University of Minnesota
ST. ANTHONY FALLS HYDRAULIC LABORATORY

Project Report No. 137

FLOOD FORECASTING IN THE UPPER MIDWEST
Data Assembly and Preliminary Analysis

by
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LIST OF TABLES

As these data were procured with state and federal funds, they are considered to be available to other users. Some expense will be involved in discussing, retrieving, and copying the tapes, and other users will be expected to cover this cost.

The data on magnetic tape are in good form for storage purposes, but not convenient to use. For operation with a mathematical model, selected stations and years were transferred to random access disk storage.

Procurement of mathematical models that are of interest in this area was initiated in an earlier study and has continued in the present project. Discussions were held with engineers, hydrologists, and meteorologists from various specializations relative to the modeling problem.

Several models, such as the SSARR (Streamflow Synthesis and Reservoir Regulation) and the Stanford Model IV, were operated with inputs of up to one year's data in a single run. Examples of such runs are included herein.

The Minnesota River basin or watershed includes an area of about 16,200 sq mi and is characterized by periodic severe floods on both the main stem and numerous tributaries. It was selected for initial studies on the project. However, data were obtained for the whole state and for adjacent states where major rivers such as the Red River of the North and the St. Croix River drain areas in these states.

II. DAILY DISCHARGE DATA OBTAINED FROM THE U.S. GEOLOGICAL SURVEY

Tables 1 through 4 list the USGS gaging station number and the name of the gaging station for which daily discharge data have been obtained. These are in three major basins: (1) the Upper Mississippi River, (2) the Red River of the North, and (3) the Lake Superior portion of the Great Lakes basin.

Table 1 - USGS GAGING STATIONS - UPPER MISSISSIPPI RIVER BASIN (Tapes 1 through 3)

Station No.	
5206500	Leech Lake River at Federal Dam
5211000	Mississippi River at Grand Rapids
5219000	Sandy River at Sandy Lake Dam, at Libby
5220500	Mississippi River below Sandy River, near Libby
5227500	Mississippi River at Aitkin
5231000	Pine River at Cross Lake Dam, at Cross Lake
5244000	Crow Wing River at Nimrod
5247000	Gull River at Gull Lake Dam, near Brainerd
5267000	Mississippi River near Royalton
5270500	Sauk River near St. Cloud
5275000	Elk River near Big Lake
5278000	M. Fk. Crow River near Spicer
5279000	S. Fk. Crow River near Mayer
5280000	Crow River at Rockford
5286000	Rum River near St. Francis
5288500	Mississippi River near Anoka
5332500	Namekagon River near Trego, Wis.
5333500	St. Croix River near Danbury (at Swiss), Wis.
5335000	Yellow Lake near Webster, Wis.
5338000	St. Croix River near Grantsburg, Wis.
5336200	Glaisby Brook near Kettle River, Minn.
5336700	Kettle River below Sandstone
5338500	Snake River near Pine City
5339500	St. Croix River near Rush City, Minn.
5340050	Sunrise River near Lindstrom, Minn.
5341500	Apple River near Somerset, Wis.
5344500	Mississippi River at Prescott, Wis.
5345000	Vermillion River near Empire City, Minn.
5345500	Vermillion River at Empire City, Minn.
5346000	Vermillion River at Hastings, Minn.
5353800	Straight River near Faribault
5355400	Moose Lake near Winter, Wis.
5356000	Chippewa River at Bishops Bridge near Winter, Wis.
5356500	Chippewa River near Bruce, Wis.
5357400	Flambeau flowage (Flambeau Reservoir) near Mercer
5358500	Flambeau River at Babb's Island near Winter, Wis.
5360500	Flambeau River near Bruce, Wis.
5365500	Chippewa River at Chippewa Falls, Wis.
5369500	Chippewa River at Durand, Wis.
5373000	S. Fk. Zumbro River near Rochester
5374000	Zumbro River at Zumbro Falls
5376000	N. Fk. Whitewater River near Elba

[Continued]

Table 1 [Continued]

5378500	Mississippi River at Winona
5382000	Black River near Galesville, Wis.
5383000	LaCrosse River near West Salem, Wis.
5383500	Mississippi River at LaCrosse, Wis.
5384000	Root River near Lanesboro
5384500	Rush Creek near Rushford
5385000	Root River near Houston
5385500	S. Fk. Root River near Houston
5457000	Cedar River near Austin
5476000	Des Moines River at Jackson (formerly W. Fk. Des Moines River)

Table 2 - USGS GAGING STATIONS - RED RIVER OF THE NORTH BASIN

Station No.	
5030000	Ottertail River near Detroit Lakes
5040500	Pelican River near Fergus Falls
5046000	Ottertail River below Orwell Dam, near Fergus Falls
5050000	Bois de Sioux River near White Rock, S. Dak.
5051500	Red River of the North at Wahpeton, N. Dak.
5051600	Wild Rice River near Rutland, N. Dak.
5053000	Wild Rice River near Abercrombie, N. Dak.
5054000	Red River of the North at Fargo, N. Dak. (Moorhead, Minn.)
5054500	Sheyenne River above Harvey, N. Dak.
5056000	Sheyenne River near Warwick, N. Dak.
5056100	Mauvais Coulee near Cando, N. Dak.
5057000	Sheyenne River near Cooperstown, N. Dak.
5057200	Baldhill Creek near Dazey, N. Dak.
5058000	Sheyenne River below Baldhill Dam, N. Dak.
5059000	Sheyenne River near Kindred, N. Dak.
5059500	Sheyenne River at West Fargo (at or near Haggart)
5059700	Maple River near Enderlin, N. Dak.
5061000	Buffalo River near Hawley
5061500	S. Br. Buffalo River near Sabin
5062000	Buffalo River near Dilworth
5062500	Wild Rice River at Twin Valley
5064000	Wild Rice River at Hendrum
5064500	Red River of the North at Halstad
5064900	Beaver Creek near Finley, N. Dak.
5065500	Goose River near Portland, N. Dak.
5066500	Goose River at Hillsboro, N. Dak.
5067500	Marsh River near Shelly
5069000	Sandhill River at Climax
5074500	Red Lake River near Red Lake
5075000	Red Lake River at High Landing, near Goodridge
5076000	Thief River near Thief River Falls
5077700	Ruffy Brook near Gonvick

[Continued]

Table 2 [Continued]

5078000	Clearwater River at Plummer
5078500	Clearwater River at Red Lake Falls
5079000	Red Lake River at Crookston
5082500	Red River of the North at Grand Forks, N. Dak.
5084000	Forest River near Fordville, N. Dak.
5087500	Middle River at Argyle
5090000	Park River at Grafton, N. Dak.
5092000	Red River of the North at Drayton, N. Dak.
5094000	S. Br. Two River at Lake Bronson
5099200	Pembina River near Kaleida, Manitoba
5099300	Pembina River near Windy Gates, Manitoba
5100000	Pembina River at Neche, N. Dak.
5102500	Red River of the North at Emerson, Manitoba
5104500	Roseau River below S. Fk. near Malung
5106000	Sprague Creek near Sprague, Manitoba
5107500	Roseau River at Ross
5112000	Roseau River below State ditch 51 near Caribou
5113360	Long Creek at western crossing of international boundary, Saskatchewan
5113600	Long Creek near Noonan, N. Dak.
5114000	Souris (Mouse) River near Sherwood, N. Dak.
5116000	Souris (Mouse) River near Foxholm, N. Dak.
5122000	Souris (Mouse) River near Bantry, N. Dak.
5124000	Souris (Mouse) River near Westhope, N. Dak.

Table 3 - USGS GAGING STATIONS - LAKE OF THE WOODS BASIN

Station No.	
5127000	Kawishiwi River near Winton
5128000	Namakan River at outlet of Lac la Croix, Ontario
5129000	Vermilion River below Vermilion Lake, near Tower
5131500	Little Fork River at Little Fork
5132000	Big Fork River at Big Falls
5133500	Rainy River at Manitou Rapids
5139500	Warroad River near Warroad

Table 4 - USGS GAGING STATIONS - STREAMS TRIBUTARY TO LAKE SUPERIOR

Station No.	
4010500	Pigeon River at Middle Falls, near Grand Portage
4014500	Baptism River near Beaver Bay
4015500	Second Creek near Aurora
4016000	Partridge River near Aurora
4016500	St. Louis River near Aurora
4018750	St. Louis River at Forbes
4019000	West Two River near Iron Junction
4024000	St. Louis River at Scanlon

III. NOAA, ENVIRONMENTAL DATA, SURFACE OBSERVATIONS

Environmental data are available from the National Oceanic and Atmospheric Administration, National Climatic Center, Asheville, North Carolina 28801. No attempt will be made to describe all available data. As part of this study, data were obtained in four types as shown in Table 5. Tables 6 and 7 show the stations for which daily observations (card deck 486) and hourly precipitation observations (card deck 488) are available.

Table 5 - ENVIRONMENTAL DATA OBTAINED ON MAGNETIC TAPE

Tape No.	Content	Station No. and Name	Period
25,26	Card deck 488	All available Minnesota	1/60 - 6/70
27-30	Card deck 486	All available Minnesota	10/63 - 12/70
32	TDF 14	14920 LaCrosse, Wisc.	1/58 - 12/68
33	TDF 14	14920 LaCrosse, Wisc.	1/69 - 12/71
34	TDF 14	14914 Fargo, N.D.	1/59 - 12/68
35	TDF 14	14914 Fargo, N.D.	1/69 - 12/71
36	TDF 14	14944 Sioux Falls, S.D.	1/59 - 12/68
37	TDF 14	14944 Sioux Falls, S.D.	1/69 - 12/71
38	TDF 14	14913 Duluth, Minn.	1/59 - 12/68
39	TDF 14	14913 Duluth, Minn.	1/69 - 12/71
40	CD 345	14910 Alexandria, Minn.	1/49 - 12/54; 1/63 - 12/71
		14913 Duluth, Minn.	1/48 - 12/71
		14922 Minneapolis, Minn.	1/45 - 12/71
		14925 Rochester, Minn.	1/48 - 12/71
		14926 St. Cloud WBO/WBAS	1/48 - 12/71
		14927 St. Paul, Minn.	1/48 - 5/53
		14928 Willmar, Minn. CAA	1/49 - 9/50
		14947 Minneapolis, Minn. NAS	3/45 - 8/46; 7/49; 9/49 - 1/58; 3/58 - 12/61
		14992 Redwood Falls, Minn. FAA	11/49 - 12/54; 1/63; 10/64 - 12/71
		94909 Duluth, Minn., Williamson Johnson Apt	9/51 - 1/52
		94931 Hibbing, Minn. FAA	11/62 - 12/71
41	Daily 1009 data (CD486)	All available Minnesota	Stations for 1971
42	Hourly precipitation data (CD488)	All available Minnesota	Stations for 1971
43	Daily solar radiation (CD480)	14926 St. Cloud, Minn.	7/54 - 5/62; 8/62 - 12/70
44	Surface data RDF14 Format	14922 Minneapolis, Minn.	1/55 - 12/64
45	Surface data TDF14 Format	14922 Minneapolis, Minn.	1/65 - 12/71
46	Surface data TDF14 Format	14925 Rochester, Minn.	1/59 - 12/68
47	Surface data TDF14 Format	14925 Rochester, Minn.	1/69 - 12/71
48	Surface data TDF14 Format	14926 St. Cloud, Minn.	1/59 - 12/68
49	Surface data TDF14 Format	14926 St. Cloud, Minn.	1/69 - 12/71

The environmental data tapes are 7 channel, 556 BPI, even parity and may or may not have a beginning tape mark. The data other than TDF14 are in card image format, blocked 10 card images per record, in chronological sort. (Ten logical records or cards make one physical record on tape.)

Table 6 - LIST OF STATIONS FOR DAILY WEATHER DATA

STATION	INDEX NO.	DIVISION	COUNTY	DRAINAGE †	LATITUDE	LONGITUDE	ELEVATION	OBSERVATION TIME AND TABLES: TEMP.	PRECIP.	EVAP.	SPECIAL (SEE NOTES)	OBSERVER
ADA	0018	01	NORMAN	10	47 18	96 31	906	6P	6P			JOHN R. PFUND
AGASSIZ REFUGE	0050	01	MARSHALL	10	48 18	95 59	1142	5P	5P			AGASSIZ NATL WL REF.
AITKIN 2 S	0059	06	AITKIN	8	46 31	93 42	1240	5P	8A			FORREST E. DEITZ
ALBERT LEA	0075	08	FREEBORN	7	43 39	93 21	1220	5P	5P			WASTE TREATMENT PLANT
ALBERT LEA 3 E	0080	08	FREEBORN	7	43 40	93 18	1230				C	EDWIN L. RABEN
ALEXANDRIA FAA AP	0112	04	DOUGLAS	8	45 52	95 23	1421	MID	MID		H	U S FED AVIATION AGENCY
ALEXANDRIA WTR TRMT PL	0116	04	DOUGLAS	8	45 54	95 22	1400					ALEXANDRIA WTR TRMT PL
AMBOY	0157	08	BLUE EARTH	7	43 53	94 10	1043				C	ALEX LARSON
ANGUS 4 NNE	0198	01	POLK	10	48 08	96 41	875	6P	6P		H	L. L. DABY
ARGYLE 4 E	0252	01	MARSHALL	10	48 20	96 44	870	7A	7A			LESTER SVENDSEN
ARTICHOKE LAKE	0287	04	BIG STONE	7	45 22	96 08	1075	6P	5P			A. W. NELSON
AUSTIN 3 S	0355	09	MOWER	7	43 37	93 00	1215	5P	5P		H	RADIO STATION KAUS
BABBITT 2 SE	0390	03	ST LOUIS	13	47 41	91 55	1615	5P	5P		H	RESERVE MINING CO
BAUDETTE	0515	02	LK OF WOODS	9	48 43	94 37	1075	5P	5P			MUNICIPAL POWER PLANT
BAUDETTE 21 SSE	0520	02	LAKE OF WOOD	9	48 25	94 34	1180	6P	6P			EDDIE SELANDER
BEARDSLEY	0541	04	BIG STONE	7	45 33	96 43	1090	6P	7A		H	WILLIAM L. KIRKEY
BEAVER	0559	09	WINONA	8	44 09	92 01	720		7A			U S CORPS OF ENGINEERS
BEMIDJI AIRPORT	0643	02	BELTRAMI	8	47 30	94 56	1392	MID	MID		H	NATL WEATHER SERVICE
BENSON	0667	04	SWIFT	7	45 19	95 36	1040	7P	7A			LESTER PHILBRICK
BIG FALLS	0746	02	KOOCHICHING	9	48 12	93 48	1270	1P	1P		C H	MINNESOTA FOREST SERV
BIGFORK	0754	02	ITASCA	9	47 45	93 39	1316	5P	5P		C	WAYNE C. FREEBERG
BIRD ISLAND	0783	05	RENVILLE	7	44 46	94 54	1089	5P	5P			NORTHERN STATES POWER
BLANCHARD POWER STA	0826	05	MORRISON	8	45 52	94 21	1100		7A			MINN POWER AND LIGHT CO
BLUE EARTH	0852	08	FARIBAULT	7	43 39	94 06	1095		7A			GREEN GIANT COMPANY
BRAINERD RANGER STA	0939	06	CROW WING	8	46 22	94 12	1214	8A	8A			MINN FORESTRY SERVICE
BRICELYN	0981	08	FARIBAULT	7	43 34	93 48	1190		6A			M. D. JIPSON
BRIMSON	0989	03	ST LOUIS	13	47 16	91 52	1520		7A			MINN POWER AND LIGHT CO
BUFFALO	1107	05	WRIGHT	7	45 11	93 53	1000	5P	5P			TOIVO A. KANGAS
CALEDONIA	1198	09	HOUSTON	11	43 38	91 29	1170	6P	7A			IRWIN N. SCHROEDER
CAMBRIDGE ST HOSPITAL	1227	06	ISANTI	8	45 34	93 14	1000	MID	MID		C H	CAMBRIDGE ST HOSPITAL
CAMPBELL	1246	04	WILKIN	10	46 06	96 25	975	7A	7A			ARLO KATH
CANBY	1263	05	YELLOW MED	7	44 43	96 17	1243	6P	7A		C H	DAROLD L. SNORTUM
CARIBOU 2 S	1303	01	KITTSON	10	48 58	96 27	1020		6P		H	M. MARGARET RISLIE
CASS LAKE	1374	02	CASS	8	47 23	94 37	1296	8A	8A			U S FOREST SERVICE
CEDAR	1390	06	ANOKA	8	45 19	93 17	907	6P	6P			MRS DONALD GALLEGHER
CHASKA 1 NE	1465	08	CARVER	8	44 48	93 35	726	5P	5P			AM CRYSTAL SUGAR CO
CLEMENTSON 6 E	1589	02	KOOCHICHING	9	48 42	94 18	1100				C	ELMER COOK
CLOQUET FOR RES CENTER	1630	06	CARLTON	13	46 42	92 31	1265	5P	5P			CLOQUET FOR RES CENTER
COKATO	1669	05	WRIGHT	7	45 05	94 12	1060		7A			GREEN GIANT COMPANY
COLLEGEVILLE ST JOHN U	1691	05	STEARNS	8	45 35	94 24	1225	7P	7P			ST JOHN UNIVERSITY
COMFREY 4 E	1718	08	BROWN	7	44 07	94 49	1090		9A			MRS STACHIA SCHUMACHER
COOK 18 W	1776	03	ST LOUIS	9	47 52	93 04	1315	5P	5P			VICTOR M. ZGAYNOR
CORRELL	1812	04	BIG STONE	7	45 14	96 10	980		7A			KENNETH H. KLAGES
COTTON 3 NE	1840	03	ST LOUIS	13	47 11	92 25	1370	5P	5P			HENRY H. NOBERG
CRANE LAKE RANGER STA	1857	03	ST LOUIS	9	48 16	92 28	1120	5P	5P			MINN CONSERVATION DEPT
CROOKSTON NW EXP STA	1891	01	POLK	10	47 48	96 37	883	5P	5P		H	NORTHWEST EXP. STATION
DAWSON	2038	04	LAC QUI PARL	7	44 56	96 03	1056		6P			RAYMOND D. HULL
DETROIT LAKES 1 NNE	2142	01	BECKER	10	46 50	95 51	1375	5P	6A		H	RADIO STATION KDLM
DODGE CENTER 2 W	2166	09	DODGE	14	44 02	92 53	1240				C	CHARLES KRAMER
DULUTH HARBOR STATION	2246	03	ST LOUIS	5	46 46	92 05	610	MID	MID			U S COAST GUARD
DULUTH WSO AP R	2248	03	ST LOUIS	5	46 50	92 11	1428	MID	MID		C HJ	NATL WEATHER SERVICE
ELBOW LAKE	2476	04	GRANT	10	45 59	95 58	1195	5P	5P			MR. LOWELL SWENSON
ELGIN	2486	09	WABASHA	8	44 08	92 15	1070		6P			IRLE R. GUSA
ELK RIVER	2500	06	SHERBURNE	8	45 18	93 35	910		7A			MUNICIPAL POWER PLANT
FAIRMONT	2698	08	MARTIN	7	43 38	94 28	1187	MID	7A		H	MARVIN J VAN RIPER
FARIBAULT	2721	08	RICE	2	44 18	93 16	940	5P	8A			HOWARD M. HELGESON
FARMINGTON 3 NW	2737	09	DAKOTA	2	44 40	93 11	980	7P	7P			JEROME AKIN
FERGUS FALLS	2768	04	OTTER TAIL	10	46 17	96 04	1210	6P	6P		H	JOSEPH W. FELIX
FOREST LAKE 4 SE	2881	06	WASHINGTON	12	45 16	92 55	940	6P	6P			FLOYD W. COHOES
FORT RIPLEY	2904	06	CROW WING	8	46 11	94 22	1160		7A			GLADYS B. NELSON
FOSSTON	2916	01	POLK	10	47 35	95 45	1299	6P	6P		C H	MARTIN L. HONSON
FRAZEE	2964	01	BECKER	10	46 44	95 43	1380					JAMES H. ANDERSON
GAYLORD	3076	05	SIBLEY	7	44 33	94 13	1018	5P	5P			GEORGE ANDERSON
GEORGETOWN	3104	01	CLAY	10	47 05	96 48	884	6P	6P			JOHN STEIN
GLENWOOD	3174	04	POPE	7	45 39	95 24	1147	9A	9A			GRANT H. EASTBURG
GOLDEN VALLEY	3202	06	HENNEPIN	8	44 59	93 23	915					CITY ENGINEER
GONVICK	3206	01	CLEARWATER	10	47 44	95 30	1454		9A			VICTOR H. AALBU
GRAND MARAIS	3282	03	COOK	5	47 45	90 20	688	9P	9P			AXEL J. BERGSTROM
GRAND MEADOW	3290	09	MOWER	11	43 42	92 34	1348	7A	7A			MELVIN A. SHEEN
GRAND PORTAGE RS	3296	03	COOK	5	47 58	89 41	670	5P	8A		C	U S INDIAN SERVICE
GRAND RAPIDS NC SCHOOL	3303	02	ITASCA	9	47 14	93 30	1310	5P	5P		H	N CENT EXPERIMENT FARM
GRANITE FALLS POWER PL	3311	04	CHIPPEWA	7	44 49	95 33	892					GARY O HANSON
GULL LAKE DAM	3411	02	CASS	8	46 25	94 21	1215	6P	6P		C	U S CORPS OF ENGINEERS
GUNFLINT LAKE 8 WSW	3417	03	COOK	9	48 04	90 50	1750	6P	6P		C	JERRY MARK
HALLOCK	3455	01	KITTSON	10	48 46	96 57	819	8A	8A			CHARLES CEDERHOLM
HALSTAD	3463	01	NORMAN	10	47 21	96 50	864		8A		H	HENRY O. GILBERTSON
HARMONY	3520	09	FILLMORE	11	43 33	92 00	1340		7A			CARL J. DIEDERICHS
HASTINGS DAM 2	3567	09	DAKOTA	8	44 46	92 52	695		7A			U S CORPS OF ENGINEERS
HAWLEY	3587	01	CLAY	10	46 53	96 19	1174	5P	5P			A. LEONARD JENSON
HIBBING PWR SUBSTATION	3727	03	ST LOUIS	13	47 26	92 58	1534	11P	7A			MINN POWER AND LIGHT CO
HIBBING FAA AP	3730	03	ST LOUIS	13	47 23	92 51	1347	MID	MID			FEDERAL AVIATION AGENCY
HIGH LANDING 2 NW	3736	01	PENNINGTON	10	48 04	95 31	1162		7A			MRS. MABEL PAULSON
HINCKLEY	3793	06	PINE	12	46 01	92 56	1035		8A			WAYNE M. COLLY
HOLYOKE	3863	06	CARLTON	13	46 28	92 23	1050		7A			TONY FABRELLO
HOYT LAKES 5 N	3921	03	ST LOUIS	13	47 35	92 08	1520	MID	MID	MID	H	ERIE MINING COMPANY
HUTCHINSON 1 N	3962	05	MCLEOD	7	44 54	94 22	1093	5P	5P			RADIO STATION KDUZ
INDUS	4008	02	KOOCHICHING	9	48 34	93 50	1100		7A			MRS. EMILY PETERSON
INTERNL FALLS WSO AP R	4026	02	KOOCHICHING	9	48 34	93 23	1179	MID	MID		C HJ	NATL WEATHER SERVICE
ISABELLA 1 N	4068	03	LAKE	5	47 37	91 23	2010	1P	1P			U S FOREST SERVICE
ISLAND LAKE RESERVOIR	4096	03	ST LOUIS	13	46 59	92 14	1372		7A			MINN POWER AND LIGHT CO
ISLE 8 N	4103	06	AITKIN	8	46 15	93 30	1300	6P	6P			ARNOLD A. PILLOLA
ITASCA STATE PARK SCH	4106	01	CLEARWATER	8	47 13	95 12	1490	5P	5P			U OF MINN FORESTRY SCH
JORDAN 1 S	4176	05	SCOTT	8	44 39	93 37	930	6P	6P		H	MRS. GUSTAVE SLAVICEK
KARLSTAD	4213	01	KITTSON	10	48 35	96 31	1040	6P	6P			OLGER B. OLSEN
KELLIHER	4233	02	BELTRAMI	10	47 56	94 27	1388	7A	7A			NORMAN THORHAUG
KETTLE FALLS	4306	03	ST LOUIS	9	48 30	92 39	1122		7A			MINN AND ONT PULP CO
LA CRESCENT DAM 7	4418	09	WINONA	8	43 52	91 18	647		8A			U S CORPS OF ENGINEERS
LAKE CITY	4438	09	WABASHA	8	44 27	92 16	680		7A			BERNARD J. SIMONS
LAKEFIELD	4453	07	JACKSON	4	43 41	95 11	1508		7A			RAYMOND W. PALMBY
LAMBERTON SW EXP STA	4546	07	REDWOOD	7	44 15	95 19	1144	8A	8A	5P	G	SW EXPT STA LAMBERTON
LANESBORO	4563	09	FILLMORE	11	43 43	91 59	1000		7A			EDWARD C. SIMPSON
LE CENTER 1 NE	4641	08	LE SUEUR	7	44 22	93 43	1090		7A			HERBERT P SCHLOESSER
LEECH LAKE DAM	4652	02	CASS	8	47 15	94 13	1302	5P	5P		C	U S CORPS OF ENGINEERS
LE SUEUR	4721	08	LE SUEUR	7	44 28	93 55	845		7A			GREEN GIANT COMPANY
LITCHFIELD	4778	05	MEEKER	7	45 07	94 32	1132	5P	7A			LOUIS E. NELSON
LITTLE FALLS 1 N	4793	05	MORRISON	8	45 59	94 21	1120	5P	5P			WILLIAM C. BANGSTON
LONG PRAIRIE	4861	05	TODD	8	45 59	94 51	1290	6P	8A		H	KENNETH H. FREIE
LUVERNE	4937	07	ROCK	1	43 40	96 12	1500	6P	7A		C	DARRELL W. STRASSBURG
MADISON SEWAGE PLANT	4994	04	LAC QUI PARL	7	45 00	96 11	1090	4P	4P			MUNICIPAL UTILITIES
MAHNOMEN 1 W	5012	01	MAHNOMEN	10	47 19	95 59	1203	5P	5P		H	OSCAR NELSON
MAPLE PLAIN	5136	06	HENNEPIN	8	45 01	93 39	1030	6P	6P			CARL H. HEYER
MARSHALL	5204	07	LYON	7	44 27	95 47	1165	8A	8A			H. VERNON ENGLISH
MEADOWLANDS	5298	03	ST LOUIS	13	47 04	92 44	1280	6P	6P		C H	MRS. ADOLPH ANDERSON
MELROSE	5325	05	STEARNS	8	45 40	94 49	1210	6P	7A			MELROSE LIGHT AND PWR
MILACA	5392	06	MILLE LACS	8	45 45	93 39	1080	6P	7A			ROBERT W. JOHNSON
MILAN	5400	04	CHIPPEWA	7	45 07	95 56	1005	7P	7P		H	TORFINN OPJORDEN
MINN-ST PAUL WSO AP R	5435	06	HENNEPIN	7	44 53	93 13	834	MID	MID		C HJ	NATL WEATHER SERVICE
MINNEOTA	5482	07	LYON	7	44 34	95 59	1165		7A			EDWIN H. LYNG
MINNESOTA CITY DAM 5	5488	09	WINONA	8	44 10	91 49	670		7A			U S CORPS OF ENGINEERS
MONTEVIDEO 1 SW	5563	04	LAC QUI PARL	7	44 56	95 45	985	6P	7A		H	GERALD C HENNEN
MONTGOMERY	5571	08	LE SUEUR	7	44 26	93 35	1100		7A			GREEN GIANT COMPANY
MOOSE LAKE 1 SSE	5598	06	CARLTON	12	46 27	92 45	1110	5P	8A		H	STATE HOSPITAL
MORA	5615	06	KANABEC	12	45 53	93 18	990	5P	5P		H	SEWAGE TREATMENT PLT
MORRIS W C SCHOOL	5638	04	STEVENS	7	45 35	95 55	1130	8A	8A		GH	SAMUEL D. EVANS
NEW ULM 2 SE	5887	08	BROWN	7	44 17	94 25	826	5P	7A		H	RADIO STATION KNUJ
NORTHFIELD 2 NNE	5987	08	DAKOTA	2	44 28	93 09	890				C	SEWAGE TREATMENT PLANT
NORTH MANKATO	6007	08	NICOLLET	7	44 10	94 02	785	6P	7A			WARREN H. HEISER
OKLEE	6148	01	RED LAKE	10	47 50	95 51	1150	5P	5P			OTTO A. BAKKEN
ONAMIA RANGER STATION	6166	06	MILLE LACS	8	46 04	93 40	1260				C	MINN CONSERVATION DEPT
ORR 13 W	6212	02	KOOCHICHING	9	48 03	93 06	1300	6P	6P			MRS. LESLIE CONNER
ORR RANGER STATION	6213	03	ST LOUIS	9	48 03	92 50	1390				C	MINN CONSERVATION DEPT
ORTONVILLE	6224	04	BIG STONE	7	45 18	96 27	976		8A			OTTER TAIL POWER CO
ORWELL DAM	6228	04	OTTER TAIL	10	46 13	96 11	1080				C	U S CORPS OF ENGINEERS
OTTERTAIL	6276	04	OTTER TAIL	10	46 25	95 34	980	6P	6P			THOMAS AHLFS
OWATONNA	6287	08	STEELE	2	44 06	93 14	1150	5P	5P			SEWAGE TREATMENT PL
PARK RAPIDS	6360	02	HUBBARD	8	46 55	95 04	1434	6P	8A		H	FRED A. ZELLER
PAYNESVILLE	6386	05	STEARNS	8	45 23	94 44	1175	8A	8A			CARY J. THELEN
PELICAN RAPIDS	6405	04	OTTER TAIL	10	46 35	96 05	1365		7A			ENGEBRETSON CON, INC.
PINE RIVER DAM	6547	06	CROW WING	8	46 40	94 07	1251	6P	6P		H	MRS, LORETTA A. BOHALL
PIPESTONE	6565	07	PIPESTONE	1	44 01	96 19	1705	5P	5P		H	NATIONAL PARK SERVICE
POKEGAMA DAM	6612	02	ITASCA	8	47 15	93 35	1280	5P	5P		C	U S CORPS OF ENGINEERS
PRESTON	6654	09	FILLMORE	11	43 40	92 05	930	6P	6P			WASTE TREATMENT PLANT
RED LAKE FALLS	6787	01	RED LAKE	10	47 53	96 17	1035	6P	6P			REV. ROGER E. RAEBEL
RED LAKE INDIAN AGENCY	6795	02	BELTRAMI	10	47 52	95 02	1216	8A	8A		C H	U S INDIAN SERVICE
RED WING	6817	09	GOODHUE	8	44 34	92 32	688		7A			WASTEWATER TREATMENT PL
RED WING DAM 3	6822	09	GOODHUE	8	44 37	92 37	677		8A		C	U S CORPS OF ENGINEERS
REDWOOD FALLS FAA AP	6835	07	REDWOOD	7	44 33	95 05	1025	MID	MID		H	U S FED AVIATION AGENCY
REMER NO 2	6849	02	CASS	8	47 03	93 54	1345	6P	8A			FRANCIS V. VOYTAS
RIVERTON	6972	06	CROW WING	8	46 28	94 03	1182		7A			MINN POWER AND LIGHT CO
ROCHESTER WSO AP R	7004	09	OLMSTED	14	43 55	92 30	1297	MID	MID		C HJ	NATL WEATHER SERVICE
ROSEAU 1 E	7087	01	ROSEAU	10	48 51	95 45	1047	5P	5P			KRWB RADIO
ROSEMOUNT AGRI EXP STA	7107	09	DAKOTA	8	44 43	93 06	950	5P	5P			AGRICULTURAL EXP STA
ROTHSAY	7149	04	WILKIN	10	46 29	96 16	1206	6P	6P			S. E. MAGNUSSON
RUSHFORD 1 SSW	7184	09	FILLMORE	11	43 47	91 45	733				C	KERMIT J. HOLGER
ST CLOUD WSO AP R	7294	05	STEARNS	8	45 35	94 11	1034	MID	MID		C HJ	NATL WEATHER SERVICE
ST FRANCIS 4 S	7308	06	ANOKA	8	45 20	93 22	925		7A			PETER GEORGES
ST JAMES FILTRATION PL	7326	08	WATONWAN	7	43 59	94 37	1090	5P	5P			FILTRATION PLANT
ST PAUL	7377	06	RAMSEY	8	44 59	93 05	920	5P	7A			JOHN H. RIDDELL
ST PETER 2 SW	7405	08	NICOLLET	7	44 18	93 58	825	9A	9A			MINNESOTA SECURITY HOSP
SANDY LAKE DAM LIBBY	7460	06	AITKIN	8	46 48	93 19	1234	5P	5P		C H	U S CORPS OF ENGINEERS
SANTIAGO 3 E	7502	05	SHERBURNE	8	45 33	93 46	1020	6P	6P			GORDON W. WOLD
SHERBURN 3 WSW	7602	08	MARTIN	4	43 38	94 47	1320				C	FRANCIS M. THEOBALD
SLAYTON 9 SW	7740	07	MURRAY	4	43 54	95 53	1580	6P	6P			HENRY H HILFERS
SPRINGFIELD 1 NW	7907	08	BROWN	7	44 15	94 59	1066	6P	6P		C	RICHARD A. FESER
SPRING GROVE 1 NW	7915	09	HOUSTON	11	43 34	91 40	1324		6P		C	CLIFFORD NARVESON
SPRING VALLEY	7941	09	FILLMORE	11	43 41	92 25	1298				C	KENNETH C. MOON
STEWART 6 SSW	8025	05	SIBLEY	7	44 39	94 31	1035	5P	5P			WALTER SCHREINER
STILLWATER 1 SE	8037	06	WASHINGTON	12	45 02	92 47	710	7P	7A			WASTE TREATMENT PLANT
THEILMAN	8227	09	WABASHA	14	44 18	92 12	737	5P	7A			U S CORPS OF ENGINEERS
THIEF LAKE REFUGE	8235	01	MARSHALL	10	48 29	95 57	1142				C	STATE GAME WARDEN
THIEF RIVER FALLS	8243	01	PENNINGTON	10	48 04	96 11	1130	8A	8A			HAROLD H. ANDERSON
THORHULT	8254	02	BELTRAMI	10	48 14	95 15	1185	6P	6P		H	EDITH HOLTHUSEN
TOFTE RANGER STATION	8280	03	COOK	5	47 34	90 52	680				C	U S FOREST SERVICE
TOWER	8311	03	ST LOUIS	13	47 48	92 16	1390	7A	7A			STANLEY J. HILL
TRACY	8323	07	LYON	7	44 14	95 37	1403	8A	8A		C H	CITY WATER UTILITY
TWIN VALLEY 3 SW	8411	09	NORMAN	10	47 14	96 17	1075				C	ROY I. MICHELSON
TWO HARBORS	8419	03	LAKE	5	47 01	91 40	625	3P	3P			WASTE TREATMENT PLANT
TYLER	8429	07	LINCOLN	7	44 17	96 08	1745	7A	7A		H	MUNICIPAL L & P PLANT
UNIV OF MINN ST PAUL	8450	06	RAMSEY	8	44 59	93 11	969				G	UNIV OF MINNESOTA
VESTA	8520	07	REDWOOD	7	44 30	95 25	1080		7P			LOUIS LIESKE
VIRGINIA	8543	03	ST LOUIS	13	47 30	92 33	1435	7P	11A		C	SEWAGE TREATMENT PLANT
WABASHA	8552	09	WABASHA	8	44 23	92 02	700		7A			RICHARD V. GOSSE
WADENA 3 S	8579	05	WADENA	8	46 24	95 09	1350	7A	7A		H	HENRY C. CLARKSEAN
WALES 2 SE	8613	03	LAKE	5	47 13	91 43	1715				C	GEORGE S. KELLER
WALKER AH GWAH CHING	8618	02	CASS	8	47 04	94 35	1407	6P	6P			AH-GWAH-CHING STATE N H
WALKER RANGER STATION	8621	02	CASS	8	47 06	94 34	1362				C	U S FOREST SERVICE
WANNASKA 8 SE	8656	01	ROSEAU	10	48 34	95 38	1190	5P	5P			GEORGE MORK
WARROAD	8679	01	ROSEAU	9	48 55	95 19	1069	5P	5P		C H	WILLIAM LANDBY
WASECA EXP. STATION	8692	08	WASECA	7	44 04	93 31	1153	8A	8A	8A	GH	UNIVERSITY OF MINNESOTA
WASKISH RANGER STATION	8700	02	BELTRAMI	10	48 10	94 31	1174	1P	1P			U S FOREST SERVICE
WATSON 1 NE	8729	04	CHIPPEWA	7	45 01	95 48	1070				C	U S CORPS OF ENGINEERS
WAYLAND 13 NW	8763	02	LK OF WOODS	9	48 36	94 33	1130		6P		H	MRS. JOSEPHINE AERY
WELLS 1 NW	8808	08	FARIBAULT	7	43 45	93 44	1197		7A			GERALD H. THISIUS
WHEATON	8907	04	TRAVERSE	10	45 48	96 29	1018	4P	4P			VERDI A. JOHNSON
WHITEFACE RESERVOIR	8939	03	ST LOUIS	13	47 17	92 11	1492		7A			MINN POWER AND LIGHT CO
WHITE ROCK DAM	8947	04	TRAVERSE	10	45 52	96 34	1024				C	U S CORPS OF ENGINEERS
WILLMAR COUNTY HWY GAR	8999	05	KANDIYOHI	7	45 07	95 01	1141				C	INACTIVE 8/15/70
WILLMAR STATE HOSPITAL	9004	05	KANDIYOHI	7	45 08	95 01	1133	6P	7A		H	BERNARD GUNDERSHAUG
WINDOM	9033	07	COTTONWOOD	4	43 52	95 07	1370	8A	8A			WINDOM SEW TREATMENT PL
WINNEBAGO	9046	08	FARIBAULT	7	43 46	94 10	1110	7A	7A			NORA T. LOFSTUEN
WINNIBIGOSHISH DAM	9059	02	ITASCA	8	47 26	94 03	1315	5P	5P		C	U S CORPS OF ENGINEERS
WINONA	9067	09	WINONA	8	44 03	91 38	652	8A	8A		H	GARY W. EVANS
WINONA DAM 5 A	9072	09	WINONA	8	44 05	91 41	663		7A			U S CORPS OF ENGINEERS
WINSTED	9085	05	MCLEOD	8	44 58	94 03	1025		6P			JAMES BAIRD
WINTON POWER PLANT	9101	03	LAKE	9	47 56	91 46	1337	MID	MID		C	WINTON POWER PLANT
WORTHINGTON 2 NNE	9170	07	NOBLES	6	43 39	95 35	1570	7A	7A		C H	WORTHINGTON SEW TRMT PL
WRIGHT 4 NW	9173	06	AITKIN	8	46 43	93 04	1290	6P	6P			GUSTAVE H. JOHNSON
YOUNG AMERICA	9208	05	CARVER	7	44 47	93 55	1020		7A			HAROLD E. RANZINGER
ZUMBROTA	9249	09	GOODHUE	14	44 18	92 40	985	5P	7A		H	ALVIN B. LOHMANN

From "Climatological Data--Minnesota," U.S. Dept. of Comm., Natl. Climatic Center

Table 7 - LIST OF STATIONS FOR WHICH HOURLY PRECIPITATION DATA ARE AVAILABLE

Albert Lea 3 E
Alexandria FAA AP
Amboy
Big Falls Ranger Sta.
Bigfork

Buffalo
Cambridge State Hosp.
Canby
Clemenson 6 E
Correll

Crane Lake Ranger Sta.
Dodge Center 3 NW
Duluth WB AP
Fosston Power Plant
Frazee

Grand Portage RS
Granite Falls Power Pl
Gull Lake Dam
Gunflint Lake
Hawley

Hinckley
Holyoke
Hutchinson 1 N
Int. Falls WB Airport
Lakefield

Leech Lake Dam
Le Sueur
Little Falls Water Wks.
Luverne
Meadowlands

Minneapolis WB AP
Northfield Carleton
Onamia Ranger Station
Orr Ranger Station
Orwell Dam

Pokegama Dam
Preston 6 SW
Preston 8 SW
Preston 6 S
Red Lake Indian Agency

Red Wing Dam 3
Rochester WB Airport
Rushford
St. Cloud WB Airport
Sandy Lake Dam Libby

Sherburn 3 NNE
Springfield
Spring Grove 1 NW
Spring Valley
Thief Lake Refuge

Tofte Ranger Station
Tracy
Twin Valley 3 SW
Virginia
Wales 2 ENE

Walker Ranger Station
Warroad
Watson 1 NE
White Rock Dam
Willmar Co Hwy Gar

Winnibigoshish Dam
Winton Power Plant
Worthington

IV. WATER CONTENT OF SNOW

Information on the water content of snow and on frost depths in this area is procured and prepared in map form by both the St. Paul District of the U.S. Army Corps of Engineers and the National Weather Service. The procurement of data and the preparation of maps depends to some extent on the severity of the winter weather. Years in which snow accumulations developed early in the winter resulted in the preparation of a series of maps starting as early as January. While flood problems may depend primarily on the water content of the snow in about mid-March, the early maps are essential to assist in flood defense preparations.

Figures 1 and 2 illustrate the maps obtained from the Corps of Engineers and the National Weather Service.

Tables 8 and 9 list the maps of which copies have been obtained for this study. The National Weather Service maps start with the year 1948 and the Corps of Engineers maps with 1949. Maps are not available for certain years, in some cases due to little snow accumulation.

To aid in the application of these data to mathematical models in this area, the data from one map for each year have been stored on magnetic tape. Using the world latitude and longitude coordinate system, the water content at grid points 10 minutes apart in latitude and 15 minutes apart in longitude was determined, punched on cards, and transferred to tape. The date for each map was about March 15 of the respective year. If funds permit it, the data from other maps will be stored also.

Table 8 - NATIONAL WEATHER SERVICE - WATER EQUIVALENT OF SNOWPACK

SDWE = Snow Depth, Water Equivalent; TP = Total Precipitation; FD = Frost Depth

Type of Map	Date	Description
SDWE	1 March 1948	Snow Survey Water Content - North Dakota
"	1 March 1955	Water Equivalent Only
"	8 March 1955	" " "
"	18 March 1955	" " "
SDWE	6 March 1956	Snow Depth Water Equivalent above Dam No. 2, Mississippi River
"	6 March 1956	Mississippi River, Dam No. 2 to Dam No. 10
"	13-27 March 1956	" " " " " " " " "
"	13 March 1956	" " " " "
"	28 March 1956	" " " " "
"	28 March 1956	" " " " " " " " "
"	5 March 1957	" " " " " " " " "
"	14 March 1957	" " " " "
"	14 March 1957	" " " " " " " " "
"	4 April 1957	" " " " "
"	6 March 1959	" " " " " " " " "
"	6 March 1959	" " above Dam No. 2
"	10-11 March 1959	" " Dam No. 2 to Dam No. 10
"	10-13 March 1959	" " " " " " " " "
"	23-24 March 1959	" " " " " " " " "
"	26-31 March 1959	" " " " " " " " "
"	26-31 March 1959	" " above Dam No. 2
"	15 Feb 1960	" " Dam No. 2 to Dam No. 10
"	15 Feb 1960	" " above Dam No. 2
"	19 March 1960	" " Dam No. 2 to Dam No. 10
"	19 March 1960	" " above Dam No. 2
"	7-10 March 1961	" " Dam No. 2 to Dam No. 10
"	7-10 March 1961	" " above Dam No. 2
"	11-20 March 1961	" " Dam No. 2 to Dam No. 10
"	11-20 March 1961	" " above Dam No. 2
"	11-13 March 1962	" " above Dam No. 10 and Lake Drainage
"	13-23 March 1962	" " " " " " " " "
"	4-10 Feb. 1962	" " " " " " " " "
"	26-30 March 1962	" " " " " " " " "
"	16-20 March 1963	" " " " " " " " "
"	22 March 1963	" " " " " " " " "
"	18 Feb-10 Mar 1964	" " " " " " " " "
"	10-26 March 1964	" " " " " " " " "

Table 8 [Continued]

Type of Map	Date	Description								
SDWE	16-23 Feb 1965	Mississippi	River	above	Dam	No.	10	and	Lake	Drainage
"	1-3 March 1965	"	"	"	"	"	"	"	"	"
"	4-17 March 1965	"	"	"	"	"	"	"	"	"
"	9-12 March 1965	"	"	"	"	"	"	"	"	"
"	17-18 March 1965	"	"	"	"	"	"	"	"	"
"	22 March 1965	"	"	"	"	"	"	"	"	"
"	23-26 March 1965	"	"	"	"	"	"	"	"	"
"	18-26 March 1965	"	"	"	"	"	"	"	"	"
"	27-29 March 1965	"	"	"	"	"	"	"	"	"
"	30 March 1965	"	"	"	"	"	"	"	"	"
"	22 Mar-1 Apr 1965	"	"	"	"	"	"	"	"	"
TP	April 1965	"	"	"	"	"	"	"	"	"
SDWE	1-5 March 1966	"	"	"	"	"	"	"	"	"
"	8-18 March 1966	"	"	"	"	"	"	"	"	"
"	19-22 March 1966	"	"	"	"	"	"	"	"	"
"	13 Feb 1967	"	"	"	"	"	"	"	"	"
"	14-21 Feb 1967	"	"	"	"	"	"	"	"	"
"	28 Feb-21 Mar 1967	"	"	"	"	"	"	"	"	"
"	20-24 March 1967	"	"	"	"	"	"	"	"	"
"	2-3 April 1967	"	"	"	"	"	"			
"	6-7 April 1967	"	"	"	"	"	"			
FD	Feb. 1968	"	"	"	"	"	"			
SDWE	13-27 Feb 1968	"	"	"	"	"	"			
"	1-12 March 1968	"	"	"	"	"	"			
"	18-21 March 1968	"	"	"	"	"	"			
"	6-9 Jan 1969	"	"	"	"	"	"			
"	21 Jan 1969	"	"	"	"	"	"			
"	28 Jan 1969	"	"	"	"	"	"			
"	4 Feb 1969	"	"	"	"	"	"			
"	11-12 Feb. 1969	"	"	"	"	"	"			
"	18 Feb. 1969	"	"	"	"	"	"			
"	25 Feb. 1969	"	"	"	"	"	"			
"	4 March 1969	"	"	"	"	"	"			
"	11-15 March 1969	"	"	"	"	"	"			
"	18 March 1969	"	"	"	"	"	"			
"	25-26 March 1969	"	"	"	"	"	"			
"	1 April 1969	"	"	"	"	"	"			
"	4-5 April 1969	"	"	"	"	"	"			
"	3-6 March 1970	"	"	"	"	"	"			
"	10 March 1970	"	"	"	"	"	"			
"	19-23 March 1970	"	"	"	"	"	"			
"	17-26 March 1970	"	"	"	"	"	"			
"	27 Mar-3 Apr 1970	"	"	"	"	"	"			

Table 8 [Continued]

Type of Map	Date	Description
SDWE	16 Feb 1971	Mississippi River above Dam No. 10
"	23 Feb 1971	" " " " " "
"	2 March 1971	" " " " " "
"	9 March 1971	" " " " " "
FD	No date given-- assume Mar 1971	" " " " " "
SDWE	16 March 1971	" " " " " "
"	16 March 1971	Missouri River and Upper Mississippi
"	23 March 1971	Mississippi River above Dam No. 10
"	23 March 1971	Missouri River and Upper Mississippi Basin
"	30 March 1971	Mississippi River above Dam No. 10

Table 9 - CORPS OF ENGINEERS - WATER EQUIVALENT OF SNOWPACK

Date

8 - 14 March 1949

13 - 20 February 1950
13 - 22 March 1950

5 - 22 March 1951

10 - 19 March 1952

1 - 8 March 1955

12 - 19 March 1956

19 - 20 February 1962
6 March 1962
13 March 1962
20 March 1962
30 March - 3 April 1962

11 - 19 March 1965

1 - 8 March 1966

15 February 1967
21 February 1967
27 February - 2 March 1967
3 - 8 March 1967

7 February 1969
13 February 1969
4 March 1969
11 March 1969
21 March 1969

19 January 1970
22 January 1970
27 January 1970
4 February 1970
12 March 1970

8 January 1971
10 February 1971
25 February 1971
4 March 1971
11 March 1971
25 March 1971

V. FROST DEPTH DATA

Understanding of the snowmelt runoff process requires a knowledge of many hydrometeorological parameters as well as characteristics of the watershed. Several meteorological parameters can cause changes in the watershed's characteristics. An obvious example is that of a lack of precipitation causing soil moisture to decrease and thus changing the infiltration rate of the soil.

In the Upper Midwest the depth and type of frost in the ground over the winter months has an important effect on loss rates during the spring melt period. Currently, little is known regarding the depth and type of frost that forms each year.

The depth of frost can be determined in several ways. In the past some data have been assembled based on reports from electric power and telephone utility companies and other sources. However, the lack of data at regular intervals and locations limits the application of this type of information.

To increase knowledge of local frost conditions, the St. Paul District Corps of Engineers established a network of 34 frost tubes over the state of Minnesota and adjoining area. A frost tube is an inexpensive device for determining the depth of frozen soil. It consists of a clear plastic tube containing water which is inserted into an access tube in the ground. The inner tube can then be withdrawn at any time. If properly constructed, the tube will be frozen to the same depth as the surrounding soil. Data from the Corps of Engineers frost tube network was first collected in the winter of 1971-72. The establishment of this network is an important step toward understanding the effect of frost depth on flood runoff magnitudes.

While the frost tube is an efficient indicator of the portion of the soil that is frozen, considerably more information is obtained by measuring the temperature of the soil at various depths. The depth of frozen soil can then be inferred from a soil temperature profile. In addition, the temperature profile shows the direction of movement of heat into or out of the soil. If the thermal properties of the soil are known, such things as the depth of freezing and the thawing rate can be predicted for a given surface condition.

The soil temperature profile in Minnesota has been recorded at a very limited number of stations. A station located on the St. Paul campus of the University of Minnesota has recorded soil temperatures for about 10 years.

Presently, temperature profile data are published for three other stations which have records for shorter periods. To supplement the soil temperature data that are available at these three stations, four additional temporary stations were established under this project.

Decisions relating to the selection of equipment for measuring soil temperature were influenced by a very limited budget. The temperature profiles are measured using a series of thermistors buried at various depths in the soil. The thermistor is a solid state device which has a high negative temperature resistance characteristic; that is, a small increase in temperature causes a large decrease in resistance, as shown in Fig. 3.

If the resistance of the thermistor is known, its temperature can be found from a relationship like that in Fig. 3. The resistance of the thermistor can be determined very accurately using a null balance bridge. This method was chosen due to its high accuracy, simplicity, and low cost. A typical resistance readout circuit is shown in Fig. 4.

In use, the meter was brought to a null position, indicating that the resistance bridge was in balance. The dial reading on variable resistor R_3 then indicated the resistance of the thermistor. The dial had previously been calibrated against a precision decade resistance box. Because inexpensive thermistors were used, each one required an individual calibration. In practice, the dial reading was used to enter a table which yields the temperature for a given thermistor. Figure 5 shows one page of the temperature tables. The table is entered with a range and dial reading (i.e., resistance) and a particular thermistor or probe number. The tabular value is the temperature in degrees Fahrenheit.

The thermistors were mounted in a white pine wooden pole. A cable was provided to a readout station about 10 ft from the pole. Figure 6 shows a typical layout. In most cases, nine thermistors were used, eight mounted in the pole below ground level as shown in Fig. 6 and one above ground in the connection box. The user connects his readout device at the connection box to determine the temperature of any of the nine thermistors.

The results of measuring soil temperatures at the four stations over the winter of 1971-72 are shown in Figs. 7 through 10. One station is located at Watson, Minnesota in the western area of the Minnesota River watershed. This pole is buried in an earthen dike adjacent to the Chippewa

River. The gage is read by personnel of the Corps of Engineers. Since it is located on an exposed dike, little snow accumulation occurs, allowing the frost to penetrate deep into the ground. Figure 7 shows that by the 4th of March 1972 the 32°F isotherm was 152 cm deep. Melting occurred from the surface downward and from the deeper layers upward. This resulted in unfrozen soil at the surface beginning about March 12 and a layer of frozen soil persisting until about April 15.

A second station is located at St. James, Minnesota in the southern portion of the Minnesota River watershed. The temperature pole is buried in a flat field containing low (0.5 to 1.0 m) brush. This field is part of a State of Minnesota Game Farm and is read by state personnel. The water table at the time of installation (November 1971) was approximately 6 ft (1.75 m) beneath the surface. As shown in Fig. 8, the 32°F isotherm reached a maximum depth of only 22 cm. This site encouraged the deposition of a uniform blanket of snow. The snow on the ground was 20 to 30 cm deep during the entire winter period and acted as a very effective insulator between the cold air above and the ground below. In addition, it is likely that the water table in close proximity acted as a relatively large source of heat.

A third station is located in Shoreview, Minnesota near the northeast corner of the Minnesota River watershed. This station is in a residential area on the side of a hill, and drifting snow often covered the test site. Snow depths of 40 to 80 cm were reported. This station is read by personnel of the St. Anthony Falls Hydraulic Laboratory. Figure 9 shows that the maximum depth that the 32°F isotherm reached was 42 cm on January 26. From that time on a large snowfall provided an effective insulating blanket, allowing the soil to warm due to heat from the ground below. By the middle of February no frost existed in the soil profile.

The fourth station is located in Brooklyn Park, Minnesota, also near the northeast corner of the Minnesota River watershed. This site is in a flat residential area. A light uniform snow cover existed most of the winter period. As shown in Fig. 10, a maximum depth of 133 cm was reached by the 32°F isotherm on about March 12. In this case a very rapid melt of frost occurred over a period of only five days.

The data collected during the winter of 1971-72 substantiate the supposition that, for given climatic conditions, frost depth can vary considerably over an area due to the combined effects of snow cover, soil surface cover, soil type, soil moisture, location of water table, and other factors.

VI. DATA STORAGE SYSTEM

The availability of hydrometeorological data on a mass storage medium such as magnetic tape is one of the factors that make the study of snowmelt and rainfall floods on a large scale possible. The required data on observed daily discharges, daily and hourly precipitation, maximum and minimum daily air temperatures, three hourly dewpoint temperature, wind velocity, and other parameters were all obtained on 1/2-inch magnetic tape from the appropriate collecting agency. These data were obtained for most stations within or near the state of Minnesota. A total of 20 tapes are required to store all these hydrometeorological data. To provide a margin of safety against the inadvertent loss or destruction of a data tape, a working copy tape is made as soon as a new data tape is received. The original tape is then stored at a separate location in a secure area and the working copy kept at the University of Minnesota Computer Center to be used for all further processing.

The data required for a given study depend on the specific parameters to be used and the geographical area on which the study is to be made as well as on the time period needed. To obtain the required data it may be necessary to mount and search through anywhere from one to ten tapes. Such an operation may become expensive if it is repeated a large number of times. In such a situation the pertinent data tapes can be searched once to extract the records required for the given study and these data preserved on punched cards, another magnetic tape, or a disk, depending on the quantity of information and the needs of the study. This subset of data can then be used much more economically in the specific study.

The format used when transferring the subset of data to punched cards can be one specifically required by a given computer program or it can be of some general form. If the format on punched cards is of a general form decided upon by the user, it is a definite advantage to include on each card an indication of the type of data, the date, and the station. This overcomes the common difficulty of identifying a data deck two weeks or a month after it has been used.

If the quantity of data in the subset is relatively large, it may be advantageous to store it on magnetic tape. In such a case it is again possible to store it either in a specific format required by a computer program or in a general format decided on by the user. Again it is desirable to completely identify the information on the tape so that the parameter, date, and station of each set of data can be determined from the tape. In running a program with a tape file of data, the user has the added difficulty of always searching (reading) sequentially through the information to locate the parameter, date, and station desired. When using punched cards it is a simple matter to pull out a group of cards with the specific information required for a given run.

A third alternative for storing the subset of data is the use of disk storage. Here two options are usually available. Disk storage can be used in a manner identical with that of magnetic tapes. In this mode the only advantage is the much greater speed of data transmission. As with magnetic tapes, the information must be searched sequentially. The second option exploits both the high speed capability of the disk and its capability for random access. With the random access option it is possible to jump from one position in the data file to another without reading through the intervening information. To achieve this capability for random access an index is kept of where each data record is written. Then by consulting the index first it is possible to move directly to the location on the disk that contains the data required.

This random access disk storage system was used to hold a subset of data for all mean daily discharges, daily precipitation, and daily maximum and minimum air temperature stations in and around the Minnesota River basin. The system uses Fortran callable routines to perform the random access operations.

A subroutine RANDSK was prepared which allows the user to simply ask for an array of data by specifying anywhere from one to four subscripts. As an example, if the mean daily discharges are required for the month of April (4) in 1965 (65) at the third (3) station in the discharge data file, all the user needs to do is specify (4,65,3) to the subroutine RANDSK. A listing of this routine is shown in Appendix C. The array of data returned would contain identifying information as well as the actual mean daily discharges for the month.

Subroutine RANDSK is a FORTRAN routine to handle the operations of reading and writing both indexes and data on a random access disk. To illustrate how this routine works it is necessary to first discuss a simple example of random access storage. This discussion will pertain to specific system I/O routines available at the University of Minnesota Computer Center (CDC 6600). Other systems with random access disk storage may utilize slightly different routines; however, the basic concepts are still applicable.

When a random file is created, an index is first established in core to hold a count which will indicate where any block of data is located. Data are transferred to or from the disk in blocks of varying sizes. The block of data is normally called a logical record. A record may be one computer word in length or it may be any other number of words. Whatever the length, a record is treated as a unit. All transfer operations (i.e., read or write operations) begin at the beginning of a record. Under the CDC system a record is given an identifier which may be either a number or a name. Only the number identifier will be considered here. The index is an array of length equal to the largest number of identifiers that will be used. Thus, for example, if a total of 100 records are to be written, an index of 100 elements is required. In actual practice 101 elements are required, with the first element used to tell the routine that the number identifier system is being used. Thus when record number 3 is written, the location in the file at which it begins is stored in the index in element 4. In general, when record N is written, its starting location is saved in the index in element N+1. The record number is simply an identifier and does not correspond to the order in which the records were written. That is, the record identified as number 5 may be written first, then record 2, then 8, etc. Their locations will be saved in the index in cells 6, 3, and 9 respectively. When reading information back from the disk it is necessary simply to request record 8. The read routine then checks in the index at cell 9 to find where record 8 begins, positions the disk read head at that point, and reads the record. At the end of the job the index is saved by also writing it on the disk. The file is then complete and can be either saved by copying to magnetic tape or retained on the disk. In any future use the index is read in first and then read or write operations proceed as usual.

In this simple example one level of indexing was used. It was convenient to refer to a record using one number. Often it is desirable to use two or more numbers or subscripts to refer to a record. As an example, if there were several stations in an area and data existed for several years, it might be useful to let a data record be long enough to hold one station-year of information. Then two subscripts would make it simple to refer to a particular station-year of interest, the first designating the station and the second indicating the year. In order to provide for 100 stations and 100 years it would be necessary to establish an index array of 10,000 elements to hold the starting location of each of the 10,000 possible records.

This approach, while giving rapid random access to any one of 10,000 records, has the deficiency of requiring a large amount of core storage for the index, which makes it an unattractive approach for general use. Furthermore, if it were desirable to allow a third subscript to indicate a particular parameter at the station, the index array required would become still larger. If 10 parameters were allowed, a 100,000 element array would be necessary. An alternative to holding the entire index array in core storage is to use the random disk to hold portions of the index array. Under this concept a series of indexes can be set up. The first index array, associated with the first subscript (e.g., station), is used to point to a particular subindex on the disk. This subindex, associated with the second subscript (e.g., year) is used to point to another subindex on the disk. This third subindex associated with the third subscript (e.g., parameter) is used to point to the actual data record. This approach requires slightly more time to get at the data record and additional disk storage space. Its advantage is, obviously, low core storage of index arrays (only 100 elements) while retaining the capability of randomly accessing a large number of records.

This subindexing procedure produces a tree structure data file. An example of a three-level (three-subscript) system is given in Fig. 11. The shaded cells indicate the path to the second station, first year, and second parameter.

Subroutine RANDSK performs the necessary operations to account for up to four levels of subscripts with up to 126 entries in each level. This theoretically allows for 126^4 or over 250 million data records. In a real application one level may designate a station (50 entries), the second may designate a year (20 entries), and the third may designate a month (12 entries). In such a case 12,000 data records could be handled. Any one of the records could be retrieved in three read operations. The master index (station index), which is always in core, would be used to locate the year index. The first read would obtain the year index, which would then be used to locate the month index. The second read would obtain the month index, which would then locate the data record. The third read would then obtain the actual data desired. If the same information (i.e., 12,000 data records) were kept on a sequential tape file, on the average it would require 6000 read operations (instead of only 3) to locate a given data record. This shows the great benefit of performing the slight extra work of keeping track of the indexes and using the random access approach.

As indicated, the present version of RANDSK utilizes CDC random access I/O routines. Minor changes may be required to utilize this routine on other computing systems.

VII. APPLICATIONS OF MODELS TO TEST BASIN

Several mathematical models exist to compute snowmelt, basin loss, and resulting stream runoff. Some of the most important approaches are the Stanford model, the SSARR model, and HEC-1. The Stanford model, developed in the early 1960's by Crawford and Linsley at Stanford University, is one of the earliest efforts to mathematically model the significant components of the runoff process. The SSARR--Streamflow Synthesis and Reservoir Regulation--model was developed in a combined effort by the Portland division of the Corps of Engineers and the Portland River Forecast Center of the National Weather Service. HEC-1 is a hydrologic design program developed by the Hydrologic Engineering Center of the Corps of Engineers. Each of these models attempts to represent the important aspects of the runoff process in order to simulate streamflow.

A copy of each of these programs was obtained from the appropriate source. They were then adapted to the University of Minnesota's CDC 6600 computing system. The SSARR model and HEC-1 were selected for further evaluation and testing. Certain aspects of the adaptation and evaluation were accomplished under a Corps of Engineers project and a previous OWRR project.

To illustrate the application of one of these models to real conditions, the Minnesota River watershed was selected as a test basin. This watershed comprises approximately 16,200 sq mi in southwestern Minnesota.

The general main stem flow direction is from west to east. Figure 12 is a map of the Minnesota River basin showing the sub-watershed units it was divided into for runoff analysis. Some reservoirs exist in the upper reaches of the watershed. These reservoirs have only a minor effect on high flows. Almost the entire area is devoted to agricultural use. The topography is generally quite flat. The main stem slope of the Minnesota River is 1.4 ft per mile. Several of the sub-basins contributing from the north side of the main stem contain substantial amounts of natural lake storage. Those sub-basins on the south side have very little or no lake storage.

As a preliminary analysis, the SSARR model was fitted to each of the 15 sub-watersheds of the Minnesota Basin. Figure 13 shows the results of reproducing the record snowmelt flood of 1967. In this example the snowmelt was calculated based on the degree-day method. This method utilizes only the measured air temperature to predict snowmelt. Thus this analysis assumes that the air temperature is an index to all the significant heat transfer mechanisms that affect snowmelt. Figure 14 shows the total moisture available during the spring of 1965. It includes the water equivalent in the snowpack prior to melt plus the additional precipitation that occurred during the melt period. At location 4 in Fig. 15 both the magnitude and the timing of the observed discharges agree quite well with those predicted. However, at locations 6 and 7 the predicted time was later than it should have been. Under a continuing OWRR project, consideration will be given to other melt functions which attempt to evaluate each of the heat transfer mechanisms that affect snowmelt. At location 10 in Fig. 15 near the mouth of the Minnesota River, the magnitudes of the predicted and observed discharges agree quite well; however, the predicted peak occurs slightly later than that observed.

Figures 16 and 17 show in greater detail the calculated pattern of runoff during the month of April 1965. Figure 16 for the Chippewa River basin shows the maximum, minimum, and average air temperatures and the rainfall, snowmelt, and resulting runoff. It can be seen from this figure that rainfall during the first week of April contributed most of the moisture that became spring runoff. The snowmelt contributed only a minor portion during the first two weeks of the month. In contrast, Fig. 17 for the Cottonwood River shows that the contributions from rainfall and snowmelt moisture were nearly equal for this basin.

From a preliminary application of the SSARR model to this Midwestern test basin it became evident that the methods used to model certain portions of the snowmelt-runoff process were not desirable for the Midwest. The SSARR model was originally developed for the Columbia River basin. Some of the techniques used to model a mountainous area either are not needed or do not represent the best approach to modeling a flat Midwestern area.

An attempt was made to revise the degree-day method to better reflect the changing conditions of the snowpack during snowmelt. The function initially chosen increases the degree-day melt coefficient as the snowpack melts to represent its ripening and changing albedo. Figure 17 shows that with a mean temperature of 48°F on April 10 only about 0.10 inches of snow melted; however, a few days later, on April 13, a mean temperature of 44°F yielded about 0.70 inches of melt.

Unfortunately, the particular function used to vary the melt coefficient is too sensitive to changes in its initial value. A revised function has been formulated and will be tested under an OWRR snowmelt project to begin in FY 1973.

The preliminary tests also showed the importance of being able to assess the runoff potential of the land surface at the time of melt. Relative to the flood of 1965, analysis has shown that in the southeastern portions of the Minnesota Basin, 90 to 95 per cent of the available moisture (rainfall plus snowmelt) became runoff. However, in 1969, with greater moisture available, only about 60 per cent became runoff. The difference in runoff between these two years is due to the ground condition during the melt. In 1965 a layer of ice existed at the ground surface due to a melting period in February. A period of sub-zero temperatures in March solidly refroze the snowpack and surface water, resulting in high-runoff-producing ground conditions.

Had the high runoff conditions of 1965 existed during the melt of 1969, the record flood peaks of 1969 could have been nearly twice as great as they actually were. Presently there is little information on which to base a quantitative determination of the runoff potential of the ground prior to the spring melt. The determination of frost depth as discussed in Section V will provide part of the required information. Equally important is a knowledge of the soil moisture condition prior to freezing, during the winter, and at the time of melt. It is hoped that future work will produce a practical technique that can be used to indicate the spring runoff potential of the ground surface.

VIII. SUMMARY

This project was Phase I of a three-phase study whose objective is the development of analytical procedures and the correlation of hydrological data to aid in the prediction and control of spring floods in large Upper Midwest watersheds. Phase I has involved the assembly of meteorological and hydrological data for various periods and the procurement and preliminary evaluation of selected mathematical simulation models of watersheds. Phases II and III have been authorized under a project which begins July 1, 1972.

The major portion of the hydrological and meteorological data were procured on magnetic tape to facilitate input into the mathematical models. This form is highly desirable, as some runs were performed with up to one year's data. Approximately 28 magnetic tapes were received and a duplicate was made of each to serve as a backup copy.

Of special interest in this study were the SSARR model developed by the Corps of Engineers and the National Weather Service, the Kentucky-Stanford model, the HEC-1 model of the Corps of Engineers Hydrologic Engineering Center, and programs in use by the National Weather Service River Forecast Center in Kansas City.

LIST OF FIGURES

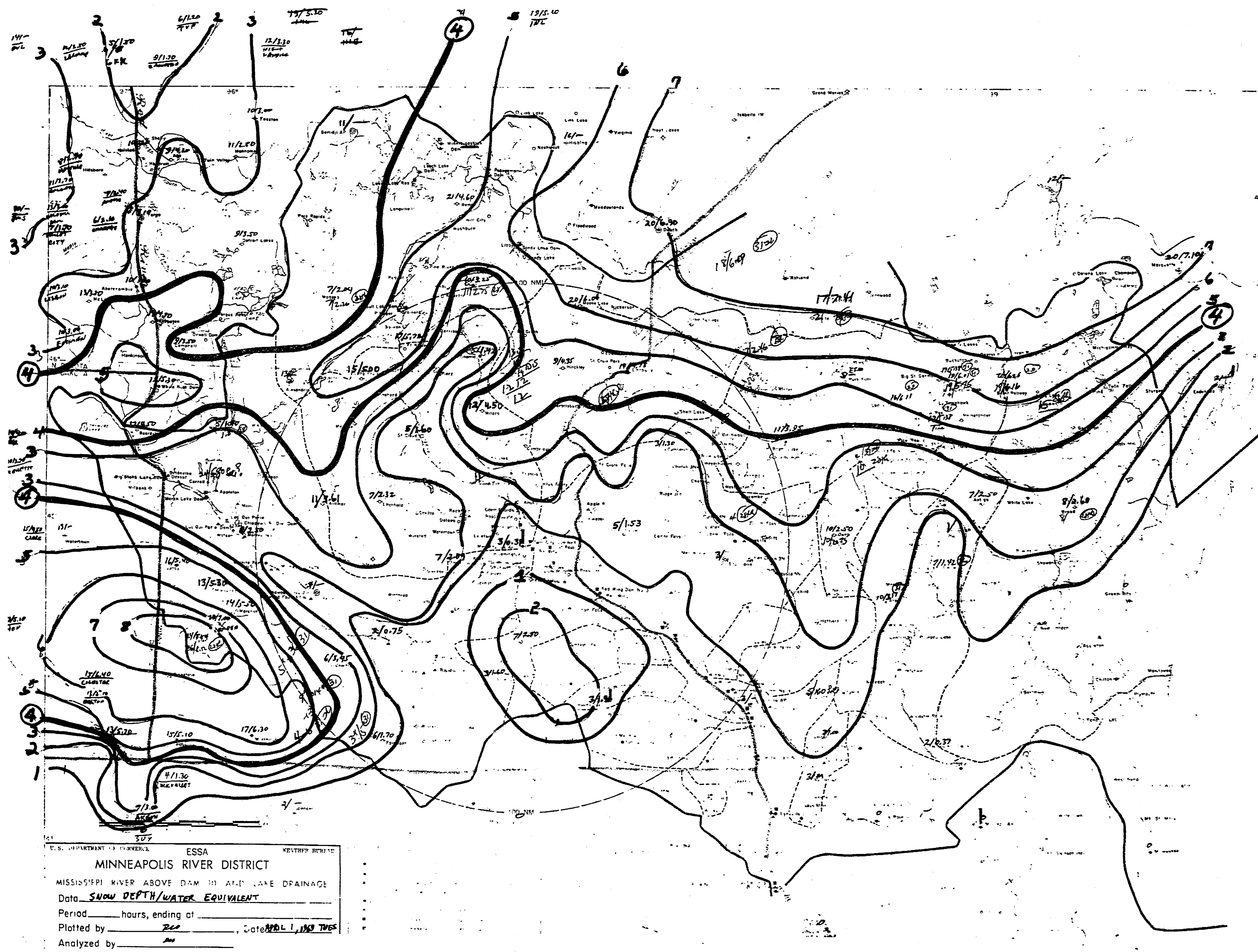


Fig. 1 Example of National Weather Service Water Equivalent of Snow Map (April 1, 1969).

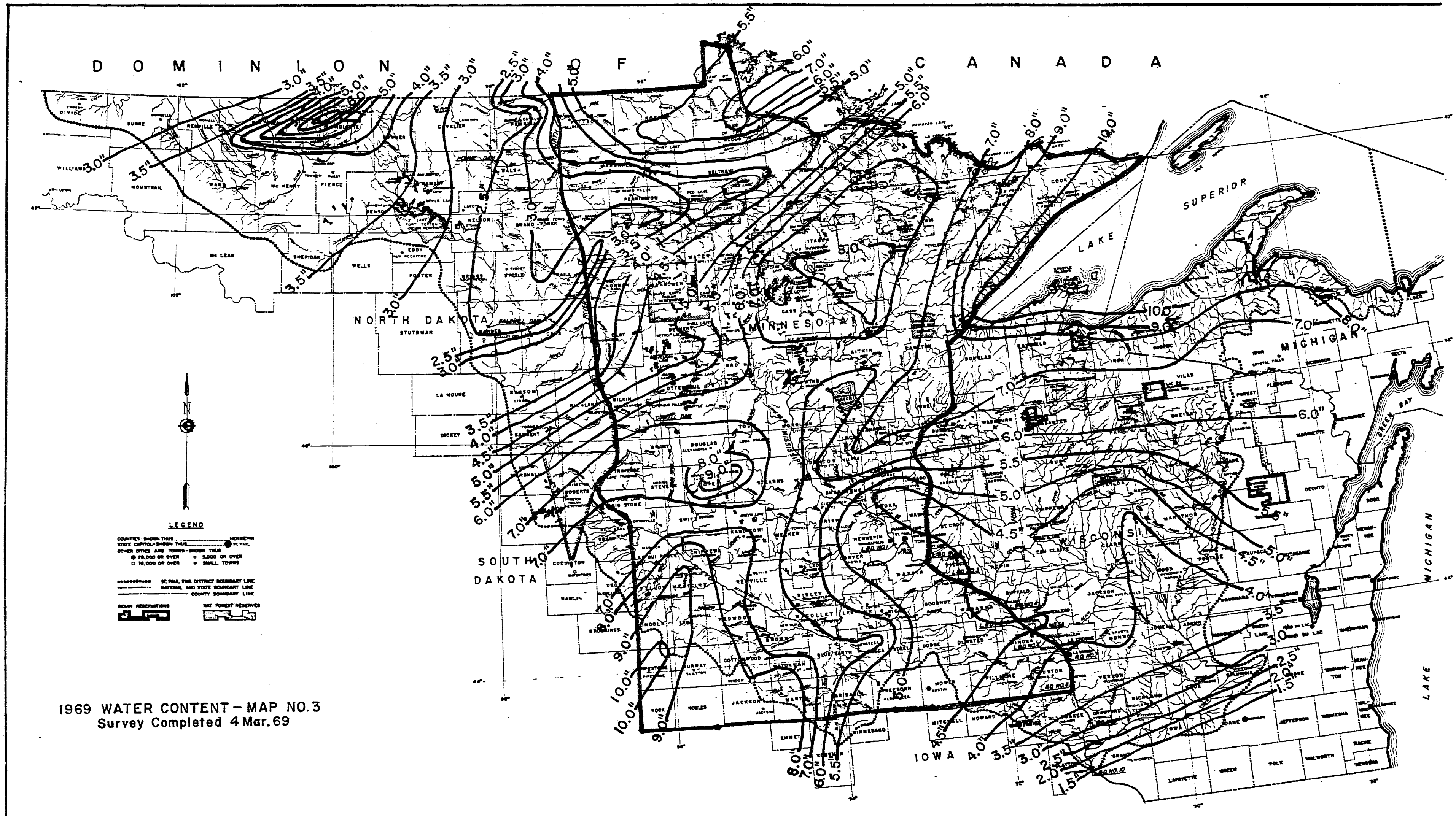


Fig. 2 Example of Corps of Engineer's Water Equivalent of Snow Map (March 4, 1969).

ST. PAUL, MINNESOTA DISTRICT

10 0 10 20 30 40 50
SCALE IN MILES

CORPS OF ENGINEERS U. S. ARMY
OFFICE OF THE DISTRICT ENGINEER
ST. PAUL, MINNESOTA

DRAWN BY D.F.J.-R.B.G. JUNE 1955

Z10-1-3

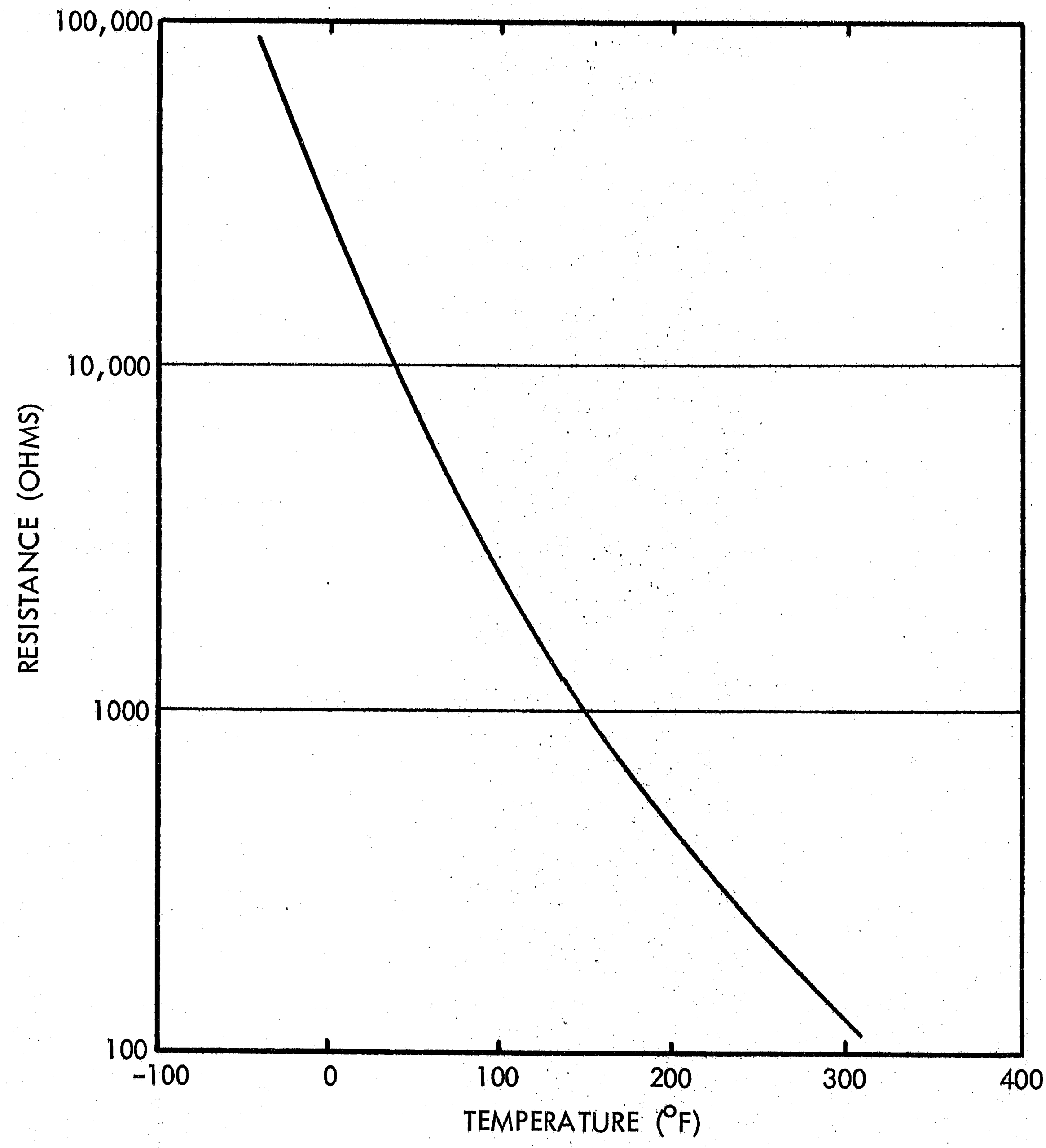


Fig. 3 – Typical Resistance versus Temperature Curve for a Thermistor

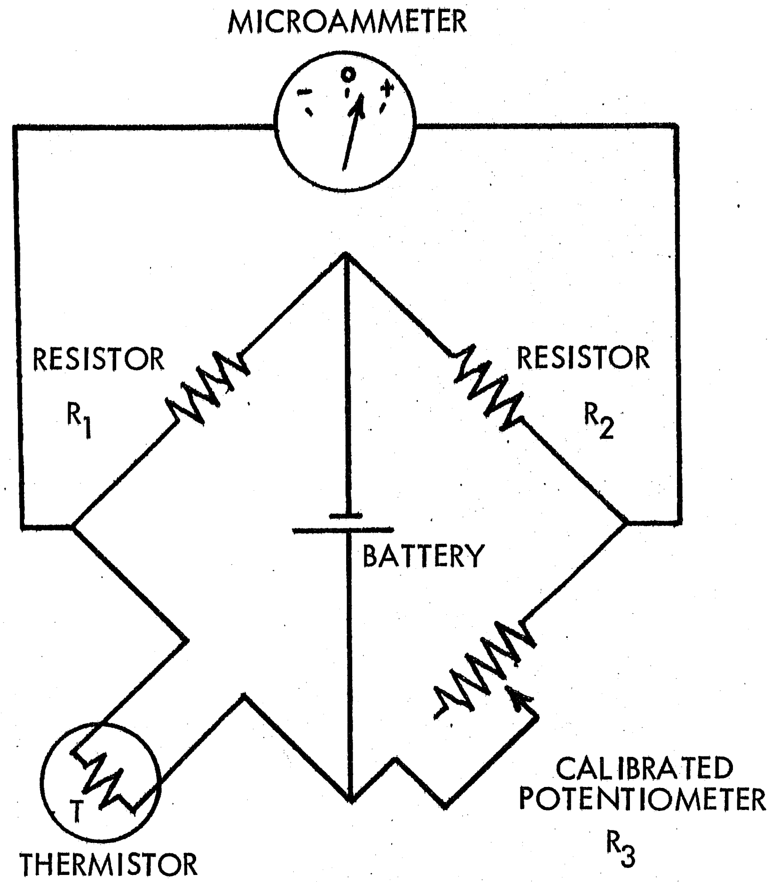


Fig. 4 - Typical Bridge for reading Thermistor Resistance

SOIL TEMPERATURE (DEGREES FAHRENHEIT)

READOUT DEVICE NO. 2 PAGE NO. 10
STATION NO. 2 DATE 11/15/71

RANGE ↓	DIAL READING ↓↓↓	PROBE NUMBER 1	2	3	4	5	6	7	8	9
1	551	32.1	39.2	37.6	32.7	36.8	35.1	32.6	30.8	36.6
1	552	32.0	39.1	37.5	32.6	36.8	35.0	32.5	30.7	36.5
1	553	31.9	39.0	37.5	32.5	36.7	34.9	32.5	30.6	36.4
1	554	31.9	38.9	37.4	32.5	36.6	34.8	32.4	30.5	36.4
1	555	31.8	38.9	37.3	32.4	36.5	34.8	32.3	30.5	36.3
1	556	31.7	38.8	37.3	32.3	36.5	34.7	32.3	30.4	36.2
1	557	31.7	38.7	37.2	32.3	36.4	34.6	32.2	30.3	36.1
1	558	31.6	38.7	37.1	32.2	36.3	34.6	32.1	30.3	36.1
1	559	31.5	38.6	37.0	32.1	36.3	34.5	32.1	30.2	36.0
1	560	31.5	38.5	37.0	32.1	36.2	34.4	32.0	30.1	35.9
1	561	31.4	38.5	36.9	32.0	36.1	34.4	31.9	30.1	35.9
1	562	31.3	38.4	36.8	31.9	36.1	34.3	31.9	30.0	35.8
1	563	31.3	38.3	36.8	31.9	36.0	34.2	31.8	29.9	35.7
1	564	31.2	38.2	36.7	31.8	35.9	34.2	31.7	29.9	35.7
1	565	31.1	38.2	36.6	31.7	35.8	34.1	31.7	29.8	35.6
1	566	31.1	38.1	36.6	31.7	35.8	34.0	31.6	29.7	35.5
1	567	31.0	38.0	36.5	31.6	35.7	34.0	31.5	29.7	35.5
1	568	30.9	38.0	36.4	31.5	35.6	33.9	31.5	29.6	35.4
1	569	30.9	37.9	36.4	31.5	35.6	33.8	31.4	29.5	35.3
1	570	30.8	37.8	36.3	31.4	35.5	33.7	31.3	29.5	35.3
1	571	30.7	37.8	36.2	31.3	35.4	33.7	31.3	29.4	35.2
1	572	30.7	37.7	36.2	31.3	35.4	33.6	31.2	29.3	35.1
1	573	30.6	37.6	36.1	31.2	35.3	33.5	31.1	29.3	35.0
1	574	30.5	37.6	36.0	31.1	35.2	33.5	31.1	29.2	35.0
1	575	30.5	37.5	36.0	31.1	35.2	33.4	31.0	29.1	34.9
1	576	30.4	37.4	35.9	31.0	35.1	33.3	30.9	29.1	34.8
1	577	30.3	37.4	35.8	30.9	35.0	33.3	30.9	29.0	34.8
1	578	30.3	37.3	35.7	30.9	35.0	33.2	30.8	28.9	34.7
1	579	30.2	37.2	35.7	30.8	34.9	33.1	30.7	28.9	34.6
1	580	30.1	37.2	35.6	30.7	34.8	33.1	30.7	28.8	34.6

Fig. 5 - Sample Soil Temperature Table

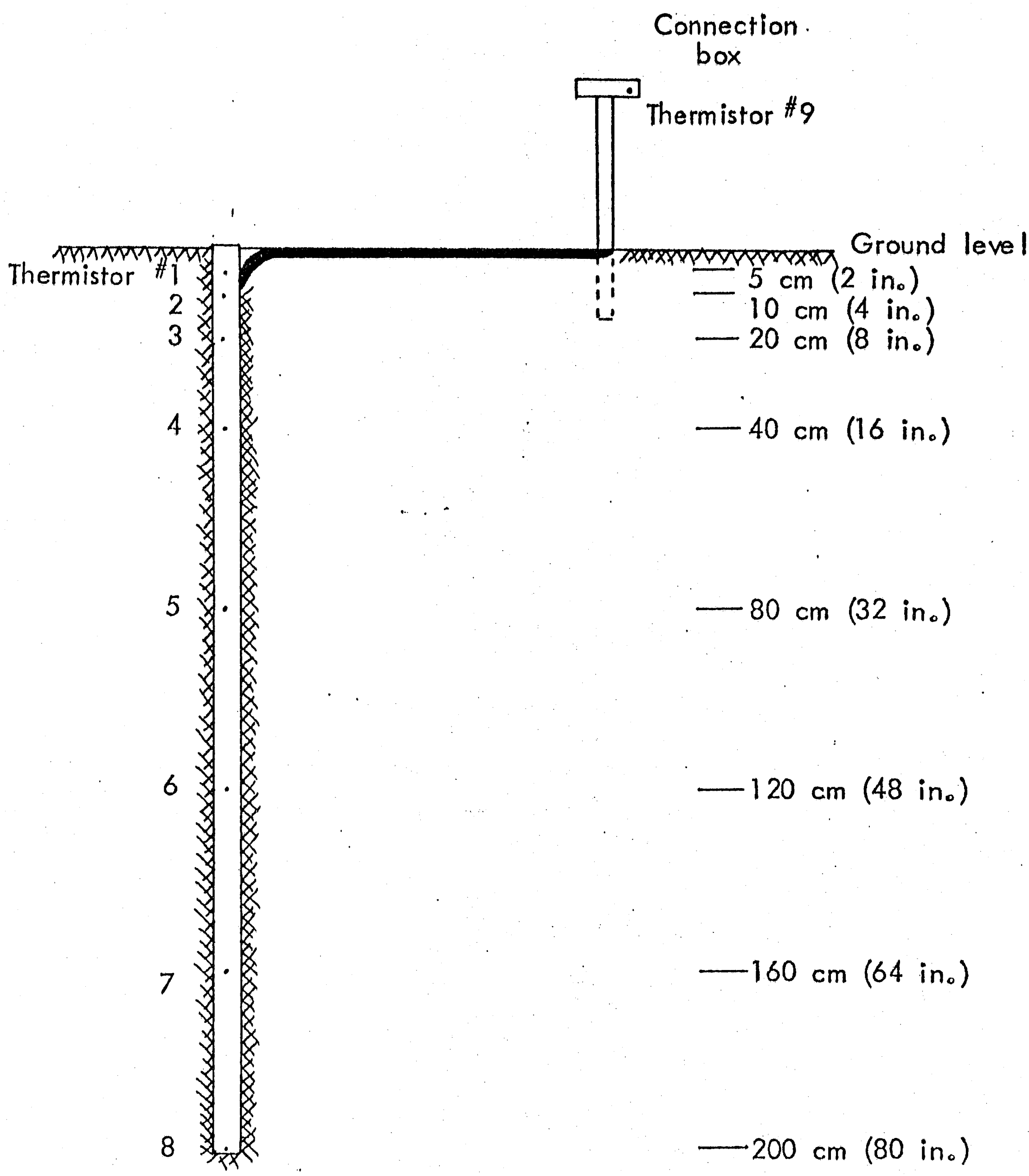


Fig. 6 - Typical Layout of Soil Temperature Station

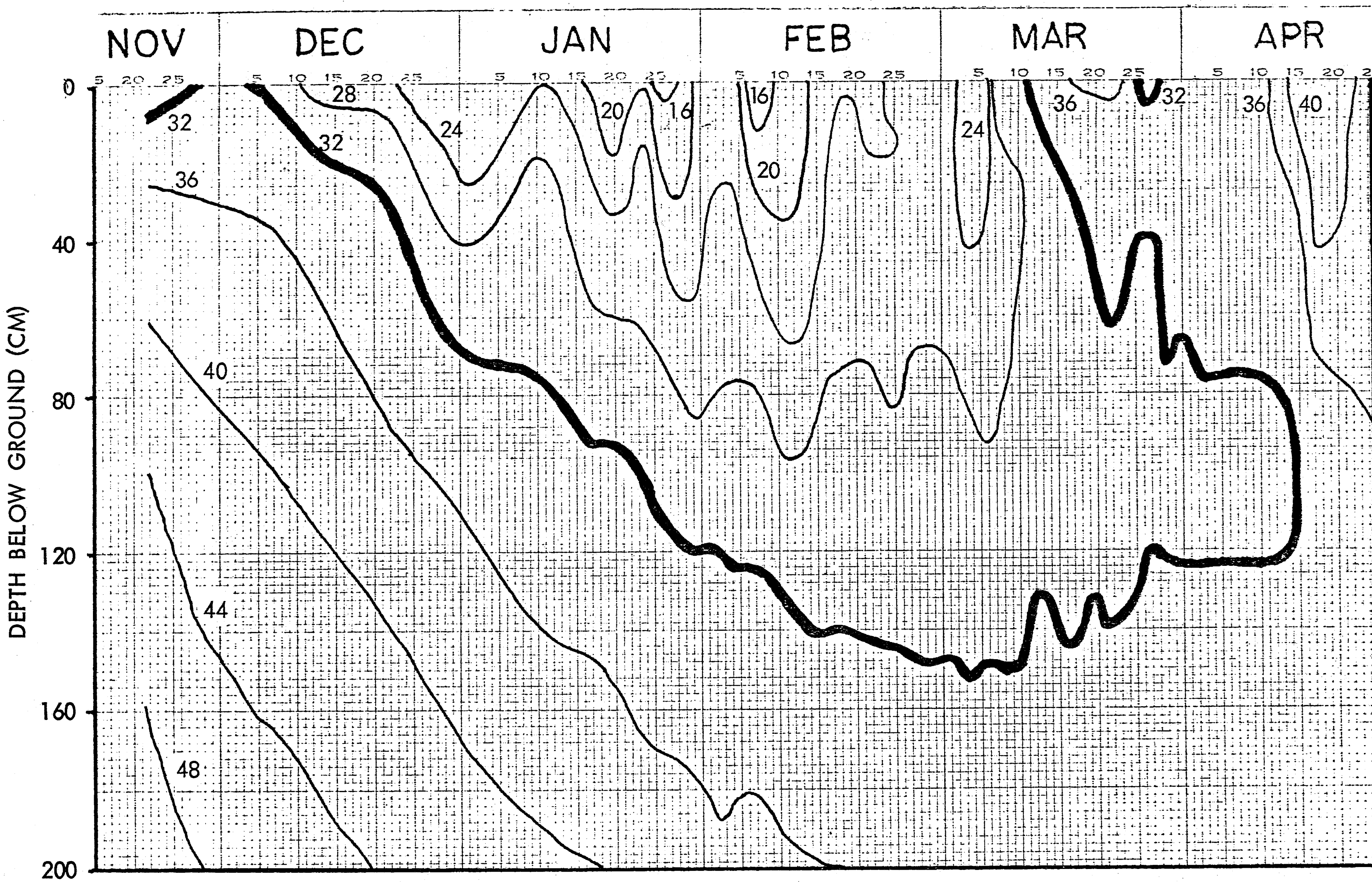


Fig. 7 - Soil Temperatures during Winter 1971 - 72 near Watson, Minnesota

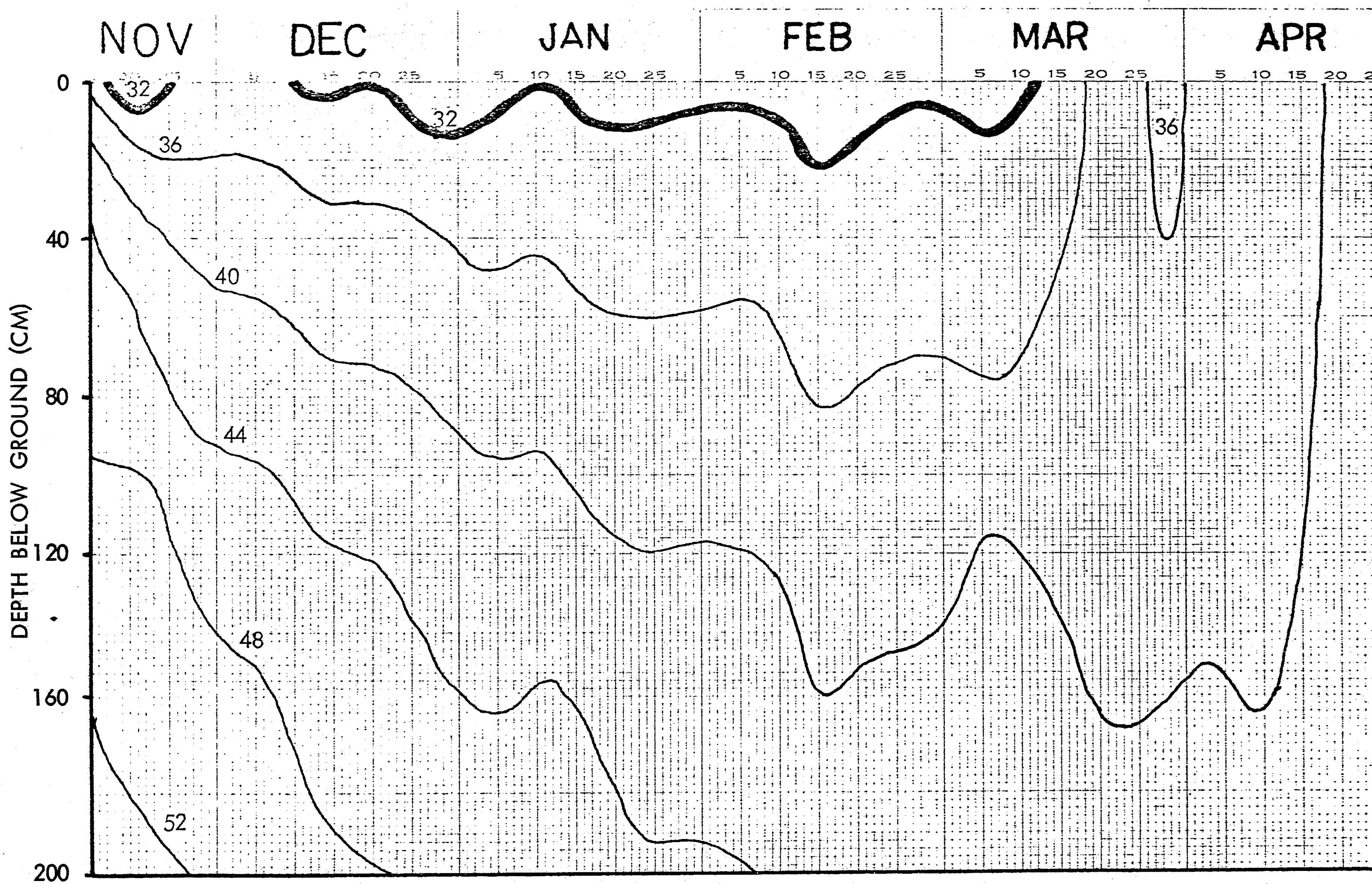


Fig. 8 - Soil Temperatures during Winter 1971 - 72 near St. James, Minnesota

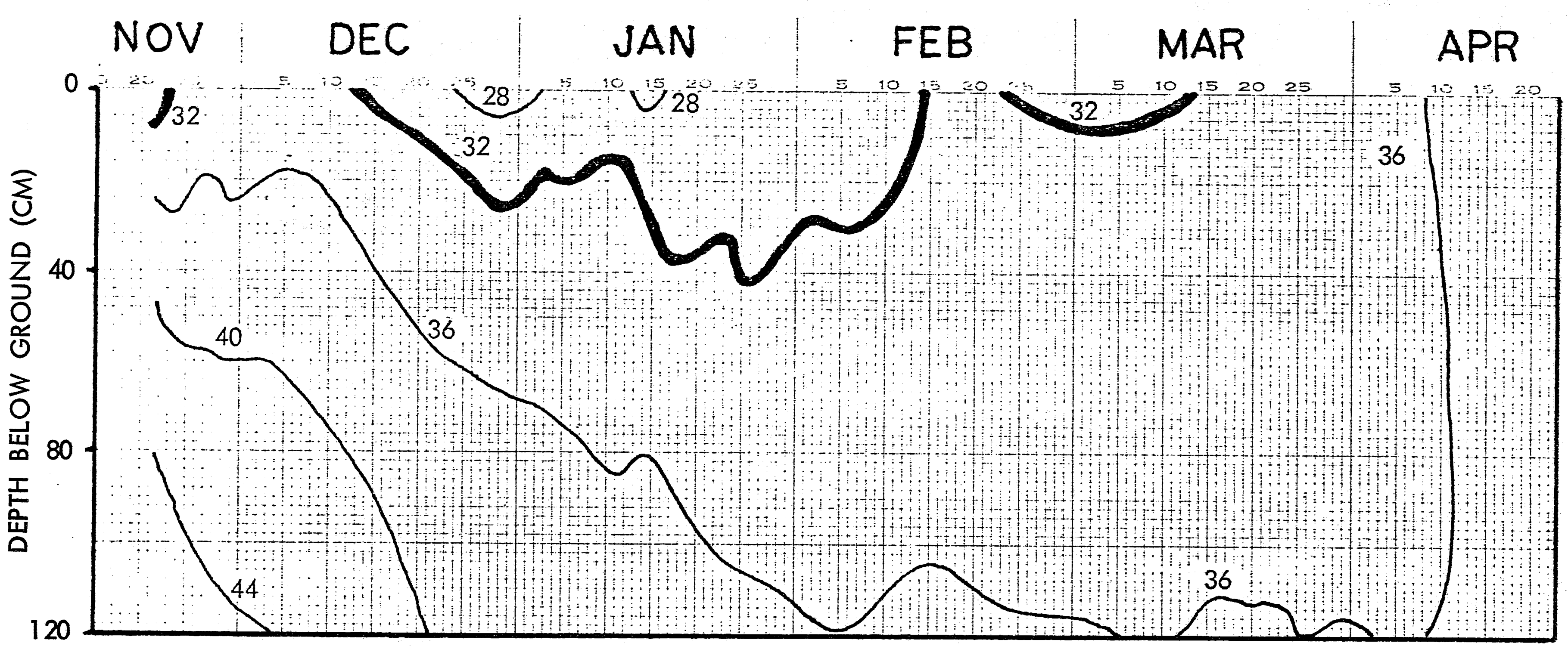


Fig. 9 - Soil Temperatures during Winter 1971 - 72 at Shoreview, Minnesota

Fig. 10 - Soil Temperatures during Winter 1971 - 72 at Brooklyn Park, Minnesota

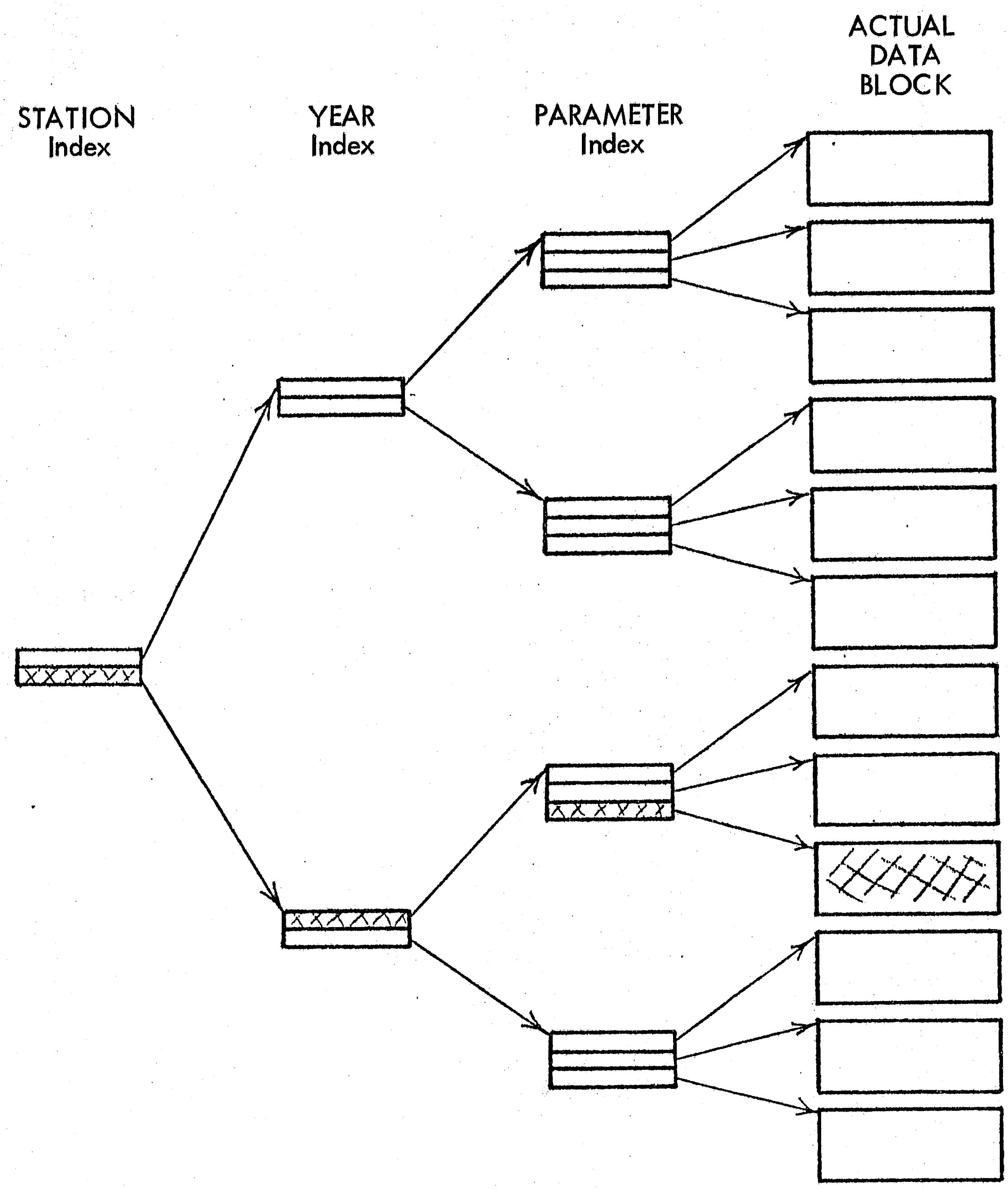


Fig. 11 - Example of Data Structure. Shaded cells show path to Station 2, Year 1, and Parameter 3.

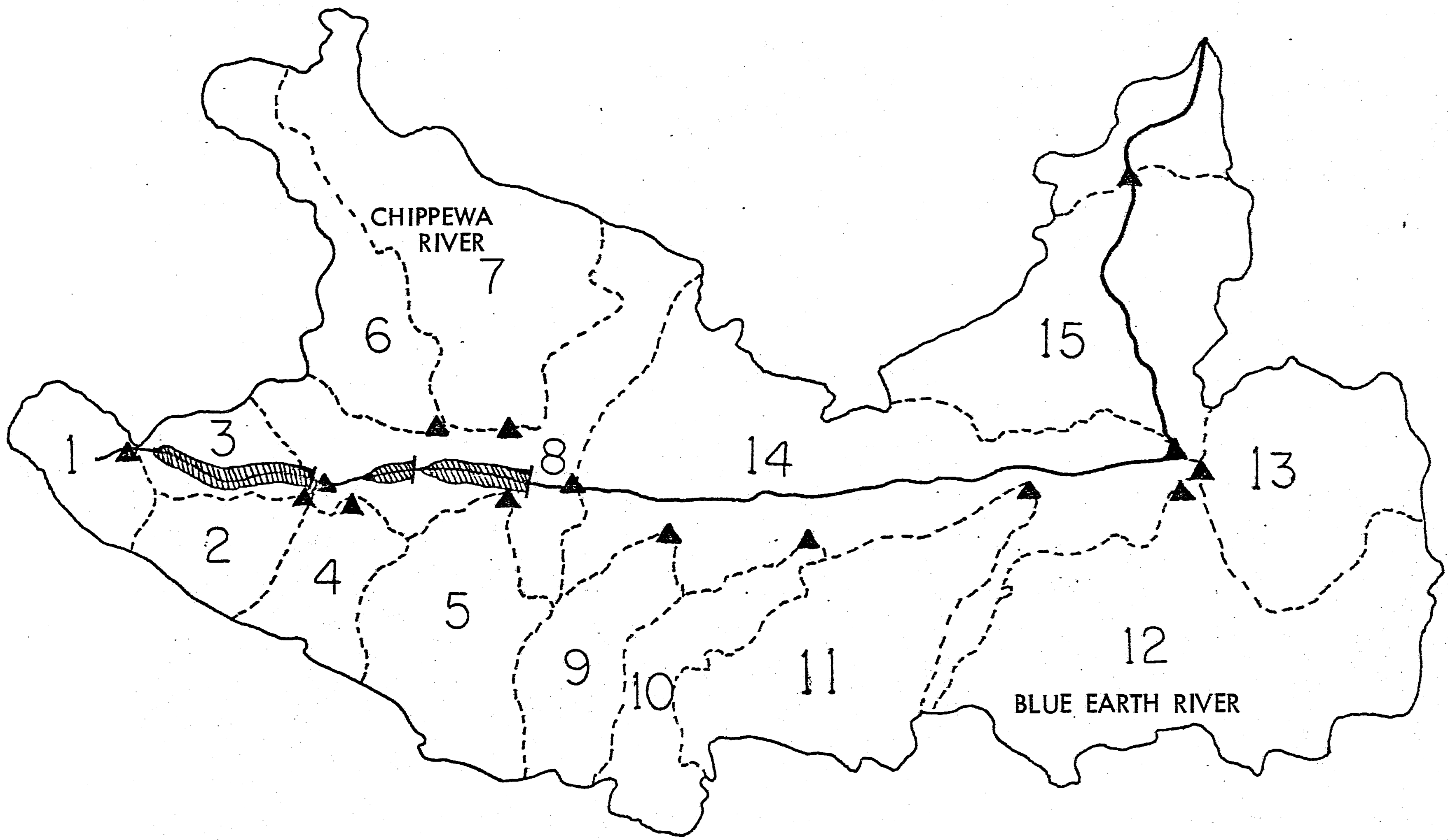


Fig. 12 - Map of Minnesota River Watershed (Area = 16,200 sq mi) showing Subwatersheds used in Runoff Analysis

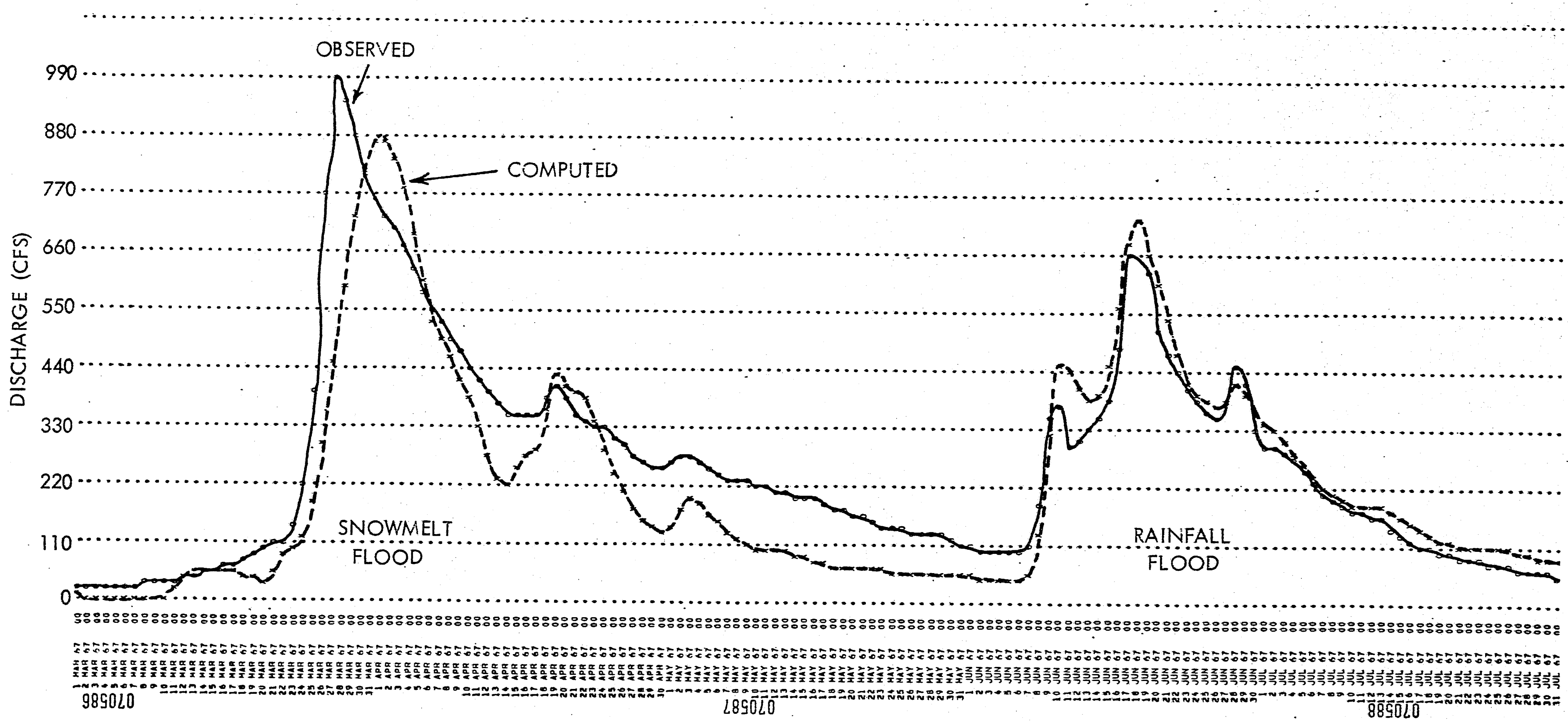


Fig. 13 - Observed and Computed Discharge for a Snowmelt and a Rainfall Event in the Pomme de Terre Watershed

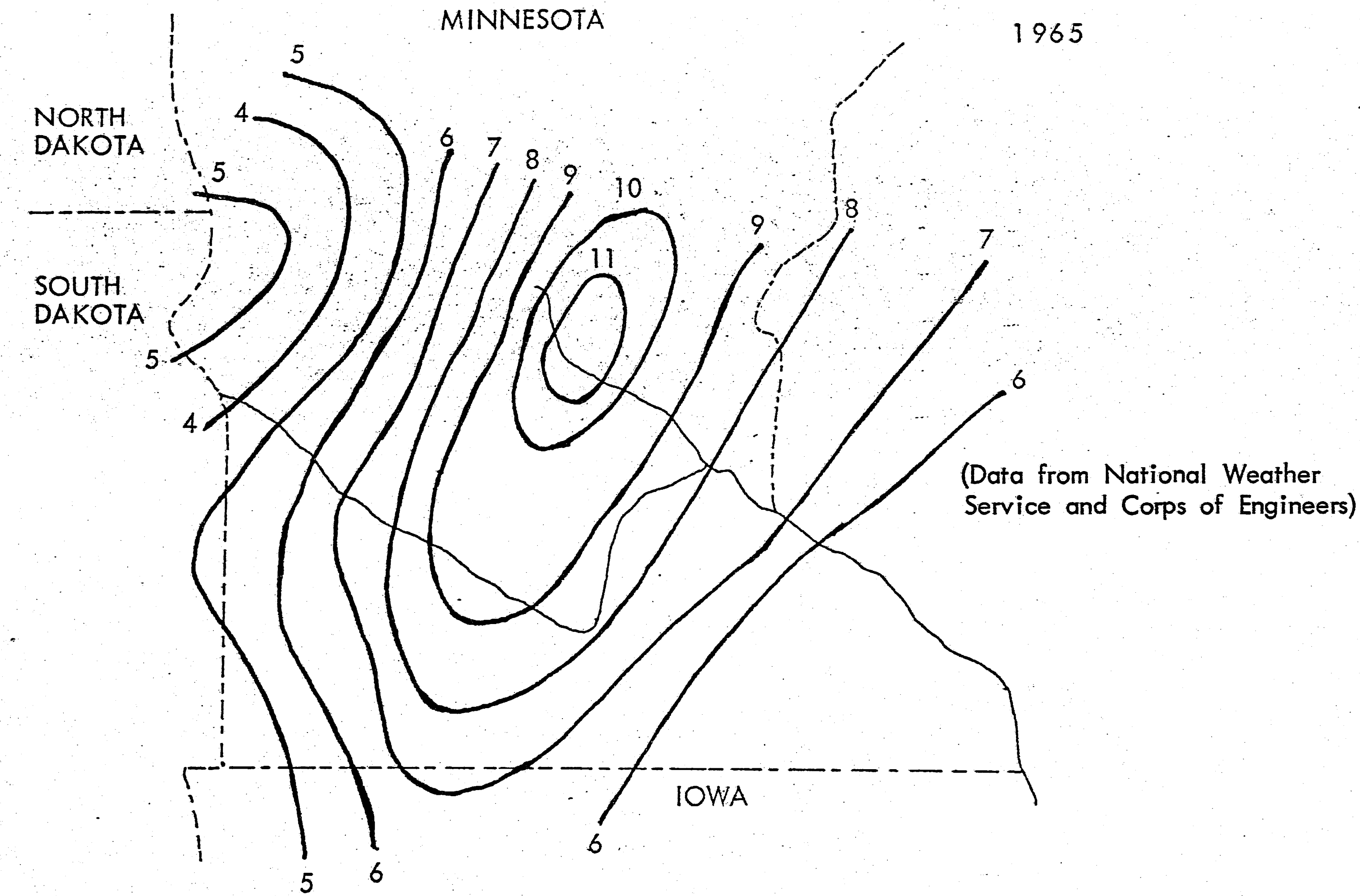


Fig. 14 - Amount of Water available for Spring Runoff in 1965: Total of Snowpack Water Equivalent plus Early Spring Rainfall

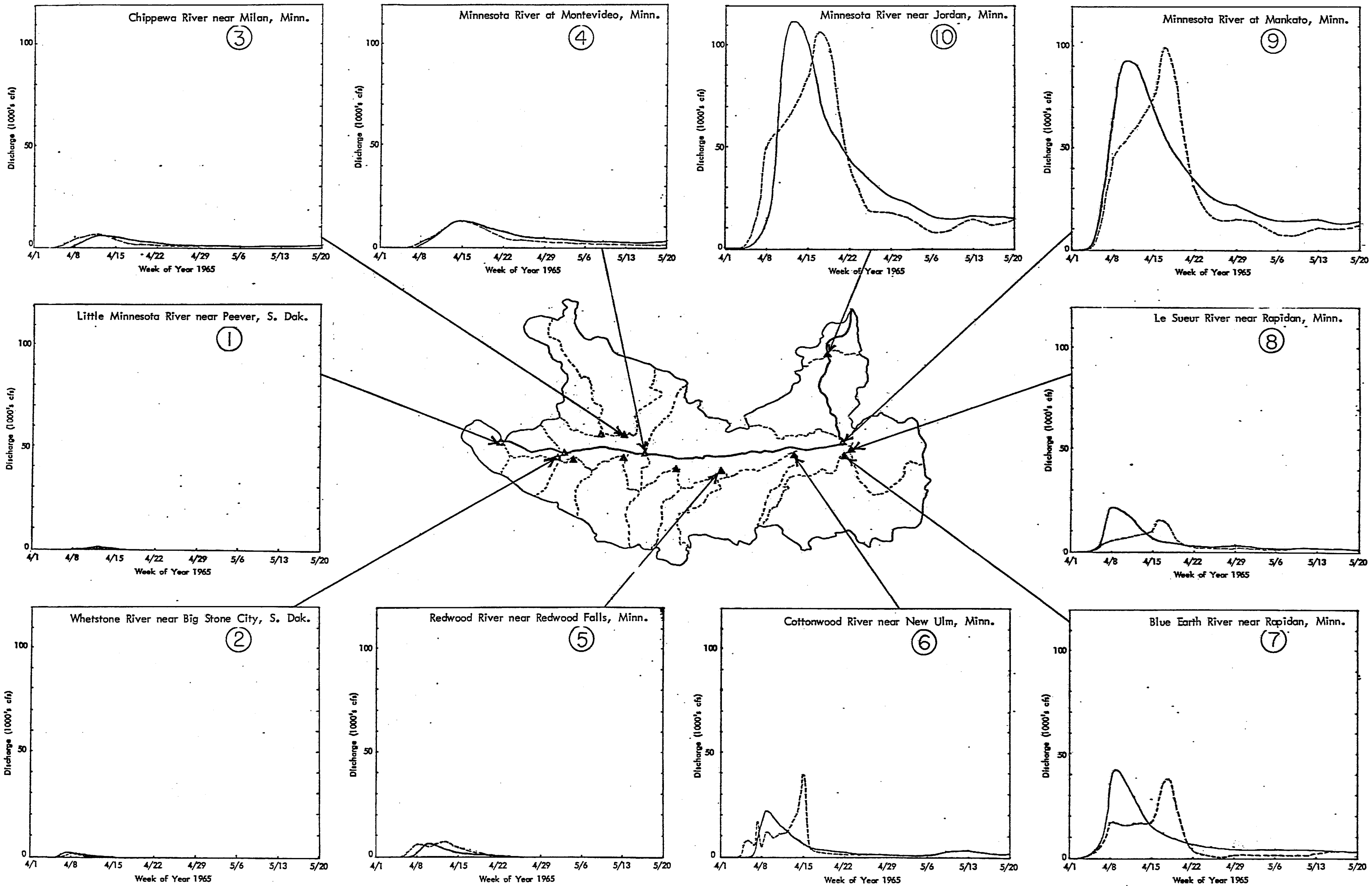


Fig. 15 Observed (solid) and computed (dotted) discharge from SSARR model for 1965.

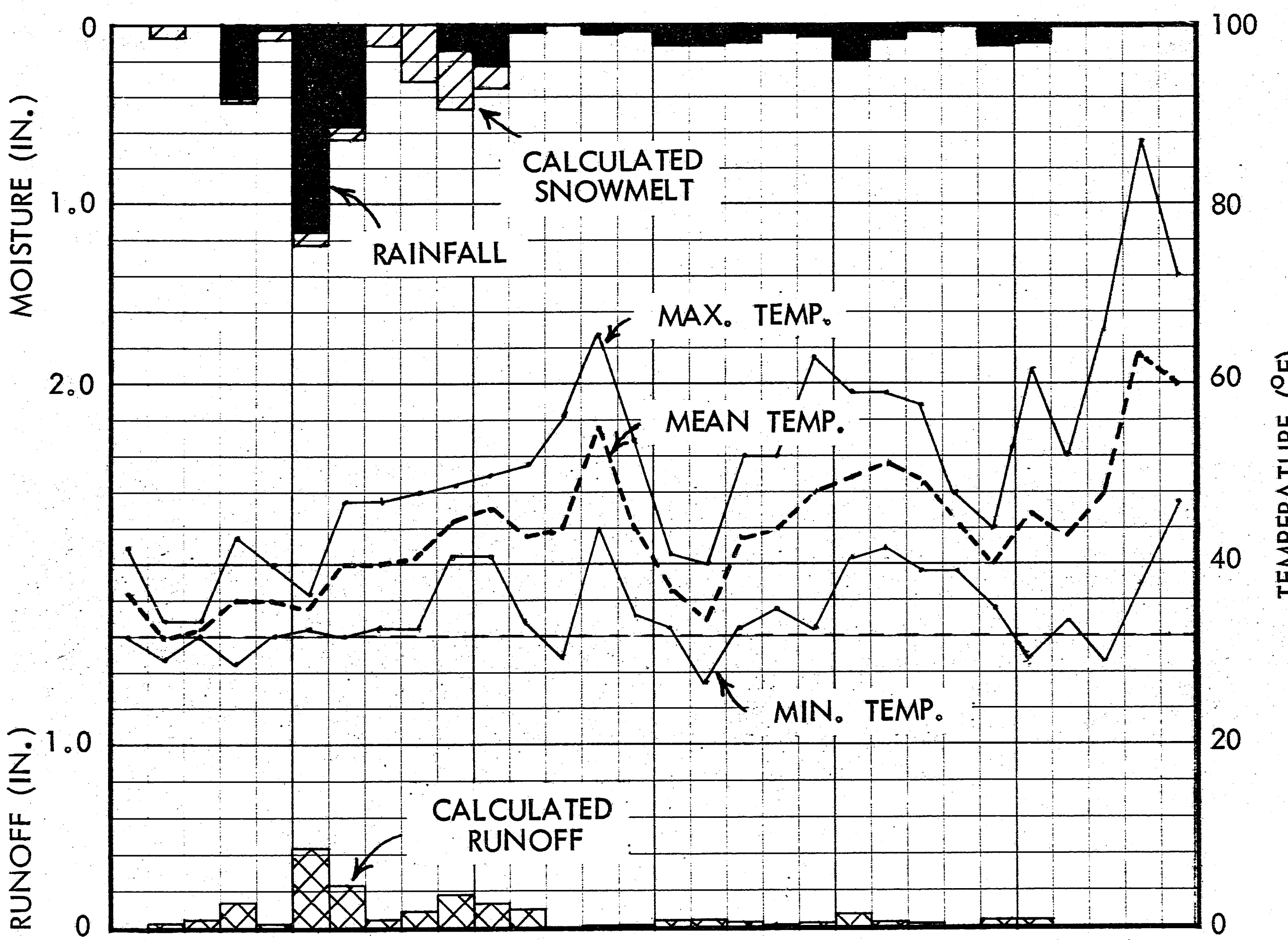


Fig. 16 - Chippewa River, April 1965 - SSARR Model

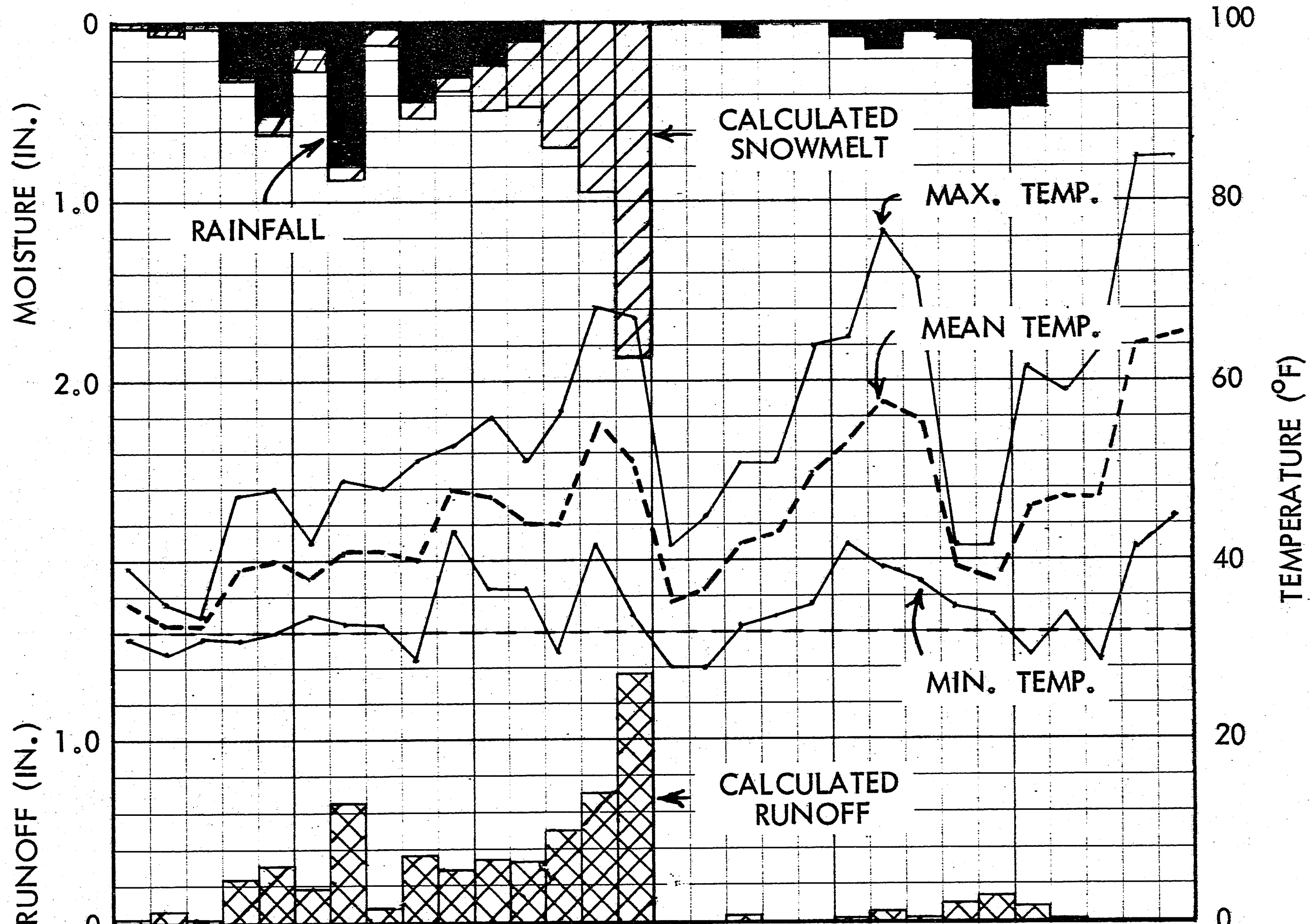


Fig. 17 - Cottonwood River, April 1965 - SSARR Model

Appendix A - USGS DATA

The water resources data from the U.S. Geological Survey were received on three tapes with a format of four cards per month's data for a given station.

Col 1-7 (I8)	Col 8-9 (2X)	Col 10-13 (I4)	Col 14-15 (I2)	Col 16-17 (I2)	Col 18-19 (I2)	Col 20-29 (F10.2)	Col 30-72 (42X)	Col 73-80 (F8.2)
05288500		1968	03	10	31	15270000		300000
USGS Station Index No.	blank	Year	Month	Data Code always 10	No. of Days in Month	Total Discharge for Month x 100 sfd	blank	Discharge for 1st Day of Month x 100 cfs

2nd, 3rd, and 4th Cards (10F8.2)

30 additional values of discharge, 10 per card, for days 2-31.

(F8.2)	(F8.2)	(F8.2)	(F8.2)	(F8.2)	(F8.2)	(F8.2)	(F8.2)	(F8.2)	(F8.2)
310000	320000	400000							

7-Track Tape in Six-Bit BCD (binary coded decimal) Tape Characters

Byte Position	Number of BCD Characters	Identifier
1	15	Station identification number - Latitude (Pos. 1-6), Longitude (Pos. 7-13), Sequence number (Pos. 14-15), OR Blank (Pos. 1-7), Downstream order number (Pos. 8-15).
16	7	Cross section locator - Distance in feet from left bank (as determined by facing downstream). Value of 999999 means no cross section locator code stored.
23	7	Depth locator - Depth in feet. Value of 999999 means no depth locator code stored. Top value stored with code 111111 and bottom value with 888888. Positive value is measured down from water surface.
30	5	Parameter code.
35	4	Calendar year.
39	2	Month.
41	5	Statistic code.
46	7	No value indicator - Value that is stored in place of a missing daily value. A value of 999999 is stored for most types of data.
53	217	Daily values (31) - Thirty-one daily values (7 characters each). Decimal point is included when applicable.
270	2	State code - FIPS state code where station is located.
272	2	District code - FIPS state code for district that operates station.
274	48	Station name.
322	7	Drainage area in square miles - A value of 0 indicates no value stored.
329	8	Reserved space.

Record length is 336 bytes and is divisible by 4, 6, 8 to fit most word lengths.

Appendix B - NOAA SURFACE DATA

The environmental data were obtained from

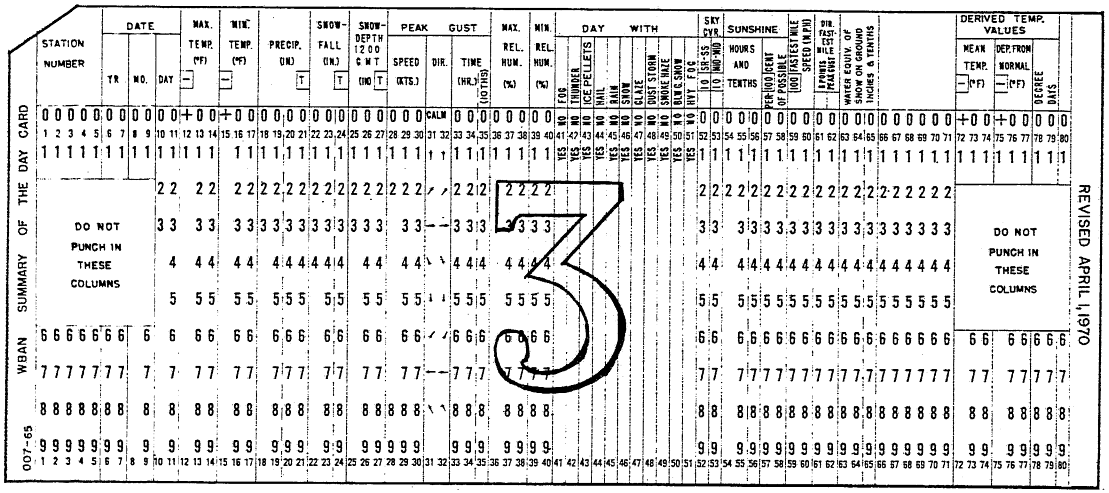
Department of Commerce
National Oceanic and Atmospheric Administration
Environmental Data Service
National Climatic Center
Federal Building
Asheville, North Carolina 28801

Twenth-four tapes have been received to date in the following formats or card decks:

No. of Tapes		
1	CD 345	WBAN Summary of Day Data for 11 Stations in Minnesota
1	CD 480	Daily Solar Radiation
5	CD 486	Weather Bureau 1009 Daily Observations for All Stations in Minnesota
3	CD 488	Hourly Precipitation for All Stations in Minnesota
13	TDF 14	Airways Surface Observations for 7 Stations in Minnesota and Adjacent States
1	RDF 14	Format Airways Surface Observations

The card deck structure of these tapes is shown in Figs. B-1 through B-4.

CARD DECK 345 WBAN SUMMARY OF DAY



Card format prior to 1 Jan 1965 is on page 2.

AREA COVERAGE: World-Wide United States operated stations.

PERIOD OF RECORD: Navy 1945- Weather Bureau Jan 1948- Air Force Jan 1949- Note: Some prior periods are included in this deck. A status of the period of record for each station is maintained at the National Weather Records Center, Asheville, North Carolina.

OBSERVATION TIME: Local Standard Time (LST). Each card summarizes the observations for the period midnight to midnight.

CODES: WMO and WBAN Codes.

SOURCE: WBAN Forms 10, 10A and 10B (includes those of FAA and Signal Corps). Effective 1 Apr 70 WBAN Forms redesignated as MF (Meteorological Forms) 1-10A, 1-10B and 1-10C. WB Form 610-10 (WB Form B-16, Apr 70) is used by WB city offices and WB Form 733-1 (WB Form F-6, Jan 70) is used by a few stations.

MISSING DATA: Respective columns for missing or obviously erroneous data were left blank. Identification cards were punched for missing days unless a whole month was missing at WB and NWS stations until 1 Jan 65; and until 1 Jan 70 at AWS stations. Prior to these dates ID cards were not punched for stations operating less than 7 days a week and with insufficient observations to determine the elements punched.

COLUMNS AND ELEMENTS PUNCHED: Columns 1-66 and 72-79 were punched during period. Changes are noted in Card Content.

Maximum Temperature
Minimum Temperature
Precipitation Amount 24 hours
Snowfall Amount for 24 hours
Snow Depth on Ground
Peak Wind Gust
  Speed
  Direction
  Time of Occurrence
x Maximum Relative Humidity
x Minimum Relative Humidity
Day with:

Fog	Snow
Thunder	Glaze
@ Sleet	Duststorm
@ Ice Pellets	Smoke, Haze
Hail	Blowing Snow
Rain	* Heavy Fog

Thickness of Ice on Water
Frozen Ground Layer
  Top Base Thickness
River Gage
* Average Sky Cover
  Sunrise to Sunset
  Midnight to Midnight
* Sunshine
  Duration
  Percent of Possible
Wind Speed and Direction
  Fastest Mile or
  Fastest Observed One-Minute Wind Speed or
  Highest Instantaneous Wind Speed
Water Equivalent of Snow on Ground
Mean Temperature

x Punching discontinued by AWS on 1 Jul 58; by WB and Navy on 1 Jan 65.

@ Sleet and Small Hail reported as Ice Pellets effective 1 Apr 70.

Punching discontinued on 1 Jan 65.

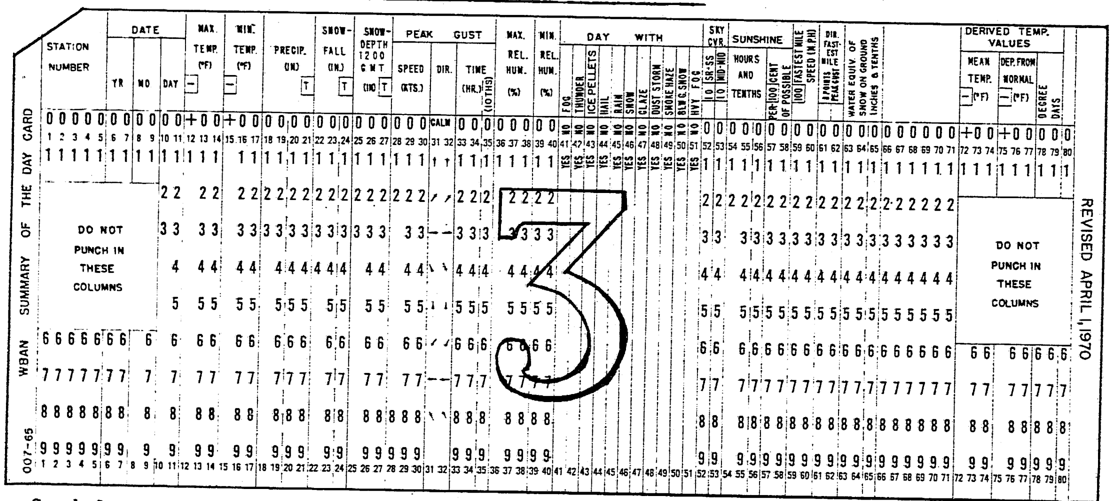
* Punching began 1 Jan 65.

Index to Elements and Items punched is on page 8.

ADDITIONAL REMARKS: The type of element reported and punched in columns 51-62 changed on 1 Jan 65. See Card Content for Items or Elements changed.
Extraneous punches may appear in columns 51-62 prior to 1 Jan 65, for stations not designated to punch these items, and also in columns 63-66 prior to Jul 52.

CORRECTIONS: Any errors detected in this manual should be called to the attention of Director, National Climatic Center, Environmental Data Service, ESSA; or Chief, Data Processing Division, Environmental Technical Applications Center, USAF. Please give specific instances of error and correct information, if available.

CARD DECK 345 WBAN SUMMARY OF DAY



Card format prior to 1 Jan 1965 is on page 2.

AREA COVERAGE: World-Wide United States operated stations.

PERIOD OF RECORD: Navy 1945- Weather Bureau Jan 1948- Air Force Jan 1949- Note: Some prior periods are included in this deck. A status of the period of record for each station is maintained at the National Weather Records Center, Asheville, North Carolina.

OBSERVATION TIME: Local Standard Time (LST). Each card summarizes the observations for the period midnight to midnight.

CODES: WMO and WBAN Codes.

SOURCE: WBAN Forms 10, 10A and 10B (includes those of FAA and Signal Corps). Effective 1 Apr 70 WBAN Forms redesignated as MF (Meteorological Forms) 1-10A, 1-10B and 1-10C. WB Form 610-10 (WB Form B-16, Apr 70) is used by WB city offices and WB Form 733-1 (WB Form F-6, Jan 70) is used by a few stations.

MISSING DATA: Respective columns for missing or obviously erroneous data were left blank. Identification cards were punched for missing days unless a whole month was missing at WB and NWS stations until 1 Jan 65; and until 1 Jan 70 at AWS stations. Prior to these dates ID cards were not punched for stations operating less than 7 days a week and with insufficient observations to determine the elements punched.

COLUMNS AND ELEMENTS PUNCHED: Columns 1-66 and 72-79 were punched during period. Changes are noted in Card Content.

Maximum Temperature
Minimum Temperature
Precipitation Amount 24 hours
Snowfall Amount for 24 hours
Snow Depth on Ground
Peak Wind Gust
- Speed
- Direction
- Time of Occurrence

x Maximum Relative Humidity
x Minimum Relative Humidity

Day with:

Fog	Snow
Thunder	Glaze
@ Sleet	Duststorm
@ Ice Pellets	Smoke, Haze
Hail	Blowing Snow
Rain	* Heavy Fog

Thickness of Ice on Water
Frozen Ground Layer
- Top Base Thickness

River Gage
* Average Sky Cover
- Sunrise to Sunset
- Midnight to Midnight

* Sunshine
- Duration
- Percent of Possible

Wind Speed and Direction
- Fastest Mile or
- Fastest Observed One-Minute Wind Speed or
- Highest Instantaneous Wind Speed

Water Equivalent of Snow on Ground
Mean Temperature

x Punching discontinued by AWS on 1 Jul 58; by WB and Navy on 1 Jan 65.

@ Sleet and Small Hail reported as Ice Pellets effective 1 Apr 70.

Punching discontinued on 1 Jan 65.

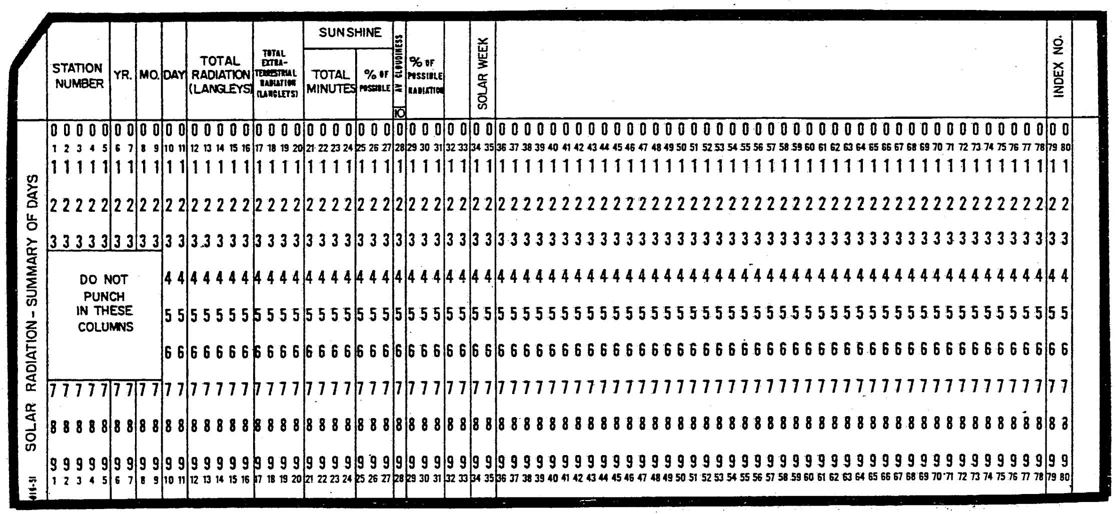
* Punching began 1 Jan 65.

Index to Elements and Items punched is on page 8.

ADDITIONAL REMARKS: The type of element reported and punched in columns 51-62 changed on 1 Jan 65. See Card Content for Items or Elements changed. Extraneous punches may appear in columns 51-62 prior to 1 Jan 65, for stations not designated to punch these items, and also in columns 63-66 prior to Jul 52.

CORRECTIONS: Any errors detected in this manual should be called to the attention of Director, National Climatic Center, Environmental Data Service, ESSA; or Chief, Data Processing Division, Environmental Technical Applications Center, USAF. Please give specific instances of error and correct information, if available.

CARD DECK 480 SOLAR RADIATION - SUMMARY OF DAY



AREA COVERAGE: The United States, Canada, West Indies, and Pacific Islands. See map on page 3 and alphabetic and numeric lists on pages 4-8.

PERIOD OF RECORD: Generally 1 Jul 52 -
Four stations have records beginning 1 Dec 51. Refer to numeric station list for dates of beginning and ending of records. Card deck 470 contains hourly, daily and weekly values of hemispheric radiation for various periods prior to 1 Jul 52 with one record beginning 1 Jul 15. Card deck 280 has hourly values of solar radiation beginning 1 Jul 52.

OBSERVATION TIME: Daily (24-hour period based on LST)

CODE: None

SOURCE: Roll or circular recorder charts.
WB Form 610-8, "Hemispheric Solar Radiation on a Horizontal Surface - Langleys" (formerly WB Form 1091 or 1091A).
Form WBAN 10B and WB Form 733-1.
Solar radiation daily cards punched at stations in the contiguous United States. Those outside the contiguous United States are punched at the National Weather Records Center, Asheville, North Carolina.

MISSING DATA INDICATION: Identification cards are punched in Columns 1-11 for missing days when less than a month's record is missing. Missing data are indicated by blanks in the appropriate field.

COLUMNS AND ELEMENTS PUNCHED: Columns 1-31 and 79-80 are punched. Columns 34-35 were punched prior to 1 Jan 63. Elements Punched:

- Total Radiation (Solar, Hemispheric) (sum of direct and diffuse)
- Total Extra-Terrestrial Radiation
- Total Minutes of Sunshine
- Percent of Possible Sunshine
- Average Cloudiness (Sunrise to Sunset)
- Percent of Possible Radiation
- Solar Week (discontinued 1 Jan 63)
- State or Area Index Number (for cooperative stations only)

ADDITIONAL REMARKS: Effective with 1 Jul 57 records, solar radiation data have been recorded in the International Pyrheliometer Scale of 1956. This scale provides values that are 2.0% less than those based on the Smithsonian Scale of 1913, the standard previously in use.

Stations measuring hemispheric solar radiation have a pyrheliometer installed in a suitably exposed location and a recorder installed in the office. Thermoelectric hemispheric pyrheliometers are used in measuring hemispheric solar radiation. Two types are in use: a "10-junction" type in general use, and a more sensitive "50-junction" type used at selected northern stations during months when solar radiation is less intense.

486 WEATHER BUREAU 1009 DAILY OBSERVATIONS

AREA COVERAGE

United States, Caribbean area, Pacific Islands.

NOTE: A few selected stations in British Columbia are included for a short period of record.

PERIOD OF RECORD

Most states began the Form 1009 program during 1948, several in 1946. All states have complete records from 1948 to date.

British Columbia cards are only from October 48 to June 54.

Through cooperative agreements with State Universities and other State organizations many years have been punched prior to 1948. The period and number of stations vary among states. Some records go back to about 1890. A status of the period for each station is maintained at the National Weather Records Center, Asheville, North Carolina.

OBSERVATION TIMES

Local Standard Time

Designated only as a.m. or p.m. observations. The scheduled time of these observations varies at different stations. The observation is generally from 6 to 8 a.m. and 5 to 7 p.m. and is for the previous 24 hours (actual time is entered on original forms). Some a.m. observations are as late as 10 a.m. with a few at noon and some p.m. observations are as early as 3 p.m. Data for USWB stations, FAA stations and a few others are for the period midnight to midnight and are punched as p.m. Noon observations are punched as a.m.

CODE

None.

SOURCE

The data were punched from the following sources:

1. Cooperative stations — WB Forms 612-14 (1009)
2. River stations — WB Forms 612-13 (1006)
3. Evaporation stations — WB Forms 612-25 (1024)
4. WBO First and Second Order stations and FAA/CAA Summary of Day cards.

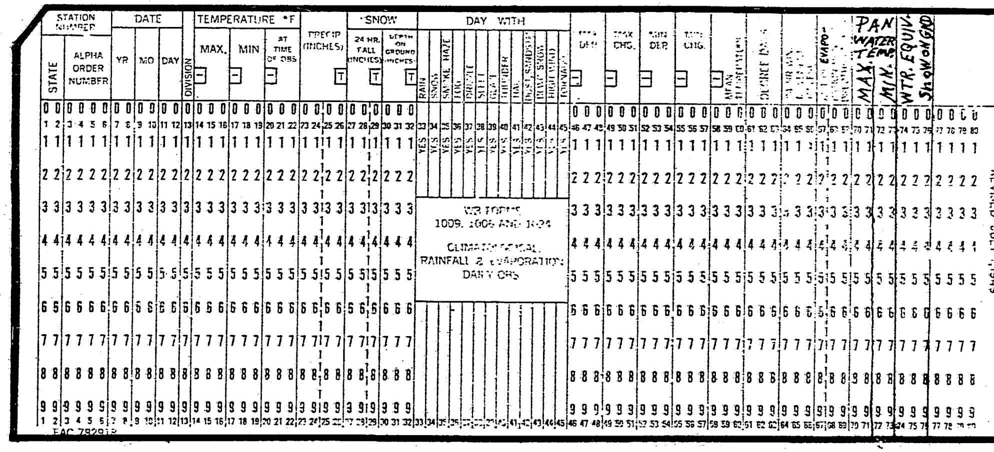
MISSING DATA

Whenever any element was not reported, the corresponding card column was left blank. Identification cards were punched for missing days, but not for an entire month.

COLUMNS AND ELEMENTS PUNCHED

At the present time columns 1-33, 35-45 and 64-76 are punched. Columns 77-80 may contain punches used for processing with no set pattern. Punching of columns 46-63 were discontinued September 1963.

Maximum Temperature	Days with Drizzle	Days with Tornado
Minimum Temperature	Sleet	*Maximum Temperature departure
Temperature at observation time	Glaze	*Maximum Temperature change
Precipitation 24 hour amount	Thunder	*Minimum Temperature departure
Snowfall 24 hour amount	Hail	*Minimum Temperature change
Snow Depth on ground	Dust-Sandstorm	*Mean Temperature
Days with Smoke-Haze	Blowing Snow	*Degree Days
Fog	High Wind	*Discontinued September 1963



COLUMNS AND ELEMENTS PUNCHED (Continued)

Wind movement for 24 hours	Maximum Water Temperature, Pan	Water Equivalent of Snow on Ground
Amount of Evaporation	Minimum Water Temperature, Pan	

The following elements were punched in columns 46-63 prior to 1950:

River Stage condition	River Stage, height of crest	Psychrometric Temperature-Wet Bulb
River Stage Gage reading	Psychrometric Temperature-Dry Bulb	Relative Humidity

ADDITIONAL REMARKS

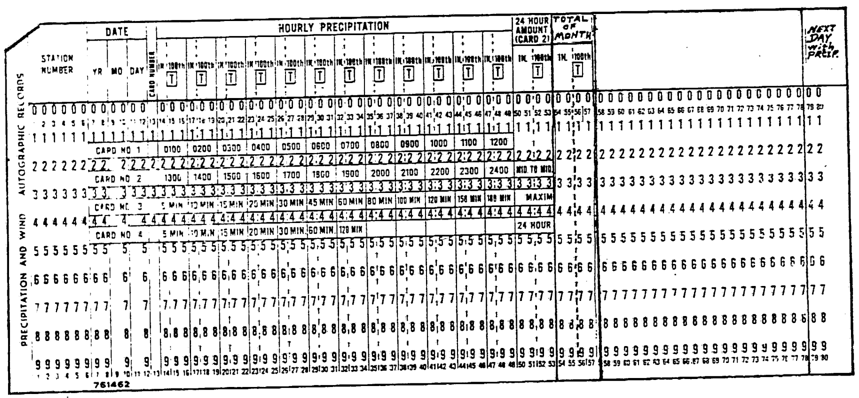
All cards processed in the National Weather Records Center through 1963 have been FOSDIC filmed. These will be updated periodically in the future. These filmed cards are no longer available in original card form. These may be retrieved from FOSDIC film. When cards are retrieved from film, columns 46-57, 70-80 are not reproduced. In cards presently being punched columns 46-63, 77-80 are not being punched, the other columns are punched when data are available.

All card data from 1948 to date for stations published in Climatological Data are edited data.

It should be noted that cards containing corrections or estimations received from the cooperatives or other sources were in some cases not substituted in the deck prior to microfilming at the beginning of the FOSDIC program. These are generally for the period of station record prior to 1948. In some instances corrected cards were added to the deck without removing erroneous cards. Corrected cards received after the regular FOSDIC microfilming are filmed on supplementary film. A list of corrections or estimations is available in some cooperative project folders.

Many of the cards in Deck 486 were punched at State Universities or other State organizations by agreements with the States. There are now 44 such Cooperative Agreements. Generally the period of record punched is prior to 1948 when the 1009 program began for most states. Cards were punched in accordance with prevailing punching procedures for columns 1-45. Columns 46-80 were generally left blank. However, these columns, especially 70-80, were used for special purposes by the State Cooperatives.

Fig. B-3



Period of Record

The period is generally August 1948 to present. Hourly precipitation data have been published in the following: (1) Prior to July 1948 in the Hydrologic Bulletin; (2) July 1948 to September 1951 in the State Climatological Data; (3) Hourly Precipitation Data from October 1951 to present; (4) Monthly Local Climatological Data (LCD) for first-order stations.

Note: Charts and data forms for published stations are available in either original records or microfilm for the period August 1948 to present, and also a preceding period for some stations.

Units

Precipitation values are reported for hourly, daily, and monthly values to the nearest one-hundredth of an inch. See Punching Practices notes and Card Content for additional information. *Pages 2,4

Station Network

Station network and period of record by station are available in a status report at the National Weather Records Center (NWRC). State climatological data (CD) base maps, indicating geographical position of the station network, with recording (weighing) rain gage instruments, are available in some of the above publications, or upon request at the National Weather Records Center.

Source

Source of data is divided into two groups: (1) The data for Weather Bureau first-order stations were obtained from monthly LCDs; (2) WB second-order stations and cooperative stations mail the weighing rain gage charts, Form WB 1028-C, to the NWRC. These are then evaluated and transferred to hourly precipitation sheets, Form WB 920-11D (formerly 1078D).

The data from the two sources were punched on cards at the NWRC for the period beginning October 1951. The preceding period approximately August 1948 thru September 1951, were punched at the regional Weather Records Processing Centers (WRPCs).

Fig. B-4

WRPC Punching Practices for Period Prior to October 1951

The punching practices were the same as the NWRC practices with the following exceptions for cols. 13, and 54 thru 77: (These columns should be used with caution.)

A. Accumulative indicator was punched at some stations as XXB instead of 0XB.

B. Col. 13 on card No. 1 was "X" overpunched to indicate no precipitation occurred for hours 01-12 LST; cols. 14-80 Blank.

C. Monthly total values were punched by some stations in cols. 54-57; other stations in cols. 70-73, and some did not punch them at all.

D. Accumulated values were indicated by some stations by an "X" overpunch in the tenths position for both hourly, daily and monthly data.

E. Station name was punched by some stations in cols. 55-69; others in cols. 59-78 on card No. 1, Standard Alphabetic Code.

F. Control "X" punches were made by some stations in cols. 54, 58, 70, 71 and 75 that have no meaning in this deck.

G. Some stations may have a daily total value punched in cols. 70-73, duplicating the values in cols. 50-53 for check purposes.

H. Daily total amounts were not punched in cols. 50-53 for 6-hourly reporting stations.

I. Data for some stations punched in cols. 70-73 have no meaning for this manual.

J. Some stations punched values in cols. 73-76. These values were the total precipitation values for the hours on that particular card.

NWRC Punching Practices for Period October 1951 to Present

(1) Both No. 1 and No. 2 cards were always punched on: (a) the first day of each month; (b) days with precipitation amounts of one-hundredth of an inch or more per hour; (c) days with precipitation beginning and ending of accumulative period (for accumulative and missing record, the cards were punched for only the first and last days of such entry) -- see 4C; (d) day of beginning of missing data and day of ending of missing data; (e) when missing data overlapped between two or more months, the last day of the month was also punched with identification data (cols. 1-13). Blank cols. 14-78 and cols. 79-80 will be punched 01 to indicate the first day of the next month for additional information.

(2) The first day of the month was always punched as indicated in 1(a). Cols. 79-80 were punched with the date of the next day with precipitation, or the beginning or ending of missing or accumulative data.

(3) The hour field on the card indicates the hour of the period ending Local Standard Time (LST), (card No. 1 for hours 1-12, and card No. 2 for hours 13-24), and total daily sum. The last day of the month with precipitation will have the monthly total precipitation sums punched in cols. 54-57 to the nearest one-hundredth of an inch.

NWRC Punching Practices - Cont'd. Page 2

TAPE DECK	STATION NUMBER	DATE			HR	CEILING	VIS.	WIND		DRY BULB	WET BULB	DEW PT	REL. HUM.	SEA LEVEL PRESS.	STATION PRESS.	SKY COND.
		YR	MO	DAY				DIR	SPEED							
1 4 X X	X X X X X	X X	X X	X X	X X	i X X X	i X X X	X X	X X X	X X X	X X X	X X X	i X X X	X X X X X	X X X X	i X X X X
001	002	003	004	005	101	102	103	104	105	106	107	108	109	110	111	112

a_t	a_o	CLOUDS															WEATHER				WIND DIR		RM	HR
		1st			2nd				3rd				4th											
		a_1	t_1	h_1	a_2	t_2	h_2	Σ_2	a_3	t_3	h_3	Σ_3	a_4	t_4	h_4		LIQ RR	FRZN RRR	OBS TO VIS					
X	X	X	X	X X X	X	X	X X X	X	X	X	X X X	X	X	X	X X X	X	X X	X X X	X X	X X	X X X	±	X X
113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	201

HR	CEILING	VIS.
X X	i X X X	i X X X
601	602	603

CLOUDS							WEATHER				WIND DIR		RM	IRG
3rd				4th										
a_3	t_3	h_3	Σ_3	a_4	t_4	h_4		LIQ RR	FRZN RRR	OBS TO VIS				
X	X	X X X	X	X	X	X X X	X	X X	X X X	X X	X X	X X X	±	
622	623	624	625	626	627	628	629	630	631	632	633	634	635	

Fig. B-5 - TDF 14 Standard Tape Form - Airways Observations

Appendix C

Subroutine RANDSK

```
      SUBROUTINE RANDSK(IRW,IBUFF,LEVEL,LA,LB,LC,LD,NMX)
C     THIS ROUTINE WILL READ OR WRITE A RECORD FROM A RANDOM DISK FILE
C     THE RECORD MAY BE UP TO NMX WORDS IN LENGTH
C     FOUR (IB) LEVELS OF SUBSCRIPTING MAY BE USED TO IDENTIFY RECORDS
C     UP TO 125(IA) RECORDS MAY BE WRITTEN AT ANY LEVEL
C     IT IS ASSUMED BY THIS ROUTINE THAT THE FIRST WORD IN THE ARRAY
C     TO BE WRITTEN OR READ CONTAINS SOME ARRAY IDENTIFICATION CODES
C     THE SECOND ELEMENT SHOULD CONTAIN THE ACTUAL NUMBER OF USEFUL
C     WORDS IN THE ARRAY
C     IRW- READ OR WRITE INDICATOR(0=READ)(1=WRITE)
C     IBUFF-ARRAY TO BE TRANSFERRED TO OR FROM DISK
C     LEVEL-NUMBER OF SUBSCRIPTS USED TO IDENTIFY ARRAY (GE.1.AND.LE.4)
C     LEV(1)-1ST SUBSCRIPT (IE.YEAT) (GE.1.NAD.LE.73)
C     LEV(2)-2ND SUBSCRIPT (IE.MONTH) (GE.1.AND.LE.73)
C     LEV(3)-3RD SUBSCRIPT (IE.STATION) (GE.1.AND.LE.73)
C     LEV(4)-4TH SUBSCRIPT (IE.PARAMETER) (GE.1.AND.LE.73)
C     IF ONLY 2 LEVELS OF SUBSCRIPTS USED LEVELS 3 AND 4 ARE IGNORED
C     IMX-MAXIMUM NUMBER OF WORDS TRANSFERRED ON A READ  USUALLY DIMENSION
      DIMENSION IBUFF(3),INDEX(127,4),LEV(4),ITEST(500)
      COMMON/BLOCK/JSWT
      DIMENSION INDX(2)
      DATA ISTAT,IA,IB   /0,127,4/
      DATA IWTFLG/0/
      LEV(1)=LA
      LEV(2)=LB
      LEV(3)=LC
      LEV(4)=LD
C     IF CALLED WITH -1 CLOSE FILE
      IF(IRW.NE.-1)GO TO 5
      IF(ISTAT.EQ.0)RETURN
      CALL STINDX(1,INDX,2)
C     CALL CLOSE
      CALL CLOSMS(1,INDX,2,0)
      IJ=10HCLOSMS
      PRINT 93,IJ
      ISTAT=0
      RETURN
C     CHECK FOR BAD ARGUMENTS
    5 IF(IRW.EQ.-10.AND.LEVEL.EQ.0)GO TO 95
      IF(IRW.LT.0.OR.IRW.GT.1)GO TO 700
      IF(LEVEL.LT.1.OR.LEVEL.GT.IB)GO TO 700
      IF(NMX.LT.1)GO TO 700
      DO 6 I=1,LEVEL
      IF(LEV(I).LT.1.OR.LEV(I).GT.IA-2)GO TO 700
    6 CONTINUE
C     IS FILE OPEN
      IF(ISTAT.NE.0) GO TO 100
      IJ=10HOPENMS
      PRINT 93,IJ
C     CHECK FOR  EXISTANCE OF FILE
      CALL OPENMS(1,INDX,2,0)
      IWTFLG=0
      ISTAT=1
      IF(EOF,1)91,92
   91 I=3HEOF
      PRINT 93,I
   93 FORMAT(1X,A10)
   92 I=4HNEOF
```

```
      PRINT 93,I
      IF(INDX(1).EQ.0.AND.INDX(2).NE.0)GO TO 11
C***  GO TO 12
C     FILE EXISTS
   11 INDX(1)=0
      INDX(2)=1
      CALL READMS(1,INDEX(1,1),IA,1)
      GO TO 100
C     FILE NON-EXISTANT
   95 IJ=10HOPENMS-NEW
      CALL OPENMS(1,INDX,2,0)
      ISTAT=1
      PRINT 93,IJ
   12 INDX(1)=0
      INDX(2)=0
      INDEX(1,1)=0
      INDEX(2,1)=-IA
      DO 13 I=3,IA
   13 INDEX(I,1)=0
      CALL WRITMS(1,INDEX(1,1),IA,1)
      IWTFLG=1
      PRINT 111,INDX,INDX
      RETURN
  100 NLEVEL=LEVEL-1
      CALL STINDX(1,INDEX(1,1),IA)
C     IS LEVEL 1 DESIRED
      IF(NLEVEL.EQ.0) GO TO 500
      DO 120 I=1,NLEVEL
      M=LEV(I)+1
      N=M+1
C     IS THIS A READ FROM A RECORD THAT DOES NOT EXIST
      IF(INDEX(N,I).EQ.0.AND.IRW.EQ.0)GO TO 200
C     DOES NEXT LEVEL EXIST
      IF(INDEX(N,I).EQ.0) GO TO 400
C     READ IN NEXT INDEX
      CALL READMS(1,INDEX(1,I+1),IA,M)
C     IS THIS AN INDEX
      IF(INDEX(1,I+1).EQ.0.AND.INDEX(2,I+1).EQ.-IA)GO TO 120
C     PRINT ERROR MESSAGE
      PRINT 110,LEVEL,LEV,IBUFF(1),IBUFF(2),INDEX(1,I+1),INDEX(2,I+1),I
  110 FORMAT(/2X22HRECORD IS NOT AN INDEX,5I5,4I16,I5)
      CALL STINDX(1,INDX,2)
      CALL CLOSMS(1,INDX,2,0)
      IJ=10HCLOSMS
      PRINT 93,IJ
      PRINT 111,INDEX
      PRINT 111,INDX
      STOP 22012
C     CHANGE INDEX
  120 CALL STINDX(1,INDEX(1,I+1),IA)
      GO TO 500
C     NO READ POSSIBLE
  200 NMX=0
      CALL STINDX(1,INDX,2)
      RETURN
C     CREAT NEW INDEXES
  400 I=I+1
      DO 450 J=I,LEVEL
```

```
      INDEX(2,J)=-IA
      DO 450 K=3,IA
  450 INDEX(K,J)=0
C     SET DESIRED INDEX
      CALL STINDX(1,INDEX(1,LEVEL),IA)
  500 M=LEV(LEVEL)+1
      N=M+1
C     N IS WORD IN INDEX THAT HOLDS ADDRESS N-2 RECORD
C     IS THIS A WRITE
      IF(IRW.EQ.1)GO TO 600
C     CHECK FOR EMPTY RECORD
      IF(INDEX(N,LEVEL).EQ.0)GO TO 200
C     READ DESIRED RECORD
      CALL READMS(1,IBUFF,NMX,M)
C     RESTORE PRIMARY INDEX
      CALL STINDX(1,INDX,2)
      RETURN
C     CHECK IF RECROD EXISTS
  600 IF(INDEX(N,LEVEL).EQ.0)GO TO 620
C     READ FIRST TWO WORDS OF RECORD
      CALL READMS(1,ITEST,500,M)
      NLEN=LENGTH(1)
C     IS THIS AN INDEX
      IF(ITEST(1).NE.0.OR.ITEST(2).NE.-IA)GO TO 621
C     YES PRINT WRITE ERROR MESSAGE
      PRINT 610,LEVEL,LEV,IBUFF(1),IBUFF(2),ITEST(1),ITEST(2)
  610 FORMAT(/2X,27HATTEMPT TO WRITE OVER INDEX,5I5,4I16)
      CALL STINDX(1,INDX,2)
      CALL CLOSMS(1,INDX,2,0)
      IJ=10HCLOSMS
      PRINT 93,IJ
      PRINT 111,INDEX
      PRINT 111,INDX
      STOP 22011
C     WRITE RECORD
  620 IF(IWTFLG.NE.0)GO TO 627
      CALL WRITMS(1,I,1,2)
      IWTFLG=1
  627 CALL WRITMS(1,IBUFF,NMX,M)
      IJ=10H    WRITE
      NLEN=0
      GO TO 628
  621 CALL REWRIT(1,IBUFF,NMX,M)
      IJ=10H RE-WRITE
C     RESTORE ALL INDEXES
C     IS THIS PRIMARY INDEX
  628 IF(NLEVEL.EQ.0)GO TO 623
      DO 630 I=1,NLEVEL
      II=LEVEL-I+1
      M=LEV(II-1)+1
      CALL STINDX(1,INDEX(1,II-1),IA)
  630 CALL REWRIT(1,INDEX(1,II),IA,M)
      CALL STINDX(1,INDX,2)
      CALL REWRIT(1,INDEX(1,1),IA,1)
  111 FORMAT(25I5)
  623 PRINT 113,IJ,LEVEL,LEV,NMX,IBUFF(1),IBUFF(2),IBUFF(3),INDEX(N,LEVE
     1L),NLEN
  113 FORMAT(1X,24HRECORD ENTERED BY RANDSK,A10,6I5,4I16,I5)
```