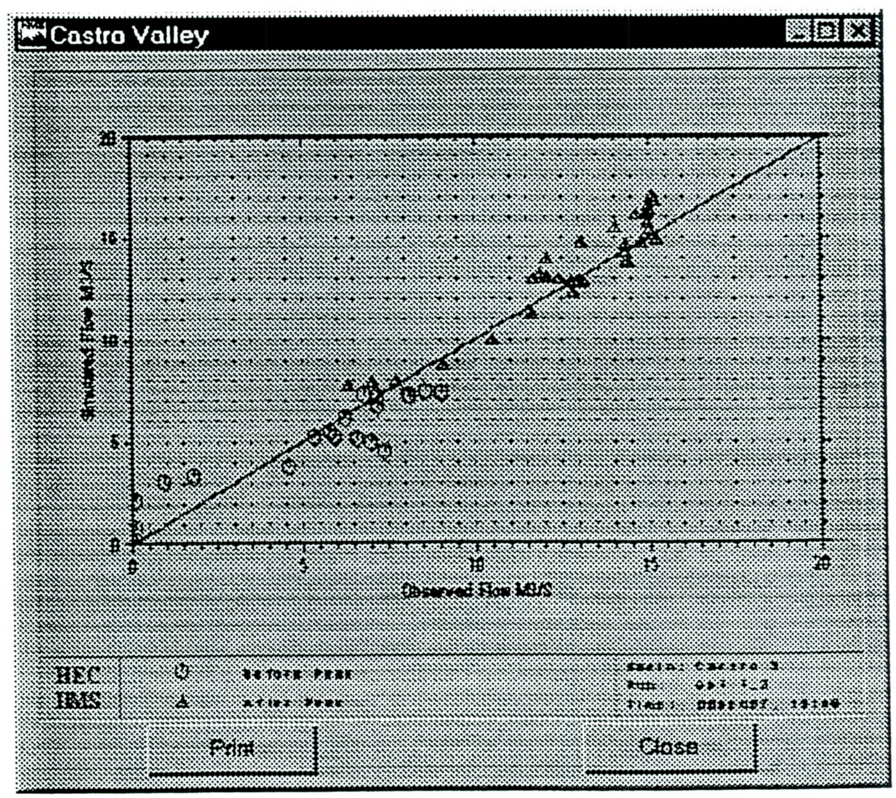


Figure 10.6 Scatter Plot

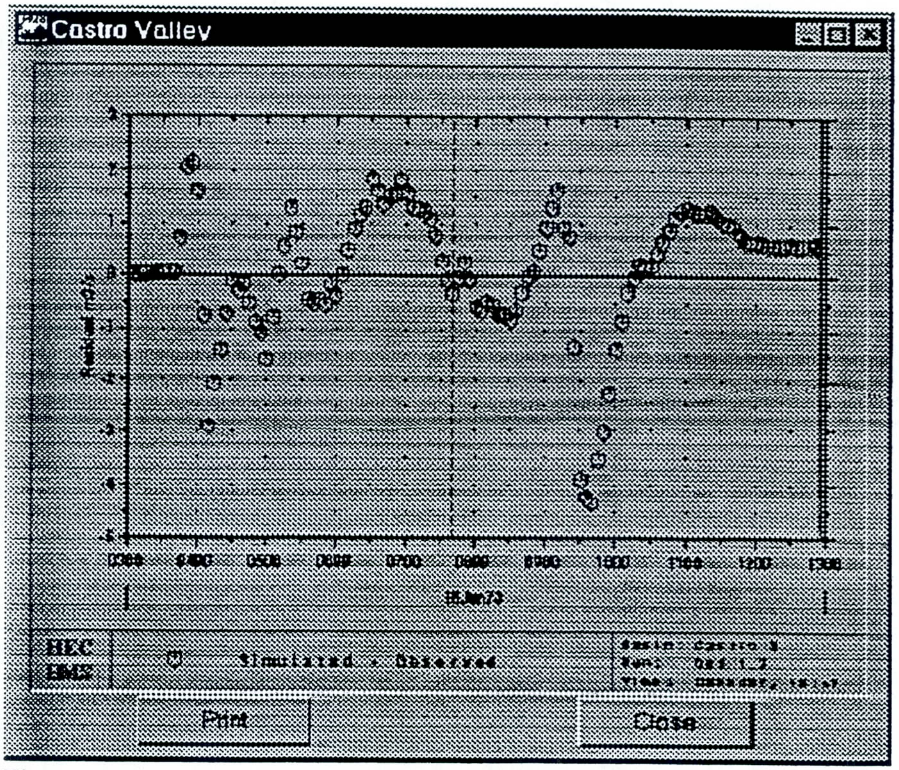


Figure 10.7 Difference Plot

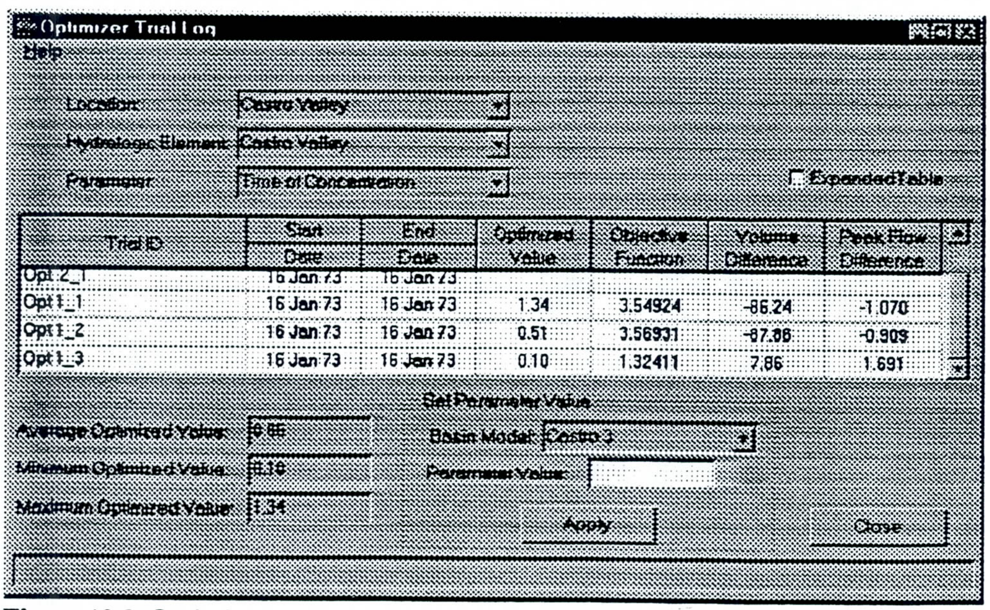


Figure 10.8 Optimizer Trial Log

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APPENDIX A

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APPENDIX B

Map-File Format

Watershed boundaries and streams can be displayed as a background for hydrologic elements on the SCHEMATIC screen. To use this capability, a *map file* that contains coordinates of the background features is required. Access to a map file is provided to a *basin model* with the **Map File option** under **Basin Model Attributes** on the menu bar of the SCHEMATIC screen.

Figure B-1 illustrates a portion of a map file. Two types of map feature can be specified: watershed boundaries and rivers. The portions of the map file pertaining to each are initiated with the key word **MapGeo** followed by a colon (":"), and either **BoundaryMap** or **RiverMap**.

```
MapGeo:  BoundaryMap
MapSegment: closed
    582242.875000, 4174922.500000
    582220.875000, 4174961.500000
    582205.625000, 4175013.750000
    ...
    581981.000000, 4174672.750000
    582025.812500, 4174696.250000
    582068.812500, 4174711.000000
MapSegment: closed
    582810.125000, 4174024.500000
    582874.687500, 4173973.750000
    582950.687500, 4173902.750000
    ...
    582554.000000, 4174000.250000
    582667.687500, 4174003.750000
    582810.125000, 4174024.500000
MapGeo: RiverMap
MapSegment: open
    582750.187500, 4176706.000000
    582687.000000, 4176594.000000
    582657.375000, 4176468.500000
    582613.125000, 4176359.500000
    ...
    582482.125000, 4174521.500000
    582555.250000, 4174377.500000
    582555.250000, 4174378.000000
MapSegment: open
    582941.500000, 4175098.500000
    582920.500000, 4175009.750000
    582912.312500, 4174956.500000
    ...
    582699.375000, 4174540.500000
```

Figure B.1 Map File

The definition of a map segment is initiated with the key word **MapSegment** followed by a colon (":"), and either **closed** or **open**. A *closed* segment defines a polygon for which the last coordinate is automatically connected to the first coordinate. An *open* segment defines a vector which does not extend beyond the last coordinate. Each map feature can have an unlimited number of segments.

Segment coordinates are defined with x-y pairs. The display of map features is automatically scaled to fit in the SCHEMATIC screen, and is therefore independent of map units and the location of the origin for the coordinate system. The same coordinate system must be used for all segments.

APPENDIX C

Search Methods

The technical bases for the two search methods used for parameter optimization are described in this appendix.

Univariate Gradient Method (UG)

Procedure. In the UG, the objective function is minimized by adjusting the value of a selected parameter while all other parameter values are held constant. For a minimization iteration for a parameter, the objective function is evaluated for three values of the selected parameter:

$$X_0 = 1.00X \qquad Z_0 = f(X_0)$$

$$X_1 = 0.99X \qquad Z_1 = f(X_1)$$

$$X_2 = 0.98X \qquad Z_2 = f(X_2)$$

where X is the value of the variable at the beginning of the iteration.

The three sets of values are used with the Newton method to estimate a value for the parameter that will further reduce the value of the objective function. First differences in the objective function are:

$$\Delta_1 = Z_1 - Z_0$$

$$\Delta_2 = Z_2 - Z_1$$

The second difference is:

$$\Delta^2 = \Delta_2 - \Delta_1 = (Z_2 - Z_1) - (Z_1 - Z_0) = Z_2 + Z_0 - 2Z_1$$

The first projected value of the parameter, $X^{[1]}$, is computed from the initial value, $X^{[0]}$, as follows:

$$X^{[1]} = X^{[0]}(1 + 0.01C)$$

where C is defined as follows:

for $\Delta^2>0$ ($Z=f(X)$ is concave up)

$$C = \frac{\Delta_1}{\Delta^2} - 0.5$$

for $\Delta^2<0$ ($Z=f(X)$ is concave down)

$$C = 50 \qquad for\ \Delta_1>0$$

$$C = -33 \qquad for\ \Delta_1\leq 0$$

for $\Delta^2=0$ ($Z=f(X)$ is linear)

$$C = -33 \qquad for\ \Delta_1<0$$

$$C = 0 \qquad for\ \Delta_1=0$$

$$C = 50 \qquad for\ \Delta_1>0$$

If the value of the objective function is not reduced with the new parameter value, the parameter value is adjusted to a value between the old and new values, as follows:

$$X^{[2]} = 0.7X^{[0]} + 0.3X^{[1]}$$

If the value of the objective function is still not reduced, the initial value, $X^{[0]}$, is retained, and the iteration is terminated.

Search Sequence. The procedure just described is applied to each selected parameter in sequence, to complete the first pass through the parameters. This is followed with three additional passes. Next, the parameter which produced the greatest reduction in the objective function (for the most recent adjustment of that parameter) is selected, and a new value is projected for that parameter. This procedure is repeated until the reduction in the objective function drops to less than 1 %.

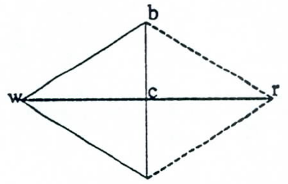
Nelder and Mead Method (N&M)

The N&M is based conceptually on constructing a polyhedron (simplex) in *n*-dimensional space. The sides of the simplex expand and contract as its vertices are moved through space until the objective function value reaches the same minimum at all except one vertex.

If there are n parameters, the space is n-dimensional, and n+1 points are chosen to define the simplex. For example, if there are two parameters the shape is a triangle; for three parameters it is a tetrahedron. The method operates as follows:

Step 1. Find the vertices with the best (lowest) and worst (highest) values of the objective function.

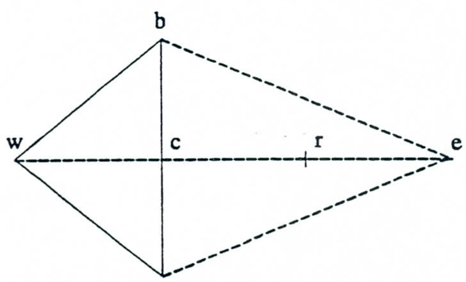
Step 2. Find the centroid of all vertices excluding the worst vertex. Project a line from the worst vertex through the centroid, and reflect the worst vertex about the centroid to a point on this line opposite the worst vertex.



Reflection

$$x_i(reflected) = x_i(centroid) + 1.0\,[x_i(centroid) - x_i(worst)]$$

Step 3a. If the reflected point is better than, or as good as, the best vertex, expand the simplex in the same direction. If the expanded vertex is better than the best vertex, replace the worst vertex with the expanded vertex. If the expanded vertex is not better than the best vertex, replace the worst vertex with the reflected vertex.

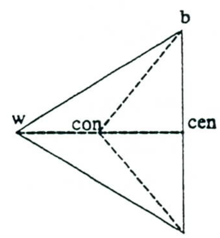


Expansion

$$x_i(expanded) = x_i + 2.0\,[x_i(reflected) - x_i(centroid)]$$

Step 3b. If the reflected vertex is worse than the best vertex, but better than some other vertex excluding the worst vertex, replace the worst vertex with the reflected vertex.

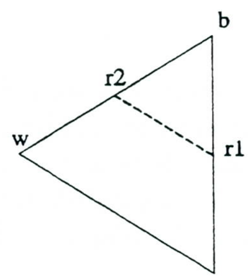
Step 3c. If the reflected vertex is not better than any other vertex, excluding the worst vertex, make the simplex smaller. First try contracting the worst vertex along the line toward the centroid. If the contracted vertex is better, use it to replace the worst vertex.



Contraction

$$x_i(contracted) = x_i(centroid) - 0.5\,[x_i(centroid) - x_i(worst)]$$

Step 3d. If the contracted vertex does not provide an improvement, reduce the simplex by moving all vertices toward the best vertex.



Reduction

$$x_{i,j}(reduced) = x_i(best) + 0.5\,[x_{i,j} - x_i(best)]$$

Step 4. The search is terminated when the square root of the average difference-squared between the objective function at the centroid and the vertices (excluding the worst vertex) is less than a specified value, or the maximum number of iterations has been reached.

$$\sqrt{\sum_{j=1,\, j \neq worst}^{n} \frac{(z_j - z_c)^2}{n-1}} < tolerance$$

The parameter values at the best vertex are used as the optimal values. The maximum number of iterations is 50 times the number of parameters to be optimized.

APPENDIX D

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There are two basic types of frequency curves used in hydrologic engineering:

1. A curve of **annual maximum events** is ordinarily used when the primary interest lies in the very large events or when the second largest event in any year is of minor concern in the analysis

2. The **partial-duration curve** represents the frequency of all events above a given base value, regardless of whether two or more occurred in the same year. This type of curve is ordinarily used in economic analysis when there are substantial damages resulting from the second largest and third largest floods in extremely wet years. Damage from floods occurring more frequently than the annual event can occur in agricultural areas, when there is sufficient time between events for recovery and new investment.

When both the frequency curve of annual floods and the partial-duration curve are used, care must be exercised to assure that the two are consistent.

Maximum Floodflows in
the Conterminous United States
Geol. Survey Water-Supply Paper 1887
J.R. Crippen & Conrad D. Bue
US Gov. printing office, Washington, 1977

FLOW FREQUENCY ANALYSIS

categories of streamflow data:

- systematic records
- historic records
- comparison with similar watersheds

  useful when gaging stations are on the same stream or in watersheds with centers not more than 50 miles apart
- flood estimates from **precipitation** data - requires use of a well calibrated rainfall-runoff model

FLOW FREQUENCY ANALYSIS

data assumptions

flood information is a reliable and representative time sample of random homogeneous events

- climatic trends
- randomness of events
- watershed changes
    1. urbanization
    2. channelization
    3. levees
    4. reservoirs
    5. diversions
    6. alteration of cover conditions
- mixed populations
- reliability of flood estimates - measuring error

Broken record (missing years) - the different record segments are analyzed as a continuous record with the length equal to the sum of the available records.

Incomplete record (missing peak flows) - estimate required.

Mixed populations (e.g. hurricane and non hurricane events) - segregate the flood data by cause, analyze each set separately, combine the data sets statistically.

*Historic flood data*_ (maximum extreme flows occurring outside of the systemic record) - should be used in frequency computation

Outliers (data points which depart significantly from the trend of the remaining data) *identifying high outliers:*

$$X_H = X + K_N S$$

X_H = high outlier threshold in log units;
X = mean logarithm of systemic peaks (X's) excluding, zero flood events, peaks below gage base, and outliers previously detected
K_N = tabular **K** value for sample size **N**
S = standard deviations of X's

- flood peaks identified as high outliers should be compared with historic flood data and flood information at nearby sites
- if the outlier is found to be the maximum in an extended period of time then it is treated as an historic flood

identifying low outliers:

$$X_L = X - K_N S$$

X_H = low outlier threshold in log units;
X = mean logarithm of systemic peaks (X's) excluding, zero flood events, peaks below gage base, and outliers previously detected
K_N = tabular K value for sample size N
S = standard deviations of X's

Reliability frequency curve is only an estimate of the parent population

Confidence limits - provide either a measure of the uncertainty of the estimated exceedance probability of a selected discharge or a measure of the uncertainty of the discharge at the selected exceedance probability

risk - the probability that one or more events will exceed a given flood magnitude within a specified period of years.

Expected probability - the average of the true probabilities of all magnitude estimates for any specified flood frequency that might be made from successive samples of a specified size.

- It is an attempt to incorporate the effects of uncertainty.
- it is most often used in estimates of annual flood damages and in establishing design flood criteria

flood frequency computation

- annual flood series
- partial duration series

flood events are a succession of natural events which as far as can be determined do not fit any one specific known frequency distribution

the Pearson Type III distribution with log transformation of the data is the recommended method for analysis of annual series data using a generalized skew coefficient

fitting a log Pearson Type III distribution to annual peaks

- compute base 10 logs of the discharge, **Q,** at selected exceedance probability, **P**, by the equation:

$$\text{Log } Q = X + KS$$

- **K** is a function of the skew coefficient and selected exceedance probability
- *skew* - more developed on one side that the other; an unsymetrical frequency distribution having the mode at a different value from the mean
- *mode* - the most frequent value in a frequency distribution
- the skew coefficient of the station record (*station skew*) is sensitive to extreme events

- the accuracy of the estimated skew coefficient can be improved by weighting the station skew with *generalized skew* estimated by pooling information from nearby sites

- generalized skew coefficients requires the use of at least 40 stream gaging stations or all stations within a 100 mile radius

- the stations should have at least 25 years of record

computing a weighted skew coefficient

$\mathbf{G_w}$ = weighted skew coefficient
$\mathbf{G}$ = station skew
G = generalized skew
$\mathbf{MSE}_{\mathit{G}}$ = mean square error of generalized skew
$\mathbf{MSE}_{\mathrm{G}}$ = mean square error of station skew

$$\mathbf{G_w} = \frac{\mathbf{MSE}_{\mathit{G}}(\mathbf{G}) + \mathbf{MSE}_{\mathrm{G}}(\mathit{G})}{\mathbf{MSE}_{\mathit{G}} + \mathbf{MSE}_{\mathrm{G}}}$$

You are designing a dam on a stream with the following stream gage record close to the damsite

The flows shown are annual peaks. Using the Weibull plotting position formula, what can you conclude about flow frequency at the site?

water year	peak flow		m	P	
1974	789	3498	1	0.038	
1975	225	3389	2	0.077	
1976	~~3300~~	3300	3	0.115	
1977	3389	2220	4		
1978	~~1122~~	1765			
1979	987	1657			
1980	267	1309			
1981	~~1309~~	1130			
1982	986	1122			
1983	873				
1984	456				
1985	~~3498~~				
1986	790				
1987	~~1765~~				
1988	998				
1989	456				
1990	876				
1991	~~2220~~				
1992	871				
1993	992				
1994	548				
1995	~~1657~~				
1996	334				
1997	980				
1998	~~1130~~				

N=26

$$P = \frac{m}{n+1}$$

Plotting Position

results of an analysis can be shown ***graphically*** to permit an evaluation of the effect on the analysis of including historic data

general equation for plotting position:

$$P = \frac{(m - a)}{(N - a - b + 1)}$$

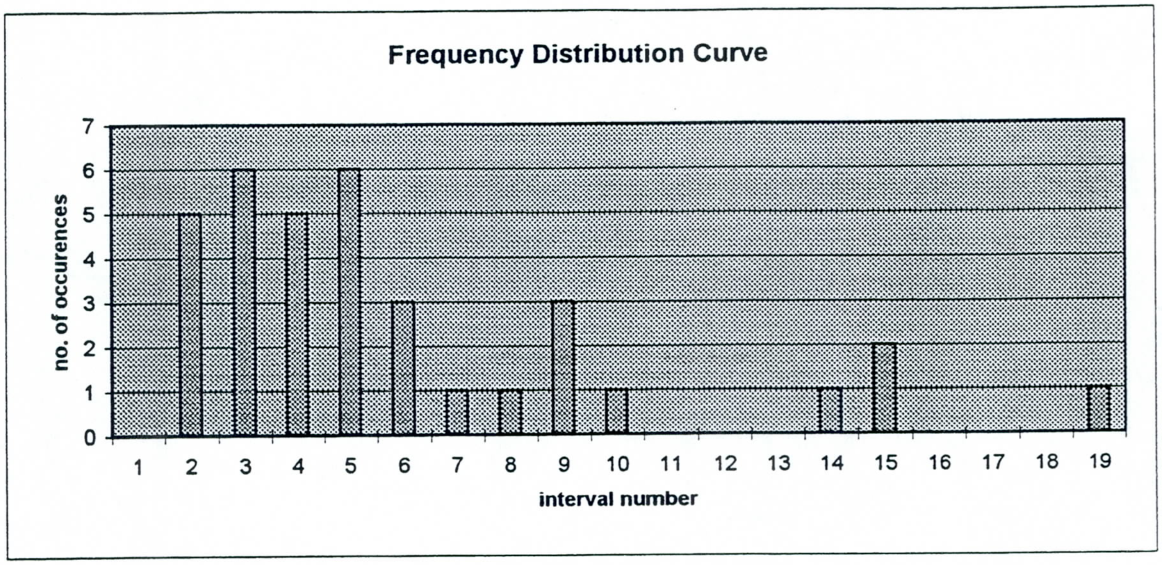
m = ordered sequence of flood values with the largest first
N = number of items in data set
a,b depend on the distribution. For symmetrical distributions **a=b**

*Weibull plotting position_* a=b =0

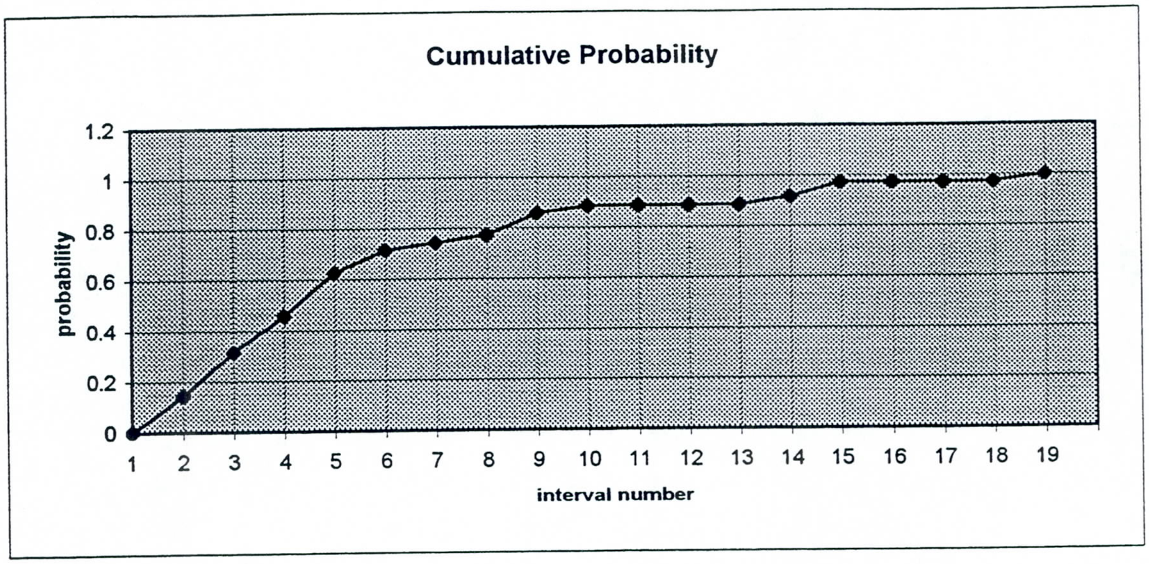
$$P = \frac{m}{N + 1}$$

147 mi²
440 cfs/mi²

water year	peak Q		water year	peak Q
	x			x
1938	5720		1938	5720
1939	4380		1939	4380
1940	3620		1940	3620
1941	1710		1941	1710
1942	8760		1942	8760
1943	8160		1943	8160
1951	2010		1951	2010
1952	6400		1952	6400
1953	15000		1953	15000
1954	2010		1954	2010
1955	2920		1955	2920
1956	1860		1956	1860
1957	5900		1957	5900
1958	4060		1958	4060
1959	2740		1959	2740
1960	2920		1960	2920
1961	9840		1961	9840
1962	8300		1962	8300
1963	5900		1963	5900
1964	15000		1964	15000
1965	18500		1965	18500
1966	3850		1966	3850
1967	1760		1967	1760
1968	1100		1968	1100
1969	4160		1969	4160
1970	4840		1970	4840
1971	2590		1971	2590
1972	1670		1972	1670
1973	4330		1973	4330
1974	3120		1974	3120
1975	4660		1975	4660
1976	3630		1976	3630
1977	3500		1977	3500
1978	7960		1978	7960
1990	13200		1990	13200
			1994	64700
sigma x	196080		sigma x	260780
n	35		n	36
ave x	5602		ave x	7243.89



		n	n/N		sum n/N
0-1000	1	0	0	1	0
1001-2000	2	5	0.14	2	0.14
2001-3000	3	6	0.17	3	0.31
3001-4000	4	5	0.14	4	0.46
4001-5000	5	6	0.17	5	0.63
5001-6000	6	3	0.09	6	0.71
6001-7000	7	1	0.03	7	0.74
7001-8000	8	1	0.03	8	0.77
8001-9000	9	3	0.09	9	0.86
9001-10000	10	1	0.03	10	0.89
10001-11000	11	0	0.00	11	0.89
11001-12000	12	0	0.00	12	0.89
12001-13000	13	0	0.00	13	0.89
13001-14000	14	1	0.03	14	0.91
14001-15000	15	2	0.06	15	0.97
15001-16000	16	0	0.00	16	0.97
16001-17000	17	0	0.00	17	0.97
17001-18000	18	0	0.00	18	0.97
18001-19000	19	1	0.03	19	1
		35	N		



Q interval		n	sum n/N
0-1000	1	0	0
1001-2000	2	5	0.14
2001-3000	3	6	0.31
3001-4000	4	5	0.46
4001-5000	5	6	0.63
5001-6000	6	3	0.71
6001-7000	7	1	0.74
7001-8000	8	1	0.77
8001-9000	9	3	0.86
9001-10000	10	1	0.89
10001-11000	11	0	0.89
11001-12000	12	0	0.89
12001-13000	13	0	0.89
13001-14000	14	1	0.91
14001-15000	15	2	0.97
15001-16000	16	0	0.97
16001-17000	17	0	0.97
17001-18000	18	0	0.97
18001-19000	19	1	1

N= 35

without Alberto data				*with Alberto data*			
sorted Q	m	P	return interval	sorted Q	m	P	return interval
18500	1	0.028	36	64700	1	0.027	37
15000	2	0.056	18.00	18500	2	0.054	18.50
15000	3	0.083	12.00	15000	3	0.081	12.33
13200	4	0.111	9.00	15000	4	0.108	9.25
9840	5	0.139	7.20	13200	5	0.135	7.40
8760	6	0.167	6.00	9840	6	0.162	6.17
8300	7	0.194	5.14	8760	7	0.189	5.29
8160	8	0.222	4.50	8300	8	0.216	4.63
7960	9	0.250	4.00	8160	9	0.243	4.11
6400	10	0.278	3.60	7960	10	0.270	3.70
5900	11	0.306	3.27	6400	11	0.297	3.36
5900	12	0.333	3.00	5900	12	0.324	3.08
5720	13	0.361	2.77	5900	13	0.351	2.85
4840	14	0.389	2.57	5720	14	0.378	2.64
4660	15	0.417	2.40	4840	15	0.405	2.47
4380	16	0.444	2.25	4660	16	0.432	2.31
4330	17	0.472	2.12	4380	17	0.459	2.18
4160	18	0.500	2.00	4330	18	0.486	2.06
4060	19	0.528	1.89	4160	19	0.514	1.95
3850	20	0.556	1.80	4060	20	0.541	1.85
3630	21	0.583	1.71	3850	21	0.568	1.76
3620	22	0.611	1.64	3630	22	0.595	1.68
3500	23	0.639	1.57	3620	23	0.622	1.61
3120	24	0.667	1.50	3500	24	0.649	1.54
2920	25	0.694	1.44	3120	25	0.676	1.48
2920	26	0.722	1.38	2920	26	0.703	1.42
2740	27	0.750	1.33	2920	27	0.730	1.37
2590	28	0.778	1.29	2740	28	0.757	1.32
2010	29	0.806	1.24	2590	29	0.784	1.28
2010	30	0.833	1.20	2010	30	0.811	1.23
1860	31	0.861	1.16	2010	31	0.838	1.19
1760	32	0.889	1.13	1860	32	0.865	1.16
1710	33	0.917	1.09	1760	33	0.892	1.12
1670	34	0.944	1.06	1710	34	0.919	1.09
1100	35	0.972	1.03	1670	35	0.946	1.06
				1100	36	0.973	1.03

water year	peak Q	log Q = X	n	X - x	(X-x)^2	(X-x)^3
	x					
1938	5720	3.76	1	0.11	0.01	0.00
1939	4380	3.64	2	0.00	0.00	0.00
1940	3620	3.56	3	-0.08	0.01	0.00
1941	1710	3.23	4	-0.41	0.17	-0.07
1942	8760	3.94	5	0.30	0.09	0.03
1943	8160	3.91	6	0.27	0.07	0.02
1951	2010	3.30	7	-0.34	0.12	-0.04
1952	6400	3.81	8	0.16	0.03	0.00
1953	15000	4.18	9	0.53	0.28	0.15
1954	2010	3.30	10	-0.34	0.12	-0.04
1955	2920	3.47	11	-0.18	0.03	-0.01
1956	1860	3.27	12	-0.37	0.14	-0.05
1957	5900	3.77	13	0.13	0.02	0.00
1958	4060	3.61	14	-0.03	0.00	0.00
1959	2740	3.44	15	-0.21	0.04	-0.01
1960	2920	3.47	16	-0.18	0.03	-0.01
1961	9840	3.99	17	0.35	0.12	0.04
1962	8300	3.92	18	0.28	0.08	0.02
1963	5900	3.77	19	0.13	0.02	0.00
1964	15000	4.18	20	0.53	0.28	0.15
1965	18500	4.27	21	0.62	0.39	0.24
1966	3850	3.59	22	-0.06	0.00	0.00
1967	1760	3.25	23	-0.40	0.16	-0.06
1968	1100	3.04	24	-0.60	0.36	-0.22
1969	4160	3.62	25	-0.02	0.00	0.00
1970	4840	3.68	26	0.04	0.00	0.00
1971	2590	3.41	27	-0.23	0.05	-0.01
1972	1670	3.22	28	-0.42	0.18	-0.07
1973	4330	3.64	29	-0.01	0.00	0.00
1974	3120	3.49	30	-0.15	0.02	0.00
1975	4660	3.67	31	0.03	0.00	0.00
1976	3630	3.56	32	-0.08	0.01	0.00
1977	3500	3.54	33	-0.10	0.01	0.00
1978	7960	3.90	34	0.26	0.07	0.02
1990	13200	4.12	35	0.48	0.23	0.11
		127.51			3.13	0.20
	mean log	3.64	x			
	mean log	***3.64***				
	stan dev of logs	***0.30***				
	skew coef of log	***0.22***				

water year	peak Q	log Q = X	n	X - x	(X-x)^2	(X-x)^3	
	x						
1938	5720	3.757	1	0.082	0.007	0.001	
1939	4380	3.641	2	-0.034	0.001	0.000	
1940	3620	3.559	3	-0.117	0.014	-0.002	
1941	1710	3.233	4	-0.443	0.196	-0.087	
1942	8760	3.943	5	0.267	0.071	0.019	
1943	8160	3.912	6	0.236	0.056	0.013	
1951	2010	3.303	7	-0.372	0.139	-0.052	
1952	6400	3.806	8	0.130	0.017	0.002	
1953	15000	4.176	9	0.500	0.250	0.125	
1954	2010	3.303	10	-0.372	0.139	-0.052	
1955	2920	3.465	11	-0.210	0.044	-0.009	
1956	1860	3.270	12	-0.406	0.165	-0.067	
1957	5900	3.771	13	0.095	0.009	0.001	
1958	4060	3.609	14	-0.067	0.005	0.000	
1959	2740	3.438	15	-0.238	0.057	-0.013	
1960	2920	3.465	16	-0.210	0.044	-0.009	
1961	9840	3.993	17	0.317	0.101	0.032	
1962	8300	3.919	18	0.243	0.059	0.014	
1963	5900	3.771	19	0.095	0.009	0.001	
1964	15000	4.176	20	0.500	0.250	0.125	
1965	18500	4.267	21	0.591	0.350	0.207	
1966	3850	3.585	22	-0.090	0.008	-0.001	
1967	1760	3.246	23	-0.430	0.185	-0.080	
1968	1100	3.041	24	-0.634	0.402	-0.255	
1969	4160	3.619	25	-0.057	0.003	0.000	
1970	4840	3.685	26	0.009	0.000	0.000	
1971	2590	3.413	27	-0.262	0.069	-0.018	
1972	1670	3.223	28	-0.453	0.205	-0.093	
1973	4330	3.636	29	-0.039	0.002	0.000	
1974	3120	3.494	30	-0.182	0.033	-0.006	
1975	4660	3.668	31	-0.007	0.000	0.000	
1976	3630	3.560	32	-0.116	0.013	-0.002	
1977	3500	3.544	33	-0.132	0.017	-0.002	
1978	7960	3.901	34	0.225	0.051	0.011	
1990	13200	4.121	35	0.445	0.198	0.088	
1994	64700	4.811	36	1.135	1.289	1.463	
		132.325		0.000	4.458	1.355	
	mean log	3.676	x				
	mean log	**3.676**					
	stan dev of logs	***0.356878***					
	skew coef of log	***0.000826***					

2 - check for outliers							
	17B - pg 4-1	n=36 K_N = 2.639					
	$Q_H = X + K_N S$					$Q_L = X - K_N S$	
	= 3.676 + 2.639 * 0.356878			4.618		2.734199	
	Q_H = 41,500 cfs				**Q_L = 542 cfs**		

Probability of exceeding the "n" year flood in "x" consecutive years

	Flood Return Period (n)					
Interval (x)	1000 year	500 year	100 year	50 year	25 year	5 year
100 years	0.095	0.181	0.634	0.867	0.983	1.000
50 years	0.049	0.095	0.395	0.636	0.870	1.000
25 years	0.025	0.049	0.222	0.397	0.640	0.996
10 years	0.010	0.020	0.096	0.183	0.335	0.893
5 years	0.005	0.010	0.049	0.096	0.185	0.672
1 year	0.001	0.002	0.010	0.020	0.040	0.200

example: The probability that the 100 year flood will be exceeded in a period of 25 years is .222

Hydrologic Engineering for Dam Design

COMPUTER APPLICATION

FLOW FREQUENCY

Installation Instructions for Microcomputer
Version of HEC-FFA

FLOOD FREQUENCY ANALYSIS

Version 3.1; February 1995

Hardware Requirements:

FFA will run on a DOS microcomputer that has the following:

* 640 Kilobytes (KB) of Random Access Memory (RAM) (300,000 bytes available for program execution)
* MS DOS 2.1 or greater
* 1 Megabyte free space on hard disk

Installation on a Hard-Disk System

Installation is accomplished through the use of an interactive program called INSTALL. If you do not want to use this installation program, see "Alternative Installation" section. To install the software onto your hard disk, using INSTALL, do the following:

1. Start your computer and go to the drive (e.g. C: or D:) in which you would like to install this software.

2. Place the HEC-FFA package diskette into the A: drive.

4. Type A:INSTALL and press enter.

5. Follow the instructions listed on the screen by the install program.

The following is a summary of what the INSTALL program accomplishes:

1. Creates directories \HECEXE and \HECEXE\SUP in the C: or D: drives. The \HECEXE directory is used to store all of the executable programs, and the \HECEXE\SUP directory is used for any supplemental files required by the executable programs.

2. Un-compresses and copies the files into the appropriate directories.

3. Displays information about modifying the CONFIG.SYS and AUTOEXEC.BAT files in order to execute the programs.

Contents of the FFA Package Diskette:

INSTALL.BAT Batch file to initiate installation of FFA programs
TMPINS.ZIP Compressed batch file to install FFA programs
FFA.ZIP This compressed file contains the following:
- FFA.EXE - Frequency analysis program
- FFAM.EXE - Menu program
- FFAMENU.BAT - Batch file for menu program
- FGRAPH.EXE - Graphics program to view frequency analysis on screen
- LIST.COM - Utility for screen displays of isk files
- PROUT.EXE - Utility to send output files to printer with carriage control invoked

FFAHPG.ZIP Compressed help file for use with COED (COEDFFA.HPG)
FGRAPH.ZIP Compressed file containing fonts for FGRAPH program (FGRAPH.FON)
DATA.ZIP Compressed FFA example input files
PKUNZIP.EXE Utility to restore compressed files
ASKME.COM Utility program used by INSTALL.BAT
README.TXT These instructions on file

Alternative Installation

For the manual installation instructions below, the root directory is assumed to be C:\, and the recommended directory tree system in Figure 1 is assumed to already exist. The following commands demonstrate how the files can be uncompressed to a hard disk.

1. To install FFA program, insert the FFA disk and (from a:\) type:

   PKUNZIP FFA.ZIP FFA.EXE C:\HECEXE

   This will produce:
   FFA.EXE FFA executable file.

2. To install FFAMENU program, (from a:\) type:

   PKUNZIP FFA.ZIP FFAM.EXE C:\HECEXE
   PKUNZIP FFA.ZIP FFAMENU.BAT C:\HECEXE

   This will produce:
   FFAM.EXE FFAMENU executable file.
   FFAMENU.BAT FFAMENU batch file.

5. To install the utilities LIST and PROUT, (from a:\) type:

   PKUNZIP FFA.ZIP LIST.COM C:\HECEXE
   PKUNZIP FFA.ZIP PROUT.EXE C:\HECEXE

   This will produce:
   LIST.COM Utility for screen display of disk files.
   PROUT.EXE Utility to send output files to printer.

4. To install FGRAPH program, (from a:\) type:

PKUNZIP FFA.ZIP FGRAPH.EXE C:\HECEXE
PKUNZIP FGRAPH.ZIP FGRAPH.FON C:\HECEXE\SUP

This will produce:
FGRAPH.EXE The Frequency Curve Graphing-to-Screen Utility Program.
FGRAPH.FON The Font file for FGRAPH (required for FGRAPH).

5. To install the FFA example input files, (from a:\) type:

PKUNZIP DATA.ZIP C:\FFA

This will produce six input files corresponding to the example problems in the user's manual. The FFA output files for these examples are shown in the user's manual.

FLOOD FREQUENCY ANALYSIS

Program Execution

Change to the FFA directory and type **FFAMENU**. This will activate the FFA menu. Use the menu to perform the desired actions.

A DOS-based screen graphics program, **FGRAPH**, is included in the **FFA** package. This program plots your frequency curve results to the screen.

I. TITLE RECORDS

TT Record - Title Information

Field	Variable	Value	Description
1-10	–	Alpha	Alphanumeric information to identify the job. As many TT records may be supplied as necessary to input the desired descriptive information.

II. JOB RECORDS

J1 Record - First Job Record

Job record which specifies program options. If omitted, default values in parentheses will be assigned. When this record is provided, the specified input options will be maintained for all succeeding stations until another J1 record is encountered.

Field	Variable	Value	Description
1	IPPC (1)	+	Plotting positions in the program are computed by the general formula (m-A)/(N+1-A-B) where: m = order number N = number of years A,B = constants The standard constants may be specified below. If other constants are desired, they may be specified on the J2 record.
		0 or 1	Weibull plotting positions will be used for output and plotting (A and B equal 0.0).
		2	Median plotting positions will be used for output and plotting (A and B equal 0.3).
		3	Hazen plotting positions will be used for output and plotting (A and B equal 0.5).
		4	Plotting positions constants (A and B) will be read in on J2 record.

J1 Record - First Job Record (continued)

Field	Variable	Value	Description
2	ISKFX	0 or 1	Adopted skew coefficient will be the weighted value computed in accordance with the WRC Guidelines and rounded to the nearest tenth.
		2	Adopted skew coefficient will be the weighted value computed as above, except it is not rounded.
		3	Adopted skew coefficient will be set equal to the input regional map skew coefficient which is read in on the GS record, i.e., no weighing with the station skew coefficient.
3	IPROUT (0)	+	The sum of the following output codes which suppress selected portions of the normal output. For example, a value of 63 would suppress all output except the printout of the frequency curve ordinates and statistics of the final results.
		0	No output suppressed.
		1	Suppress the printout of input data, arrayed data, and plotting positions of the preliminary results.
		2	Suppress the printout of the frequency curve ordinates and corresponding statistics of the preliminary results.
		4	Suppress the plot of the preliminary results.
		8	Suppress the printout of input data, arrayed data, and plotting positions of the final results.
		16	Suppress the plot based on computed flows from the final results.
		32	Suppress the plot based on the expected probability adjustment of the flows from the final results.
		64	Suppress the printout of the frequency curve ordinates and corresponding statistics of the final results. A value of 127 for IPROUT will suppress all station output except for the summary of results.

J1 Record - First Job Record (continued)

Field	Variable	Value	Description
4	IFMT	0 or 1	Flow data is in the format specified for QH or QR records.
		2	Data is in the format of four 8-column fields for day, month, year and flow (note order of day and month).
		3	Format of data is specified by FT record for month, day, year and flow (note order of day and month).
		4	Format of data is specified by FT record for day, month, year and flow (note order of day and month).
5	IWYR	0	Annual series data selected from the standard water year (October-September), IWYR will be set to 10.
		+	The order number of the first month in the water year, e.g., 1 for calendar year beginning in January, etc.
6	IUNIT	0 or 1	Label for plot will be "CUBIC FEET PER SECOND."
		2	Label for plot will be "CUBIC METERS PER SECOND."
		3	Label for plot will be input on FU record.
7	ISMRY	0	No summary will be printed.
		1	A summary of the final results will be printed for all of the stations in the run.
		2	A summary of the preliminary results will be printed.
		3	A summary of both the preliminary and the final results will be printed.

J1 Record - First Job Record (continued)

Field	Variable	Value	Description
8	IPNCH	0	No statistics written to special file.
		1	Station statistics will be written for final results.
		2	Station statistics will be written for the preliminary results.
		3	Station statistics will be written for the preliminary and final results.

Statistics will be output in the format as shown below:

Item	Record Columns
SS - Record identification	1- 2
DURN - type of analysis	3- 8
USGS part number	9-10
Station identification number	11-16
Number of events in systematic record	17-20
Historic period	21-24
Station mean	25-32
Station standard deviation	33-40
Station computed skew coefficient	41-48
Station regional skew coefficient	49-56
Station adopted skew coefficient	57-64
Number of historic events	65-68
Number of high outliers	69-72
Number of low outliers	73-76
Number of zero or missing flows	77-80

Field	Variable	Value	Description
9	IREG		This field is only needed when the input flow data is in WATSTORE format. Otherwise the field should be left blank.
		0	Delete all events with a <u>known</u> or <u>unknown</u> effect of regulation or diversion. All flow records with a "1", "2", "5", or "6 in column 33 are deleted.
		2	Include all flow data, regardless of the code in column 33 of the flow record.

J2 Record - Second Job Record

Job record which specifies nonstandard plotting position constants and criteria for confidence limits.

Field	Variable	Value	Description
1	A	+	Plotting position constants A and B. Default values are those specified by IPPC (J1.1). IPPC must equal 4 to activate these input constants.
2	B	+	
3	CLIMIT (0.05)	+	Confidence limit probability for either side. Default value of zero computes the .05 and the complimentary .95 confidence limits. The approximating equations become less accurate for small sample sizes as smaller values are specified, e.g., the .01 limit values are less accurate than .05 limit values for 10 years of data.
4	NDSSCV	0	If a DSS write is used (see ZW record) then NDSSCV specifies the frequency curves that are written to the DSS file. If NDSSCV is not specified FFA will default to writing four curves to the DSS file: the computed, the expected probability and the upper and lower confidence curves.
		1	Computed curve only.
		2	Expected Probability curve only.
5	IEXT	0	Extended character set indicator. The default for output text is to use the extended character set. (i.e. lines around the tables in printout rather than asterisks)
		1	If a printer without extended character set capability is used, then set IEXT to 1. Program will print only conventional text in output file.

FR Record - Frequency Ordinates Record

The FR record is used to specify nonstandard frequency ordinates. When specified, the number of decimal places printed in frequency curve table increases from one to two.

Field	Variable	Value	Description
1	NFRQ	+	NFRQ is the number of frequency ordinates that will be specified (up to 25). If more than nine ordinates are to be input, then more FR records must be used, but NFRQ is only specified on the first FR record.
2-10	FREQ(1...NFRQ)	+	Frequency ordinates, in percent. These must be input in ascending order. The ordinates 1., 10. and 50. percent must be included in this record. This is for the conditional probability adjustment. Note, for second FR record, ordinates are specified on fields 1-10.

FT Record - Flow Format

Provide this record if IFMT (J1.4) is 3 or 4.

Field	Variable	Value	Description
1- 10	IFRMT	Alpha	Format of data on records. If IFMT is 3, the format specification must have fields for data in the following order: month, day, year, and flow, "(8X, 212, I4, F8.0)" is the standard program format. The parentheses must be included in the format specification. If IFMT is 4, the format specification must have fields for data in the following order: day month, year, and flow, e.g., "(3I8, F8.0)" is the format of input data for the program in the WRC Guidelines. The parentheses must be included in the format specification.

FU Record - Variable Name and Units Labels (optional record)

(Can be provided anytime.)

Field	Variable	Value	Description
0	ICD	FU	Record identifier.
1	VNAME (FLOW)	Char	Variable name label, i.e., FLOW, ELEV, etc. Limited to 6 characters in columns 3 through 8 and is used in various table headings. Only the first four characters will be used in the DSS write. The default is 'FLOW'.
2	VUNIT (CFS)	Char	Units label, i.e., CFS, FEET, etc. May be 8 characters in length. The label also is used in table headings and the DSS write. The default is 'CFS '.

III. STATION DATA RECORDS

ID Record - Station Identification and Information

Field	Variable	Value	Description
1-10	ISTA	Alpha	Alphanumeric information such as station number, location, drainage area, period of record, etc. Although columns 2-8 may be used for station identification, only columns 3 through 48 are printed as a heading for each table. If this record is not provided, the brief station identification on the GS record (GS.1) will be used. if a GS record is not provided, the array is filled with blanks

GS Record - Generalized skew

This record is used to specify the generalized (regional map) skew coefficient which will be weighted with the station skew coefficient in accordance with the Bulletin 17B Guidelines. If this record is not provided, the computed station skew coefficient, founded to the nearest tenth if ISKFX(J1.2) is equal to 0 or 1, will be used in computing the frequency curve. If the GS record is included in the input file, but all fields are left blank, FFA will proceed with the analysis with a generalized skew of 0 with a mean square error of 0.302 (the default value).

Field	Variable	Value	Description
1	ISTN	Alpha	Brief alphanumeric identification of station, e.g., could be USGS station number, to assist in identifying record. If a ID record is not provided, the information in this field will be used to label the output.
2	GGMSE	+	Mean squared error (MSE) of the generalized skew if Plate I, Bulletin 17b is not used. If left blank, a value of 0.302 will be used to correspond with Plate I.
3	SKEW	+	Regional (Generalized) skew coefficient.

SI Record - Special Station Information

This record is used to input a historic period other than that represented by the flow data records, to specify the number of high outliers in the systematic record, and to input a base peak discharge.

Field	Variable	Value	Description
1	IYRA	+	The earliest year for defining a period during which the largest recorded events (see NOUTL, SI.3) or historic events (see QH records) are known to be a maximum. If left blank, IYRA will be the first year found on either QH or QR records.
2	IYRL	+	The last year of the period for which the historic information applies. if left blank, IYRL will be the last year found on either QH or QR records.
3	HITHRS	+	Magnitude of high outlier flood peak. All flood peaks <u>in the systematic record</u> (QR records) greater than or equal to HITHRS, are treated as high outliers in the historic period IYRA to IYRL.
		0	If historic data is provided and HITHRS is not specified, it will default to the lowest historic peak.
4	LOTHRS	+	Magnitude of low threshold flood peak. Any recorded event less than or equal to LOTHRS will be treated as a low outlier.
		0	The program automatically applies the WRC procedures to identify and adjust for low outliers (default).
5	LOGT (1)		Logarithmic transformation indicator for frequency analysis.
		-1	No transformation.
		0,1	Log (base 10) transformation, default.
6	NDEC (0)	+	Number of decimal places to print in tables of plotting positions and frequency curve ordinates; 0, 1, 2, or 3 allowed.
7	NSIG (3)		Number of significant figures in output of computed frequency curve ordinates.
		-1	No rounding will be done.
		0	Round to 3 significant figures, default.
		+	Round values to NSIG significant figures.

SS

SS Record - Station Statistics

With this record, FFA can be used to calculate log Pearson type III frequencies given; mean, standard deviation, and skew of the logarithm of the flows. The output tabulated frequency curve is in the same format as would normally be produced for systematic data.

This record can be input manually using the nonstandard fields listed below or can generated by FFA on a previous run. FFA will generate this record and write it to a file specified on the execution line (see IPNCH variable, field 8 on the J1 record). Common fields are not used for the station statistics because it contains 14 pieces of information. The columns numbers for the variables are listed rather than field numbers.

To calculate the frequency curve the only variables required are the mean, standard deviation and the adopted skew. The mean and standard deviation must be input, but FFA will calculate the adopted skew if the computed skew, the generalized skew and the number of years of record are input.

	Columns	Variable	Value	Description
	3-8	DURN	Alpha	Type of analysis. If left blank DURN will default to 'PEAK' analysis.
	9-11	IPART	Alpha	USGS part number.
	11-16	ISTN	Alpha	Station identification number.
	17-20	NSYS	+	Number of events in systematic record.
	21-24	NYR	+	Historic period.
	25-32	XM	+	Station mean.
	33-40	S	+	Station standard deviation.
*	41-48	G	+	Station computed skew coefficient.
*	49-56	SKEW	+	Station regional map skew coefficient.
*	57-64	AG	+	Station adopted skew coefficient.
	65-68	NHIS	+	Number of historic events.
	69-72	NOUTL	+	Number of high outliers.
	73-76	NLOW	+	Number of low outliers.
	77-80	NZMSG	+	Number of zero or missing flows.

* The value of AG will only be used for the adopted skew if the values for G and SKEW are left blank. Otherwise, the adopted skew will be computed by weighing G and SKEW via their mean square error (MSE). The MSE for G is determined based on the maximum value of NSYS and NYR, and for SKEW via the value specified on the GS record (default equals 0.302).

ZW Record - DSS Write Pathname (optional record)

This record specifies the pathname in which to write the plotting position information and frequency curve ordinates. A ZW record must be provided for each data set for which frequency relations are to be written to a DSS file.

Field	Variable	Value	Description
0	ICD	ZW	Record identifier.
1-10	CPATH	Char	Character pathname to be assigned to curves written to a DSS file. Either pathname parts A, B, C, E, and F if the first ZW record, or just the parts that are being changed may appear in columns 3-80. The parts must be separated by a space or comma. Each pathname part may not exceed 32 characters.

An example ZW record with a full pathname is:

ZW /TEST NO 1/FISHKILL CREEK/FREQ-FLOW//1945-68/USGS ANNUAL PEAKS/

The same example with pathname parts is:

ZW A=TEST NO 1 B=FISHKILL CREEK C=FREQ-FLOW E=1945-68 F=USGS ANNUAL PEAKS

The usual conventions for DSS pathnames are:

A = Project or Basin name.

B = Stream, gage or location name.

C = Curve parameters. This part contains the two parameter names for the data. Example valid parameters are FREQ-FLOW, FREQ-ELEV, FREQ-STAGE, FREQ-STORAGE, and FREQ-PRECIP. The FREQ part of the label is used by DSPLAY to set the probability scale; therefore, should not be changed.

D = Further identifies the curves. This part cannot be specified by the user and is assigned by the program, depending on the output as follows: a) For plotting positions and input events, 'MAX EVENTS'; or b) For computed frequency curve ordinates, 'MAX ANALYTICAL'. There are four curves contained within this pathname. They have the labels 'COMPUTED' for the computed ordinates, 'EXP PROB' for the expected probability ordinates, and two curves with 'x% LIMIT' for the upper and lower confidence limit curves.

E = Usually used as a time descriptor for data. This part is not required.

F = Unique user defined descriptor to identify the source of the data, the conditions, etc; i.e., USGS, WATSTORE, RESERVOIR INFLOW, NATURAL, etc.

An example of a paired data pathname written to HEC-DSS when a ZW record is specified is:

/TEST NO. 1/FISHKILL CREEK/FREQ-FLOW/MAX EVENTS/1945-68/USGS ANNUAL PEAKS/

HP

HP Records - Write Hewlet Packard Laser Jet Printer File

The HP record specifies the file name and title information necessary for FFA to produce a frequency plot. The file FFA produces contains the Hewlet Packard(HP) printer control characters necessary to produce the frequency plot. This file can then be sent to the printer for the plot. The codes in the file are in the Hewlet Packard Laser Jet II format, but most laser printers are HP compatible thus, plot files produced with this function can be printed on most laser printers.

Up to ten HP records can be input. The first HP record is used to enter the plot file name, the control variables and the basin area; the remaining HP records are used to enter the other title information that appears on the frequency plot.

The HP plot has a title area with room for 10 rows of information. The basin area input on the first HP record takes one of the rows and the period of record determined from the data set reserves an additional 3 rows. This leaves 6 title-information rows to be specified by the user. The default for FFA is to determine the period of record from the data set, though this option can be overridden with the variable IPER (HP.7) which would leave 9 rows for title information available for the user.

The basin area is specified in a different location than other information in an attempt to force the user to include the basin area on the plot; however, the basin area requirement can be overridden.

See example of HP record on TEST NO. 6 in Section 2 of this manual.

FIRST HP RECORD

Field	Variable	Value	Description
0	ICD	HP	Record Identifier.
1-4	HPFILE	alpha	Enter the file path(if desired) and the file name for the HP plot file. For example: PLOT6.PCL
5	IHPCV	0,1	IHPCV specifies the frequency curves to be written to HPFILE. IF IHPCV equals 0 or 1, the expected probability curve will be written to HPFILE.
		2	Computed curve will be written to HPFILE.
		3	Both the expected and computed curves will be written to HPFILE.
		4	No frequency curves will be written to HPFILE (only the plotting positions will be on plot).
6	KLIMIT	0	KLIMIT specifies wether of not the confidence limits will be written to HPFILE. If not specified, KLIMIT will default to 0 and write the confidence limits.
		1	The confidence limits will <u>not</u> be written to HPFILE.
7	IPER	0	FFA will automatically determine the period of record in water years and write on the title area of plot. (HP records 7-9 cannot be specified.)
		1	The period of record will not be calculated (HP records 7-9 can be specified for additional title information).
8-9	BAREA	alpha	Enter the phrase that describes the basin area for the frequency curve. For Example: 31 SQ MI. The string entered in BAREA is appended to the phrase: "BASIN AREA = ", and printed in the title area of the HP plot. If BAREA variable is blank the plot will be suppressed.
		N	If the area is unavailable, enter "N" in this field to override the basin area requirement.

SUBSEQUENT HP RECORDS

The second through seventh (or ninth) HP records are used to input title information. The area for title information in the plot has space for 10 lines, which are each 30 characters long. The basin area input from the first HP record is appended to the rows of title information. IF IPER is zero (default) the period of record will be determined from the data set and appended to the last rows in the title area. The block of titles will automatically be centered vertically and each individual title will be centered horizontally. See test no. 6 in section 2. All titles after 6 (or 9 if IPER =1) are not used.

HP record NO.	Variable	Field(Columns)	Value	Comments
2-7(9)	TITLE(N)	1-4 (3-32)	Alpha	Title information.

See the HP plot example for sample input and output (Section 2.6).

Commands to Print the HP Plot File on a Laser Printer

The file produced by FFA contains the printer control codes necessary to produce the plot. This information needs to be sent to the printer. In DOS this can be done with either the **PRINT** or the **COPY** commands. For example, if you produced the HP plot file **PLOT6.PCL**, type:

PRINT PLOT6.PCL

(If the computer responds with the prompt [prn], just press enter.)

Another option is to copy the file to the printer. The same example above using the copy command is:

COPY PLOT6.PCL LPT1

LPT1 used in this example is the path to the printer. This can vary with different computer systems, but usually LPT1 is the name for the printer.

QH Record - Historic Flood Peak

This record is used to input historic flood peaks that are to be weighted with the systematic record (QR records). Care must be exercised in selecting historic peaks as those peaks in the systematic record that the smallest historic peak will be treated as high outliers. Any peaks in the systematic record that are larger than the smallest input historic peak are automatically weighted along with the historic peaks. A nonstandard format and order of month and day may be used, see IFMT (J1.4).

Field	Variable	Value	Description
1	ISTN	Alpha	Brief alphanumeric identification of station e.g., could be USGS station number, to assist in identifying data.
2	IMO,IDAY,IYR	+	The month, number (columns 9 and 10), the day (columns 11 and 12) and the year (columns 13-16) of the flood flow peak. The month and/or day may be left blank. The year must be the calendar year of the event if the month is indicated; otherwise, the year must be the water year. (J1.5 for establishing water year.)
3	QH	+	Historic annual flood peak. The program is dimensioned for up to 50 historic peaks.

***QR Record** - Systematic (Recorded) Flood Peak

This record is used to input recorded flood peaks. A period of years may be absent (broken record). The QR is not required in the first two columns. Two blanks or a G blank (Regional Frequency Computation program flow record) is treated as a QR record. A nonstandard format and order of month and day may be used, see IFMT (J1.4). Records after the QR records will not be used in FFA analysis.

Field	Variable	Value	Description
1	ISTN	Alpha	Brief alphanumeric identification of station, e.g., could be USGS station number, to assist in identifying data.
2	IM,IDY,IY	+	The month number (columns 9 and 10), the day (columns 11 and 12) and the year (columns 13-16) of the flood flow peak. The month and/or day may be left blank. The year must be the calendar year of the event if the month is indicated; otherwise, the year must be the water year. (See J1.5 for establishing water year.).
3	Q	+	Recorded annual flood peak. If flow was too low to record, enter -1, and the data will be analyzed by the incomplete record procedure. The number of QH records plus QR records is dimensioned for up to 130 values.

* Required record

CD
ED

CD Record - Read Data From Hydrodata By Earth-Info (CD ROM) Data File

This record provides a link between the program FFA and the data retrieval system by HYDRODATA, where the information is stored on compact disk. The CD record replaces the QR records in FFA input file, by specifying a file name containing the peak flows in the format produced by the Hydrodata software when "Tabular" format is specified (See Appendix D).

Refer to Appendix D for an example of CD record.

Field	Variable	Value	Description
0	ICD	CD	Record identifier.
1-10	CDFILE	alpha	Enter the file path (if necessary) and the file name of data file retrieved from Hydrodata. Note the data must be in tabular format for FFA to read it.

ED Record - End of Data Record

The program reads flow data until it encounters a record that does not have a "20", "21", "QR", "G", and a blank, or has two blanks in the first two columns, or has a completely blank record or an ED in the first two columns. When any of these conditions occur, a new station is assumed unless there is no more data (end of file) in which case normal termination occurs.

SUMMARY OF INPUT RECORDS

Flood Frequency Analysis

I. Title Information:

TT	**Job Title Information (as many as needed)**								

II. Job Specification:

J1	**IPPC**	**ISKFX**	**IPROUT**	**IFMT**	**IWYR**	**IUNIT**	**ISMRY**	**IPNCH**	**IREG**
J2	**A**	**B**	**CLIMIT**	**NDSSCV**	**IEXT**				
FR	**NFRQ**	**FREQ(1)**	**FREQ(2)**	**FREQ(3)**	**...etc.**				
FT	**Nonstandard format for flood pead data**								
FU	**VNAME**	**VUNIT**							

III. Station Data Cards

ID	**Station Identification**							
GS	**ISTN**	**GGMSE**	**SKEW**					
SI	**IYRA**	**IYRL**	**HITHRS**	**LOTHRS**	**LOGT**	**NDEC**	**NSIG**	
SS	**See SS record for details of column specifications**							
ZW	**DSS pathname**							
HP	**HPFILE**				**IHPCV**	**KLIMIT**	**IPER**	**BAREA**
QH	**ISTN**	**DATE**	**QH**					
QR*	**ISTN**	**DATE**	**Q**					
CD	**CDFILE**							
ED*								

---

* Required Records

WATER SURFACE PROFILES

Hydrologic models

- simple
- easy to use
- computationally efficient

Hydraulic models

- capability to simulate the widest range of flow situations and channel characteristics
- more physically based - one parameter
- more applicable to ungaged situations

Factors to consider

1. backwater effects
   - tidal fluctuations
   - tributaries
   - dams
   - bridges
   - culverts
   - channel constrictions

2. flood plain storage factors
   - width of the flood plain
   - slope in the lateral direction
   - vegetation

3. channel slope and hydrograph characteristics

Criteria for the applicability of hydraulic routing technique

$$\frac{T\, S_o\, u_o}{d_o} > 171$$

T is the hydrograph duration in seconds
S_o is the friction slope or bed slope
u_o reference mean velocity*
d_o reference flow depth*

* average flow conditions

4. flow networks
    - confluences
    - divisions
    - changes in flow direction

5. flow regime
    - subcritical
    - supercritical

6. availability of observed data

All hydrologic methods tend to fail when modeling channel slopes of less than 2 ft/mile

ASSESSING "n" VALUES

procedure

- establish physically based component parts
- determine the contribution from each component

components

- stream bed roughness
- stream bank roughness
- surface irregularities
- obstructions
- vegetation roughness
- expansion/contraction losses

determining hydraulic roughness

- handbooks
- analytical methods
- compositing - combining different roughnesses across a channel cross section

USDT method

$$\mathbf{n = (n_b + n_1 + n_2 + n_3 + n_4)\, m}$$

$\mathbf{n_b}$ = base **n** value
$\mathbf{n_1}$ = addition for surface irregularities
$\mathbf{n_2}$ = addition for variation in channel cross section
$\mathbf{n_3}$ = addition for obstructions
$\mathbf{n_4}$ = addition for vegetation
m = ratio for meandering

Analytical methods

- effective surface roughness height $\mathbf{k_s}$
- relative roughness
- Strickler equation, rigid bed $\mathbf{n = C\, k_s^{1/6}}$

- Keulegan equations, rigid bed
- Iwagaki relationship

roughness in moveable bed streams

⇒ *grain roughness*
-effective surface roughness height of the mixture of sediment particles on the stream bed

⇒ form roughness
- stream bed features: ripples, dunes, transition, plain bed, standing waves, anti dunes

calculating **n** values in moveable boundary channels

⇒ Limerinos **n**-value predictor

⇒ The Brownlee bed-roughness predictor

Composite **n** values

⇒ equal velocity method

⇒ Alpha method

⇒ sum of forces method

⇒ Conveyance method

Other factors

⇒ seasonality

⇒ tubeworms and barnacles

⇒ roughness from gravel moving in a concrete channel

⇒ bed form roughness in concrete channels

⇒ large woody debris

⇒ wetlands

⇒ marsh

ACCURACY OF COMPUTED WATER SURFACE PROFILES

errors
- ⇒ technique applicability
- ⇒ computation
- ⇒ data estimation

determine the relationship between
- ⇒ survey technology and accuracy employed for determining cross sectional geometry
- ⇒ degree of confidence in Manning **n** value
- ⇒ accuracy of computed water surface profile

predicting profile error as a function of:
- ⇒ survey technology
- ⇒ selected accuracy
- ⇒ Manning **n**
- ⇒ stream hydraulic properties

Summary and Conclusions
- ⇒ stream cross sectional geometry obtained from aerial surveys (aerial spot elevations and topographic maps) that conform to mapping industry standards are more accurate than is often recognized

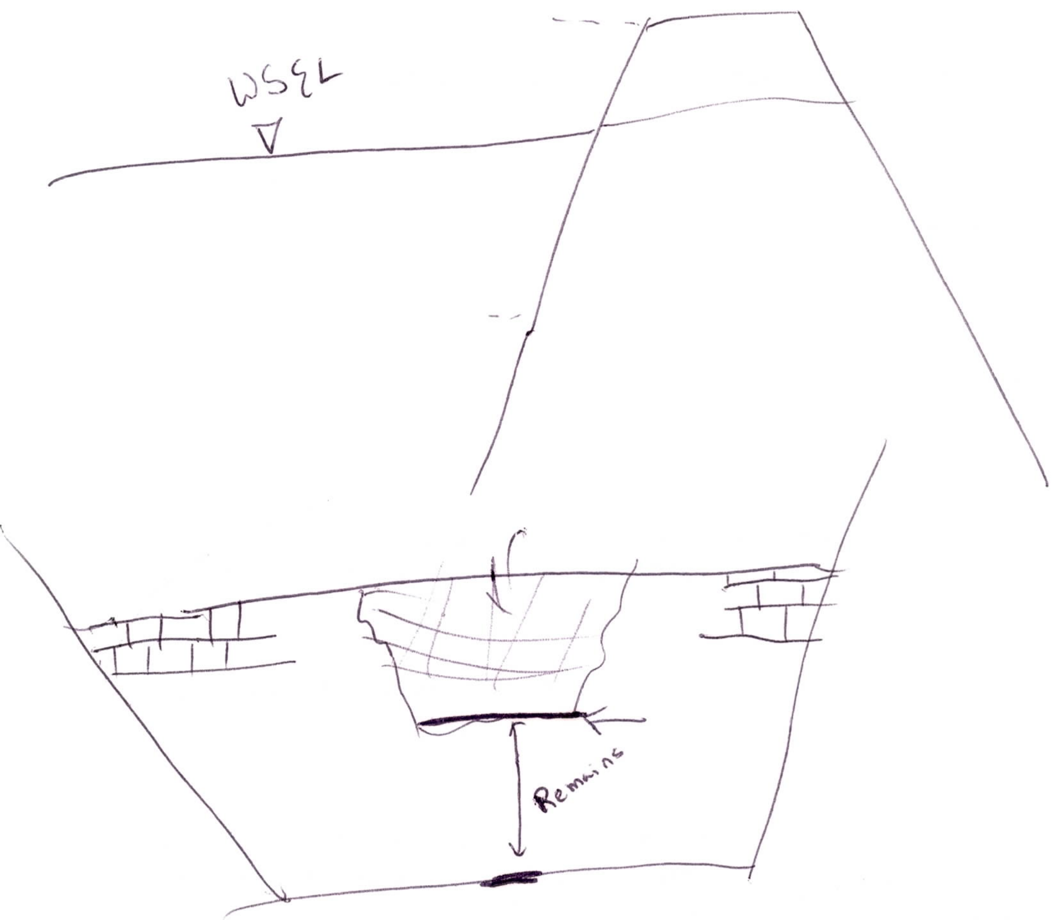
- ⇒ cross sectional geometry obtained from the aerial spot elevation surveys is about twice as accurate as cross sectional geometry obtained from topographic maps derived from aerial surveys for the same contour interval

- ⇒ the effect of aerial spot elevation survey or topographic mapping accuracy on the accuracy of computed water surface profiles can be predicted using the mapping industry accuracy standards, reliability of Manning's coefficient, and stream hydraulic variables

- ⇒ the reliability of the estimation of Manning's coefficient has a major impact on the accuracy of computed water surface profiles.

- ⇒ significant computational errors can result from using cross sectional spacing that are often considered to be adequate.

- ⇒ aerial spot elevation survey methods are generally more cost effective than field surveys when more than 15 cross sections are required


WSEL
Remains

DAM BREAK FLOOD INUNDATION MODELING

applications

- pre-computation of flood peak elevations prior to a dam failure
  - ⇒ provides information on downstream flood peak elevations and travel times

- real time computation of the down stream flooding when a dam failure is imminent or is occurring
  - ⇒ estimate crest profile and arrival times
  - ⇒ update forecasts

three components of dam break model

1. description of the dam failure mode (temporal and geometrical)

2. computation of the time history of the outflow through the breach as affected by the breach description, reservoir inflow, reservoir storage characteristics, spillway outflows, and downstream (tailwater) elevations

3. routing of the outflow hydrograph through the downstream valley

hydraulic routing

Of the many available hydrologic and hydraulic routing methods, only the ***dynamic wave method*** accounts for the acceleration effects associated with the dam break waves and the influence of downstream, unsteady backwater effects produced by channel constrictions, dams, bridge road embankments, and tributary inflows.

input data

dam

breach - failure time, final bottom width of breach, side slope of breach, final elevation of breach bottom, initial lake surface elevation, elevation of water surface when breach begins to form, elevation of top of dam

spillway - elevation of uncontrolled spillway crest, coefficient of discharge of uncontrolled spillway, elevation of center of submerged gated spillway, coefficient of discharge of gated spillway, coefficient of discharge of crest of dam, other discharge from the dam i.e. turbine

storage - surface area in acres or reservoir volume in acre feet

downstream valley
cross sections, hydraulic resistance coefficients, flow expansion coefficients (losses)

generalities

- the breach width and time of breach formation cause the greatest uncertainty in forecasting dam break flood waves
- Manning's **n** value selection influences the computed time of flood wave travel more than the computed peak discharge
- large **n** values are appropriate for dam break waves near a breached dam where extremely high flow velocities uproot trees and transport considerable sediment and boulders (if present) and generally result in large energy losses
- the cross sections selected must reflect the conveyance and storage characteristics of the downstream channel

Dam Break models
HEC-1
NWS DAMBRK
NWS SMPDBK
NWS FLDWAV MODEL - February 1, 1995 (beta test veersion)
(DWORR)?

SMPDBK

routes peak dam break discharges based on dimensionless curves derived from NWS DAMBRK simulations

produce results within 20 percent of the predictions made with DAMBRK
short version and long version

data needed

- height of dam
- reservoir storgae
- breach characteristics
- downstream channel characteristics

three major limitations in representing channel geometry

1. cross sections are represented by simple curves
2. number of cross sections is limited
3. no provisions for off channel storage

to obtain reasonable results:

1. ensure that the two cross sections immediately downstream of the dam result in the proper calculation of submergence
2. the remaining cross sections must be selected to portray the storage and conveyance characteristics of the channel
3. the computed stage corresponds to the region where top width versus elevation data is specified for the cross section

NWS FLDWAV MODEL
MODEL DESCRIPTION AND CAPABILITIES

SYNOPSIS

The NWS FLDWAV model is a combination of the NWS DAMBRK and DWOPER models. Although each of these models are quite powerful, limitations exist that hinder their flexibility. Limitations of DWOPER include its inability to interpolate cross sections when needed, its inability to handle supercritical flow, its inability to model dam breaks and assorted reservoir outflow controls, and its limited levee capability. DAMBRK can only model single rivers; also, fixed arrays for the number of time steps and number of cross sections severely limit the size of river systems that could be modelled without breaking up the problem into several datasets. FLDWAV includes the best capabilities of both models and a few enhancements that make it the model of choice. For a more detailed description of the FLDWAV model, the user is referred to papers by Fread and Lewis (1988) and Fread (1993).

OBSOLETE CAPABILITIES

DAMBRK

1. All options that involve storing a generated hydrograph and then routing it downstream (sequential method) have been eliminated (Options 1-6,9,10). Under selected conditions, these options may not adequately account for submergence below the dam due to backwater effects. The simultaneous method (Options 11,12) can adequately model these situations. In situations where the flow regime switches between subcritical and supercritical, the mixed-flow algorithm will handle the transitions. The user will see less than a 3 percent difference in the results when comparing the two techniques on datasets with no backwater effects.
2. The cross-section smoothing option is not currently available in FLDWAV.
3. The option to create cross sections within the reservoir is not currently available in FLDWAV.

DWOPER

Although no capabilities have been eliminated, some are not currently available (e.g., NETWORK option).

CURRENT FLDWAV CAPABILITIES

COMMON TO DAMBRK AND/OR DWOPER

1. ***Variable Dimensioning*** - The input data structure has been arranged in a manner so that array sizes are determined internally based on the river system. This eliminates the problem of running out of number of time steps or number of cross sections.
2. ***Multiple Rivers*** - FLDWAV can model river systems that have a dendritic structure (first order tributaries). Second order tributaries may sometimes be accommodated by reordering the system, i.e., selecting another branch of the system as the main stem.
3. ***Dam and Bridge/Embankment Failure Analysis*** - All of the capabilities associated with dams and bridges have been retained.
4. ***Levee Option*** - Flows which overtop levees located along either or both sides of a main-stem river and/or its principal tributaries may be simulated within FLDWAV. For a detailed description of this option, refer to the previously mentioned papers.
5. ***Simultaneous Method of Computation*** - FLDWAV can route unsteady flows occurring simultaneously in a system of interconnected rivers. Any of the rivers may have one or more structures (dams, bridges, levees, etc.) which control the flow and which may breach if failure conditions are reached.
6. ***Flow Regime*** - FLDWAV can handle subcritical, supercritical, or a combination of each, varying in space and time from one to another. A new computational scheme (LPI) has been developed to model mixed flow (see New Enhancements section).
7. ***Boundary Conditions*** - The upstream boundary may be either a stage or discharge hydrograph for each river. The downstream boundary choices remain the same as those for DAMBRK and DWOPER. Although the downstream boundary on tributaries is a generated stage hydrograph, the KD parameter must be set to zero for these rivers. The KD=1 option is being reserved for an observed stage hydrograph which will allow diverging channels (e.g., branches of a river delta) to be modelled more directly. Currently these channels are modelled by labelling the downstream end of the channel as the upstream boundary condition and negating the inflow hydrograph which forces it to become outflow (Q=-Q).
8. ***Initial Conditions*** - The initial conditions include the initial water surface elevations (WSEL) and discharges at each of the read-in cross section locations. FLDWAV can start up in either a steady-state (not changing temporally) or an unsteady-state condition.
9. ***Computational Time Step*** - Currently the initial computational time step must be read in. This value will be used throughout the run period until a dam breach failure mode is activated. The model will use the smallest value between failure time step(s) and the initial time step.
10. ***Roughness Coefficients*** - A Manning n table is defined for each channel reach bounded by gaging stations and is specified as a function of either WSEL (h) or discharge (Q) according to a piece-wise linear relation with both n and the independent variable (h or Q) read in to FLDWAV in tabular form. Linear interpolation is used to obtain n for values of h or Q intermediate to the tabular values. Unlike DWOPER, the Manning n reaches are defined by their upstream-most section rather than their downstream-most section. To allow FLDWAV to function

like DAMBRK, Manning n tables are duplicated internally such that there is a table at each reach between cross sections.

11. ***Automatic Calibration*** - This option allows the automatic determination of the Manning n so that the difference between computed WSELs (stage hydrographs) and observed hydrographs is minimized. In areas where detailed cross sections may not be available, there is an option (Fread and Lewis, 1986) that will automatically adjust average sections obtained from topographic maps in addition to the Manning n.
12. ***Printer Output*** - Although the format may be slightly different, FLDWAV will display the same data (e.g., echo print of the input data, hydraulic information, summary of peak data, etc.) as the DAMBRK model.
13. ***Other Options*** - The following options are in FLDWAV and have not been altered from the original definitions in DAMBRK or DWOPER. For additional information, the user is referred to the DAMBRK/DWOPER documentation.
    a. Low flow filter
    b. Pressurized flow
    c. Cross section interpolation
    d. Floodplain option (sinuosity)
    e. Conveyance
    f. Metric option
    g. Off-channel (dead) storage
    h. Robust computational features
    i. Local losses
    j. Wind effects
    k. Hydraulic radius option
    l. Lateral inflow/outflow

NEW ENHANCEMENTS

1. ***Graphical Output Display*** - A utility (FLDGRF) has been developed to display output data generated by the FLDWAV model. FLDGRF is a user friendly, menu-driven, DOS application which is written in C. The following information is displayed: peak profiles, hydrographs, cross sections, rating curves, and external boundary conditions. WSELs and/or discharges may be displayed at any interpolated cross section. Multiple profiles and hydrographs may also be displayed. Actual cross sections may be displayed showing the peak conditions. Unlike FLDWAV, this utility is not portable to the workstation environment.
2. ***LPI Mixed-Flow Algorithm*** - In the Local Partial Inertial (LPI) mixed-flow algorithm, the first two terms (inertial terms) in the momentum equation are multiplied by the factor ß, where $ß = (1-F^k)$ in which F is the Froude number and k ranges from 1 to 10. The value of ß determines the type of routing that will be used (0 for diffusion, 1 for dynamic). The diffusion routing technique tends to be more stable than the dynamic routing technique for certain mixed flows, particularly those

in the near critical range of Froude number. When routing supercritical flow (ß=0), the error between using dynamic and diffusion techniques is approximately 1 percent. For subcritical flow, the power k is used to control the portion of the inertial terms utilized. When k=10, essentially all of the inertial terms are utilized until the Froude number exceeds 0.60. (At F=0.8, 0.9, and 0.95, 90%, 65%, and 50% of the inertial terms are utilized respectively). When k=1, the ß vs. F relationship is linear where essentially all of the inertial terms are utilized at Froude numbers near zero, and none of the terms are utilized at Froude numbers near one. Although a high k value is desired to maintain accuracy, a smaller value may be needed sometimes to obtain stability. ß is a local parameter since the Froude number used is for each computational point. Therefore, portions of the routing reach with low Froude numbers will be modelled with the inertial terms essentially included, while those portions with high Froude numbers will be modelled with little or no inertial terms included.

3. ***Explicit Dynamic Routing*** - A characteristics-based upwind explicit scheme has been added to FLDWAV to model instantaneous dam failures and very rapidly occurring failures with a time of failure less than 3 minutes. This scheme is also applicable to the complicated flows in the mixed-flow regime.
4. ***Multiple Routing*** - FLDWAV has the capability of using multiple routing techniques in a river system. Currently, there are four routing techniques available: dynamic implicit, dynamic explicit, level pool (storage), and diffusion. Each reach between adjacent cross sections is assigned a routing technique by the user via the KRCH parameter. The LPI computational scheme may also be applied to specific reaches.
5. ***Kalman Filter*** - A real-time Kalman filter estimator has been added to FLDWAV. If a river has stage observations for more than two gaging stations, the Kalman filter may be turned on to update the predictions for each time step using observations. This option is applicable for real-time forecasting only.
6. ***Time Interval Time Step*** - This option allows the user to specify multiple computational time steps throughout the temporal range of the inflow hydrograph.

FUTURE ENHANCEMENTS

General Release - The following enhancements are expected to be completed in time for the general release of FLDWAV (approx. Fall, 1995):

1. ***FLDINP Utility*** - The interactive input program (written in C) is a user friendly, menu-driven, Windows application that will allow the user to generate the data file required by the FLDWAV model. FLDINP will have graphics capabilities to allow the user to display hydrographs, cross sections, and internal boundaries.
2. ***NETWORK Option*** - The multiple channel option (NETWORK) that is currently in DWOPER will be incorporated into FLDWAV. This option allows the user to model nth order tributaries as well as channel bifurcations (islands).
3. ***Other Options*** - The following options are also expected to be added to FLDWAV:

a. Muskingum-Cunge routing
b. Routing flow thru culverts
c. Mudflow/Debris flow
d. Landslide generated waves
e. Multiple movable gates
f. Routing losses
g. Automatic time step increase

4. ***Future Releases*** - Additional capabilities that are being developed and added to FLDWAV in the future include sediment transport and pollutant transport algorithms.

REFERENCES

Fread, D.L. and J. M. Lewis (1986). "Parameter Optimization for Dynamic Flood Routing Applications with Minimal Cross-Sectional Data," Proceedings: ASCE Water Forum '86, World Water Issues in Evolution, Long Beach, California, pp. 443-450.

Fread, D.L. and J.M. Lewis (1988). "FLDWAV: A Generalized Flood Routing Model," Proceedings of National Conference on Hydraulic Engineering, Colorado Springs, Colorado.

Fread, D.L. (1993). "NWS FLDWAV Model: The Replacement of DAMBRK for Dam-Break Flood Prediction," Proceedings: 10th Annual Conference of the Association of State Dam Safety Officials, Inc., Kansas City, Missouri, pp. 177-184.

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NOTICE TO FLDWAV USERS

This is to inform you of the availability of the NWS FLDWAV model for Beta testing. FLDWAV (version 02/01/95) has been under development since 1985 and has undergone extensive testing.

FLDWAV is a generalized flood routing model that can be used by hydrologists/engineers for real-time flood forecasting of dam-break floods and/or natural floods, dam-breach flood analysis for sunny-day piping or overtopping associated with the PMF flood, floodplain inundation mapping for contingency dam-break flood planning, and design of waterway improvements. The model computes the outflow hydrograph from a dam due to spillway, overtopping and/or dam breach outflows. The resulting floodwave is then routed through the downstream channel/valley using a four-point implicit finite-difference numerical solution of the complete Saint-Venant equations of one-dimensional unsteady flow along with appropriate internal boundary equations representing downstream dams, bridges, weirs, waterfalls, and other man-made/natural flow controls. The flow may be "mixed" (subcritical and/or supercritical) throughout the downstream routing reach. The following features are found in FLDWAV: (a) the flood may occur in a system of interconnected rivers such as the main-stem river and its tributaries; (b) levee-overtopping/crevasse flows into and through levee-protected floodplains; (c) automatic calibration of Manning roughness coefficients for historical floods; (d) use of multiple routing techniques throughout the river system; (e) color graphic displays of model output; and (f) variable dimensioning of arrays which eliminates the problem of exceeding number of time steps and cross sections.

The following features are currently unavailable, but are expected to be included in the general release of FLDWAV: (a) menu-driven interactive data input utility; (b) modelling flow through bifurcated channels (islands) and bypasses; (c) Muskingum-Cunge routing; (d) routing non-Newtonian (mud-debris) flow; and (e) modelling landslide-generated waves.

FLDWAV was written in Fortran and compiled with the Microsoft 32-bit Powerstation compiler which utilizes extended memory. This new compiler reduces the program's runtime by approximately 80 percent (when compared with Microsoft Fortran 5.1 which was used to compile DAMBRK). The average runtime for a typical dataset (e.g., Teton) is less than one minute. Although it is a DOS application, the model may be implemented on several other platforms (e.g., workstations, mainframes, etc.) with a minimum amount of changes. The minimum computer requirements are a 386-based IBM compatible machine with 4mb of extended memory (RAM) and 10mb of computer storage space (a 486 DX2 machine with math coprocessor is recommended) and VGA color monitor. Although the executable file requires less than 2mb of computer storage space, the files generated for the output display program (FLDGRF) could utilize space in excess of 10mb. The software is supplied on two 3.5" high-density diskettes.

The purpose of the Beta test is to allow experienced DAMBRK/DWOPER users an opportunity to use FLDWAV prior to general release to determine limitations of the model that may not have been considered or detected. FLDWAV is being offered free of charge to experienced users for the Beta test. **If you are not an experienced user of either DAMBRK or DWOPER, it is strongly recommended that you NOT participate in this test.** The only requirement for participation is that the user supply feedback about the model to this office. This feedback may include any errors found in the model, capabilities desired, difficulties encountered using the model, and limitations found. Positive comments are also welcome. The target general release date for FLDWAV is November 1996. If you wish to be a part of the Beta test group, send your request to:

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NWS Hydrologic Research Laboratory
SSMC2 #8328
1325 East-West Highway
Silver Spring, MD 20910

Tel: (301) 713-0640, ext. 125
Fax: (301) 713-0963
E-mail: elaine.hauschildt@noaa.gov

Problems and comments pertaining to the model should be reported to Janice Lewis at the above address (SSMC2 #8406)
Tel: (301) 713-0640, ext. 163
E-Mail: janice.lewis@noaa.gov

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NOTICE TO DAMBRK USERS

This is to inform you of the availability of an updated version of the NWS DAMBRK Model. The existing DAMBRK Model (version 07/18/84) has been substantially improved in that its capabilities have been increased as well as its numerical robustness. The new model is referred to as DAMBRK '88 with a release version date of 06/20/88. The model's documentation has been expanded from sixty pages to approximately three hundred pages. DAMBRK '88 (Fortran source) is available on 3.5-inch HD diskettes (both Fortran source and executable) for IBM PC compatible microcomputers having 640K and a 8087 math coprocessor.

The new capabilities of DAMBRK '88 are:

1. An option which allows all input/output to be expressed in either English or metric units.
2. Saint-Venant implicit solution algorithm has been expanded so as to be able to simulate mixed (subcritical/supercritical) flows which occur and may change from one regime to the other and vice versa in both space (along the river) and time; the algorithm requires approximately 20 percent more CPU than the '84 algorithm which blows-up when the flow passes through critical depth as it changes from subcritical to supercritical or vice versa. Also, the algorithm in DAMBRK '88 for supercritical flows has been improved concerning its numerical stability.
3. Saint-Venant implicit equations have been expanded to include the effects of channel sinuosity, momentum coefficient, a viscous internal dissipation term for non-Newtonian fluids such as mud/debris or mine-tailings flows, and the option to use channel conveyance to compute the friction slope term (Sf) which increases numerical stability when cross sections with a top width vs. elevation relation has an abrupt change at the elevation where a flat overbank floodplain joins the main channel.
4. The ability to automatically create cross sections for the Saint-Venant solution algorithm for reservoirs where only a surface area - elevation relation is known.
5. An option to use either the computed wetted perimeter or the topwidth for the computed hydraulic radius which is used to compute the friction slope (Sf).
6. An option to route the dam-break wave in a dry channel by expanding the computational net along the channel at the same velocity as the approximated wave-front velocity.
7. Automatic determination of the computational distance step (dx) to account for: (1) limitations imposed by expanding/contracting sections, (2) the condition: $dx < c\ (dt)$ where c is the wave speed which is computed within DAMBRK by the technique used in the NWS Simplified Dam-break model (SMPDBK), and (3) sudden changes in bottom slope.

8. Saint-Venant algorithm is applicable to unsteady flows which change with space or time from free surface gravity flow to pressurized flow and vice versa for any shape of channel or closed conduit.
9. Breach development may be linear or nonlinear as specified by the user.
10. Dam crest length may be a function of elevation for dams that are not level.
11. Breach may encompass only the spillway section of the dam.
12. Breach may commence when either a specified elevation is reached by the reservoir waters or when a specified time after beginning of simulation has been attained.
13. Piping failure may occur after beginning of simulation according to criteria described previously in item (12).
14. Bridge flow areas are specified as a separate top width Bbr-elevation table which enable cross sections, used by the Saint-Venant algorithm, to be located somewhat upstream or downstream of the bridge opening to avoid critical flow at the contracted bridge opening.
15. The time-dependent gate option was modified to use gate width and gate opening as user specified time series.
16. The turbine flow (QT) may be constant or time-dependent (time series).
17. Automatic interpolation of cross sections for computational convenience also now includes interpolation of landslide properties, and levee overflow sections along the channel.
18. The type of model output has been increased by adding more output options.
19. A decrease in execution time of about 50 percent due to a new compiler which is used to obtain the "load" diskette (PC version).

The first update, which included revision 1 through revision 3, was released in August 1989 and included the following:

1. Allowed for the spillway crest length to vary with elevation in the dam discharge computation; the computation uses flow area instead of top width.
2. Allowed for the length of road embankment of the bridge to vary with elevation in computing the bridge flow over the embankment; the computational use flow area instead of top width.
3. Replaced the old GATE subroutine with a new GATE subroutine to comply with the technique developed by Randy Wortman of the U.S. Army Corps of Engineers (Portland Division).
4. Included sinuosity effect of meandering channel following the work of DeLong (Journal of Hydraulics, February, 1989).
5. Corrected metric conversion errors in options 7 and 11, and metric conversion errors in the lateral weir flow and subroutines (OUTPUT and PLOT).

The latest update (revision 4) was released in August 1991; it included the following updated enhancements/corrections.

1. Increased the model's numerical robustness as follows:
    a. Implemented improvements in the mixed-flow algorithm to take advantage of flow characteristics from a previous time step. The model is better able to handle problems with reaches near critical flow and problems with gradual slope changes in which the flow changes gradually from supercritical flow to subcritical flow.
    b. Included the loop rating boundary in initial flow computation to smooth out the numerical shock encountered at the start of Saint- Venant solution. Previously, if channel control existed at the downstream end, a single-valued rating boundary was assumed to establish the initial conditions. For a nonuniform, nonprismatic downstream reach, the shock due to switching from a single-valued rating boundary to a loop-rating boundary sometimes caused the model to blow-up.
    c. Provided a temporary fix for a divergent solution of the Saint-Venant equations from going below channel bed and producing a negative area or from going above channel's highest topwidth; and sometimes, for very flat overbanks, producing computational overflow; this prevents model blow-up and allows the automatic time step reduction to occur which often allows a convergent solution to be achieved.
    d. Corrected the internal boundary algorithm in options 11 and 12 so that the model does not blow-up during supercritical flow. Supercritical flow may develop due to a dam/bridge being located on a supercritical slope. For a dam, the flow upstream of the dam can change from subcritical to supercritical as the reservoir storage is depleted due to a dam breach.
2. Included a more efficient 2-stage solution scheme for solving the normal water depth equation, critical depth equation, and backwater/downwater equation. The efficient Newton-Raphson method is used first; if it does not converge, the less efficient bi-section method is used to assure a solution.
3. Improved the numerical computational method for estimating how well the model conserves mass.
4. Allowed for initial flow to occur in the floodplain rather than only within the channel bank when using the floodplain (conveyance) option.
5. Eliminated possibility of premature initiation of dam failure due to very high water-surface elevation obtained during the iterative solution of the Saint-Venant equations, especially when the solution is diverging.
6. Corrected errors in the metric version for the bridge option and the time-dependent gate and turbine flow options for dams.

In addition to DAMBRK '88, the following models are available on 3.5-inch HD diskettes:

- **SMPDBK** -- Version 9/91 -- an interactive simplified dam-break model which computes the peak discharge, water surface elevation, and time of occurrence for selected cross sections downstream of a breached dam.

- **BREACH** -- Version 7/88 (latest revision 8/91) -- a deterministic model of the erosion-formed breach (overtopping or piping initiated) in an earthen dam (man-made or landslide-formed); it computes the outflow hydrograph and the breach parameters used in DAMBRK and SMPDBK.

- **DWOPER** -- Enhanced Network Version 7/18/84 (latest revision 8/89) -- an unsteady flow dynamic routing model (one-dimensional Saint-Venant equations) for a single channel or network (dendritic and/or bifurcated) of channels for free surface or pressurized flow.

- **CROSS-SECTION** -- plots topwidth-elevation from cross-section data in x-y coordinates; also computes distance weighted average cross sections; also converts HEC "GR" cards to the correct NWS Format.

Any or all of the above models including DAMBRK '88 are available upon request with an **enclosed check payable to the National Weather Service/NOAA for $200.00** (charge not applicable to federal agencies), i.e., the total cost for all five models is the same as the cost for one or more if requested at the same time. Documentation and floppies may be copied for multiple use within the same agency, company, etc. Requests for documentation only will be considered the same as requests for models. Please send your requests to:

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Hydrologic Research Laboratory, W/OH3
SSMC2, Room 8328
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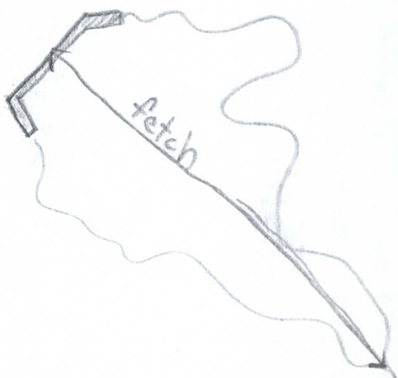
H7780 FREEBOARD COMPUTATION

To execute the program, enter H7780 at the DOS prompt.

To make a hard copy of the screen, use the DOS shift/PrtSc
(dot matrix printer).

NOTES: Answers to questions from the program must be in all **capitals**.
The config.sys file must contain the options:

buffers=25
files=20
break=on



The required **inputs** for this program consist of:

1. the job title
2. the site id
3. the number of radials(15 minimum)
4. the radial lengths in miles
5. whether to use design overland windspeed or 1 minute and 60 minute wind speed
6. the 1 minute and 60 minute wind speed or the design overland wind speed in mph
7. the factor for a significant design wave or for other related design wave
8. whether to print the deep water wave characteristics or not
9. the water depth at the toe of the structure in feet
10. the average water depth along wind fetch in feet
11. the cotangent of the angle between the embankment slope and the horizontal
12. the factor for reducing wave run up on smooth slope where the slope is slightly rougher than smooth
13. the slope cover(riprap, smooth, or other)
14. whether to save the tabulated output for graphics or other use

output includes:

1. the basic data from the input

2. the effective wave fetch in miles

3. the water wave conditions used for present problem (type embankment slope, design wind speed in mph, design wind duration in minutes, design wave height in feet, design wave period
in seconds, design deep water wave length in feet, fetch for wind setup in miles, wind setup in feet, significant wave runup in feet above swl, and total increase in water level in feet above swl)

4. if requested in input, the wind data and deep water wave characteristics(over water wind speed in mph, wind duration in minutes, significant wave height in feet and significant wave period
in seconds)

5. wave heights and wave runup for waves other than the significant wave(wave exceedance in percent, wave height in feet, wave runup in feet).