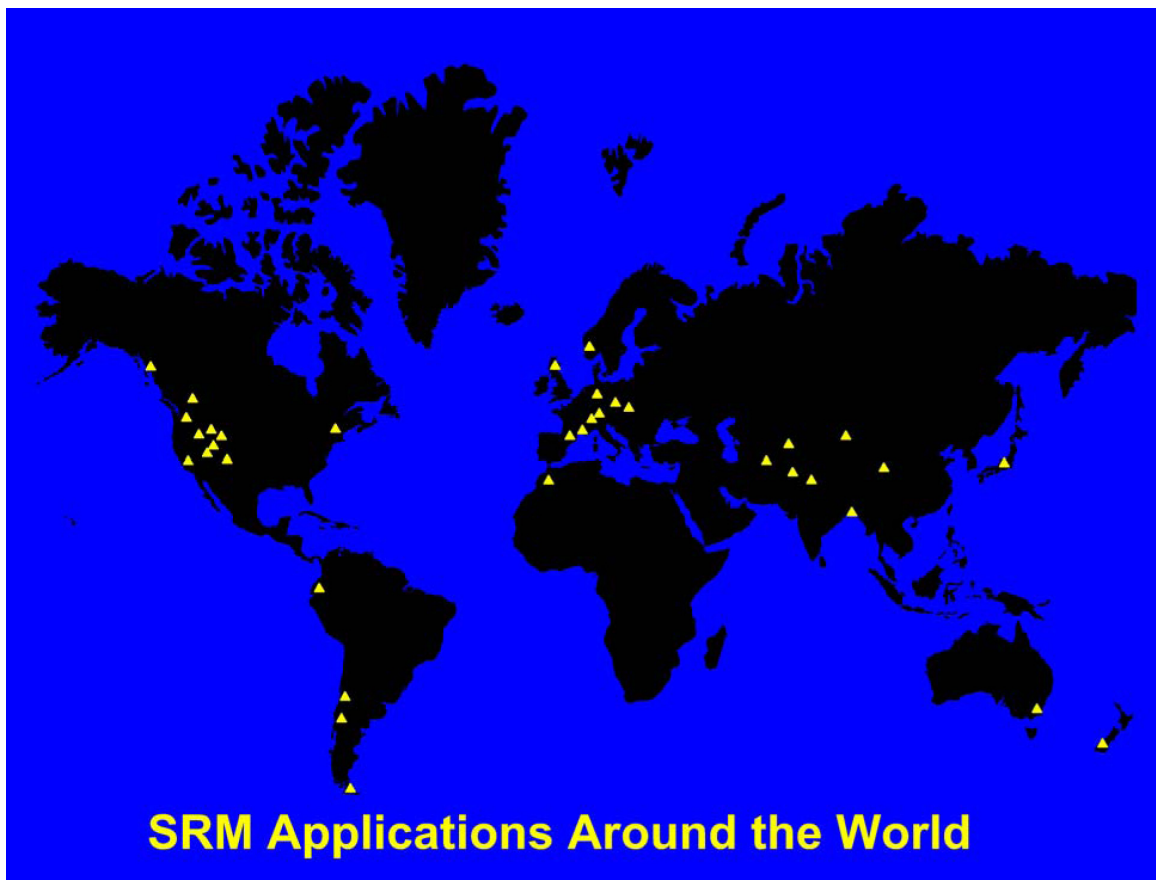J. Martinec, A. Rango, R. Roberts

Snowmelt Runoff Model (SRM) User's Manual

Edited by Enrique Gómez-Landesa & Max P. Bleiweiss

SRM Applications Around the World

WINDOWS PROGRAM FOR IMPROVED RUNOFF FORECASTS AND EFFECT OF CLIMATE CHANGE

Acknowledgment

S R M

SNOWMELT RUNOFF MODEL

USER'S MANUAL

UPDATED EDITION FOR WINDOWS

WinSRM Version 1.11   February, 2008

Jaroslav Martinec, Albert Rango & Ralph Roberts

Edited by
Enrique Gómez-Landesa & Max P. Bleiweiss

This publication is an updated edition of the Snowmelt Runoff Model (SRM) User's Manual featuring the new computer program WinSRM Version 1.11

SRM Applications Around the World

SNOWMELT RUNOFF MODEL (SRM)

USER'S MANUAL

(Updated Edition 2008, Windows Version 1.11)

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SNOWMELT RUNOFF MODEL (SRM)
USER'S MANUAL

(UPDATED EDITION 2008, WINDOWS VERSION 1.11)

1 PREFACE

This 2008 edition of the User's Manual presents a new computer program, the Windows Version 1.11 of the Snowmelt Runoff Model (WinSRM). The popular Version 4 is also preserved in the Appendix because it is still in demand to be used within its limits. The Windows version adds new capabilities: it accepts more detailed climate scenarios; for example, different daily changes of temperature and precipitation. It makes possible to substitute a data set of temperatures and precipitation of a selected year as a "climate scenario" for any available existing year and evaluate the resulting snow conditions and runoff. A normalized year, including normalized Conventional Depletion Curves (CDC's) from long term temperature and precipitation data can be derived to represent today's climate.

It is now possible to divide a basin into as many as 16 elevation or other zones in order to refine the modeling, while Version 4 only allowed 8. These improvements facilitate new developments in SRM applications which are already taking place: runoff modeling by using different land use zones, separating satellite mapping of snow and glaciers, runoff modeling in very large basins with an extreme elevation range, and others. The specific features of WinSRM Version 1.11 are explained in detail in this document in Sections 8.5, 8.6, 9, and 10.

WinSRM Version 1.11 has been developed without sacrificing the advantages of the SRM Version 4, in particular the speed of getting results. Both versions are available on the Internet by accessing http://www.ars.usda.gov/Services/docs.htm?docid=8872. Should this link not be "current" for the reader, one can "search" on "SRM home" or "WinSRM" to locate a "current site".

So far, four SRM workshops (in 1992, 1994, 1996, and 1998) have been organized at the University of Bern, Switzerland, with about 130 participants from 20 countries taking part. A fifth SRM workshop was organized in 2005 at New Mexico State University. In addition, the authors are available to assist users in overcoming special problems which may be encountered.

2 INTRODUCTION

The Snowmelt-Runoff Model (SRM) is designed to simulate and forecast daily streamflow in mountain basins where snowmelt is a major runoff factor. Most recently, it has also been applied to evaluate the effect of a changed climate on seasonal snow cover and runoff. SRM was developed by Martinec (1975) in small European basins. Thanks to the progress of satellite remote sensing of snow cover, SRM has been applied to larger and larger basins. Recently, the runoff was modelled in the basin of the Ganges River, which has an area of 917,444 km^2 and an elevation range from 0 to 8,840 m a.s.l. Contrary to the original assumptions, there appear to be no limits for application with regard to the basin size and the elevation range. Also, a dominant role of snowmelt does not seem to be a necessary condition. It is, however, advisable to carefully evaluate the formula for the recession coefficient.

Runoff computations by SRM appear to be relatively easily understood. To date the model has been applied by various agencies, institutes and universities in over 100 basins, situated in 29 different countries as listed in Table 1. More than 80% of these applications have been performed by independent users, as is evident from 80 references to pertinent publications. Some of the localities are shown in Figure 1. SRM also successfully underwent tests by the World Meteorological Organization with regard to runoff simulations (WMO, 1986) and to partially simulated conditions of real time runoff forecasts (WMO, 1992).
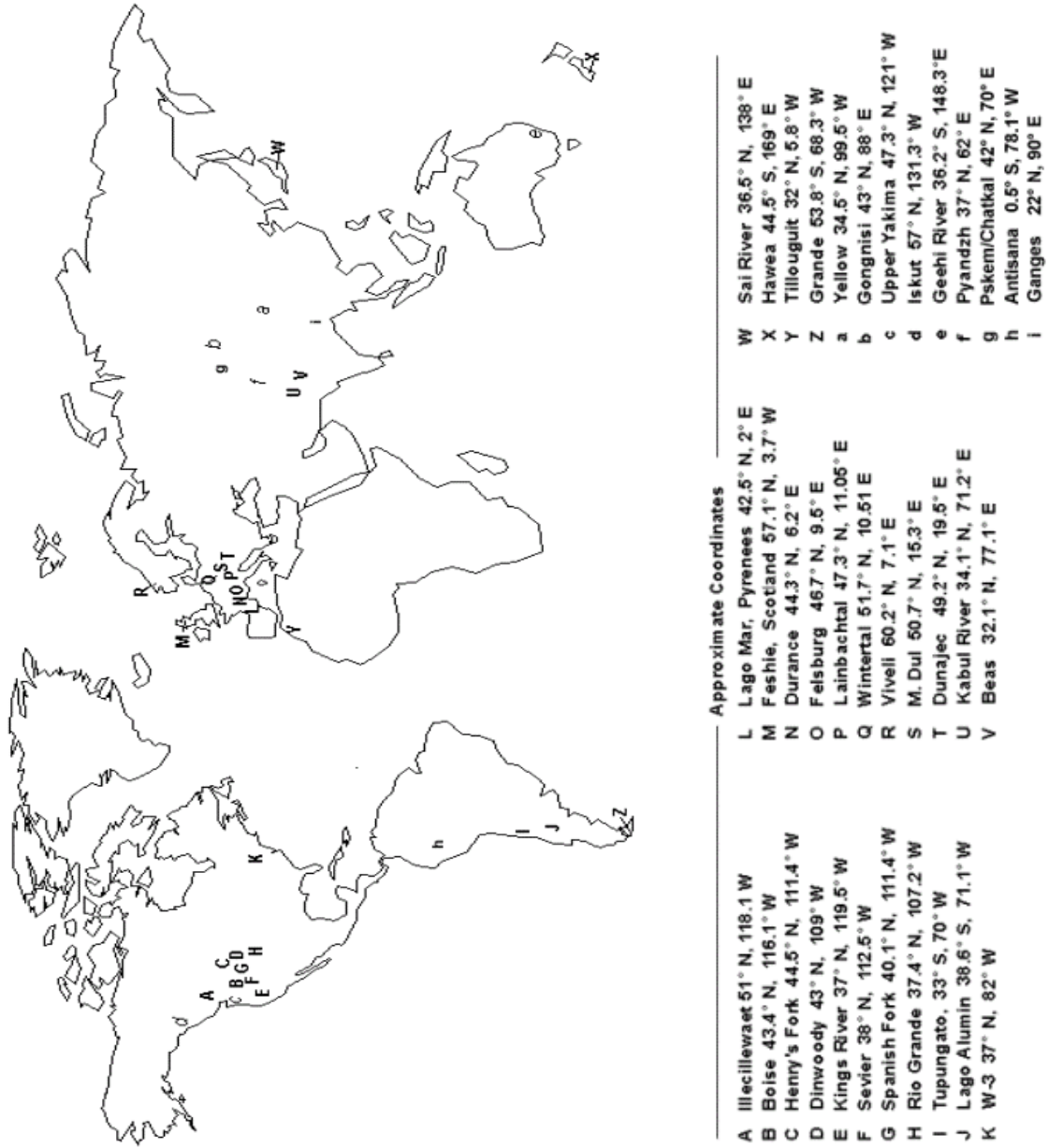
Fig. 1 Selected locations where SRM has been tested.

3 RANGE OF CONDITIONS FOR MODEL APPLICATION

SRM can be applied in mountain basins of almost any size (so far from 0.76 to 917,444 km^2) and any elevation range (Table 1). A model run starts with a known or estimated discharge value and can proceed for an unlimited number of days, as long as the input variables - temperature, precipitation and snow covered area - are provided. As a test, a 10-year period was computed without reference to measured discharges (Martinec & Rango, 1986).

The references pertinent to the following table can be seen in Section 11.2 "Specific references for Table 1" at the end of this manual. These references appear under the heading "Ref" and with a number to easily find them in Section 11.2.

Table 1 SRM applications and results

#	Country	Basin	Size (km^2)	Elevation Range (m a.s.l.)	R^2	D$_v$ [%]	Years seasons	Zones	Ref	Publ	Year appl
1	USA	EGL (Rocky Mountains)	0.29	3300-3450	N/A	N/A	N/A	N/A	[72]	1991	1989
2	USA	WGL (Rocky Mountains)	0.6	3300-3450	N/A	N/A	N/A	N/A	[72]	1991	1989
3	Germany	Lange Bramke (Harz)	0.76	540-700	N/A	N/A	1	1	[25]	1984	1981
4	Germany	Wintertal (Harz)	0.76	560-754	N/A	N/A	1	1	[25]	1984	1981
5	Czech R.	Modry Dul (Krkonose)	2.65	1000-1554	0.96	1.7	2	1	[40, 12]	1963, 1970	1962, 1966
6	USA	GLEES (Rocky M.)	2.87	3300-3450	N/A	N/A	N/A	N/A	[72]	1991	1989
7	Ecuador	Antisana (Andes)	3.72	4500-5760	N/A	N/A	1	3	[19]	1997	1996
8	Argentina	Echaurren	4.5	3000-4200	0.84	7.5	1	1	[14]	1997	1985
9	Spain	Lago Mar (Pyrenees)	4.5	2234-3004	N/A	N/A	1	1	[39]	1966	1965
10	Spain	Llauset dam (Pyrenees)	7.8	2100-3000	0.69	5.5	1	2	[23]	2001	1999
11	USA	W-3 (Appalachians)	8.42	346-695	0.81	8.8	10	1	[79]	1986	1969-1978
12	Germany	Lainbachtal (Allgauer Alps)	18.7	670-1800	N/A	N/A	5	1	[74]	1978	1978, 1979
13	Spain	Salenca en Baserca (Pyrenees)	22.2	1460-3200	0.72	4.3	3	3	[22]	2002	1999
14	Spain	Noguera Ribagorzana en Baserca (Pyrenees)	36.8	1480-3000	0.71	3.7	3	2	[22]	2002	1995
15	Switzerland	Rhone-Gletsch (Alps)	38.9	1755-3630	N/A	N/A	1	4	[49]	1980	1979
16	Switzerland	Dischma (Alps)	43.3	1668-3146	0.86	2.5	10	3	[38, 79]	1975, 1986	1973, 1970-79
17	Japan	Sai (Japan Alps)	57	300-1600	0.86	N/A	3	3	[28, 29, 30]	1982, 1987	1979-1981
18	Spain	Tor en Alins (Pyrenees)	60	1880-3040	0.71	7.3	1	4	[21]	2002	1999

#	Country	Basin	Size (km²)	Elevation Range (m a.s.l.)	R²	Dᵥ [%]	Years seasons	Zones	Ref	Publ	Year appl
19	Spain	Flamisell en Capdella (Pyrenees)	84	1440-2940	0.68	8.1	1	4	[21]	2002	1999
20	Spain	Vellós en Añisclo (Pyrenees)	85	1140-3360	0.83	1.5	1	5	[21]	2002	1999
21	Austria	Rofenache (Alps)	98	1890-3771	0.88	2.4	1	8	[46, 60]	1995, 1997	1992-1993
22	United Kingdom	Feshie (Cairngorms)	106	350-1265	0.88	N/A	2	1	[17]	1984	1979, 1980
23	Switzerland	Sedrun (Alps)	108	1840-3210	0.79	1.9	2	3	[65, 66]	1989, 1995	1985, 1993
24	Austria	Tuxbach	116	879-3062	0.44	12.7	3	7	[59]	2000	1996-1998
25	Austria	Schlegeis	121	1790-3510	0.86	8.7	3	8	[59]	2000	1996-1998
26	Australia	Geehi River (Snowy Mtns.)	125	1032-2062	0.7	6.6	6	3	[20]	1996	1989-1994
27	USA	American Fork (Utah)	130	1820-3580	0.90	1.7	1	4	[44, 26]	1985, 1986	1983
28	Austria	Venter Ache	165	1850-3771	0.82	5.4	1	8	[46]	1997	1992
29	Switzerland	Landwasser - Frauenkirch (Alps)	183	1500-3146	N/A	N/A	1	3	[48]	1979	1979
30	Switzerland	Massa-Blatten (Alps) ***	196	1447-4191	0.91	-5.3	1	6	[63]	1999	1985
31	India	Kulang (Himalayas)	205	2350-5000	N/A	N/A	N/A	N/A	---	---	---
32	Switzerland	Tavanasa (Alps)	215	1277-3210	0.82	3.1	2	4	[66,67]	1995	1985, 1993
33	USA	Dinwoody (Wind River)	228	1981-4202	0.85	2.8	2	4	[37]	1980	1974, 1976
34	Italy	Cordevole (Alps)	248	980-3250	0.89	4.6	1	3	[75]	1996	1984
35	USA	Salt Creek (Utah)	248	1564-3620	N/A	2.6	1	5	[68]	1987	---
36	India	Beas-Manali (Himalayas)	345	1900-6000	0.68	12	4	N/A	[3]	1983	---
37	Argentina	El Yeso	350	2475-6550	0.91	2.6	2	3	[13]	1998	1991, 1993
38	Norway	Laerdalselven (Lo Bru)	375	530-1720	0.86	5.2	1	5	[76]	1992	1991
39	Norway	Viveli (Hardangervidda)	386	880-1613	0.73	11.3	2	1	[58]	1992	1991
40	USA	Scofield Dam, Price River (Utah)	401	2323-3109	0.8	5.0	2	1	[78]	1999	1996, 1998
41	Spain	Cardós en Tirvia (Pyrenees)	417	1720-3240	0.8	2.6	1	4	[21]	2002	1999
42	Japan	Okutadami (Mikuni)	422	782-2346	0.83	5.4	3	3	[26]	1985	1984
43	USA	Joes Valley Dam, Cottonwood Creek (Utah)	435	2131-3353	0.83	18.5	2	3	[78]	1997	1985
44	Spain	Garona en Bossost (Pyrenees)	449	1620-3080	0.75	3.0	1	4	[23]	2002	1999
45	Spain	Noguera Pallaresa en Escaló (Pyrenees)	450	1860-2960	0.87	3.3	1	3	[21]	2002	1999
46	USA	Bull Lake Creek (Rocky Mts.)	484	1790-4185	0.82	4.8	1	4	[57]	1981	1976

#	Country	Basin	Size (km²)	Elevation Range (m a.s.l.)	R²	D_v [%]	Years seasons	Zones	Ref	Publ	Year appl
47	Switzerland	Tiefencastel (Alps)	529	837-3418	0.55	11.3	2	5	[6]	1987	1982, 1985
48	Spain	Valira en Seo d'Urgel (Pyrenees)	545	1740-3080	0.92	0.9	1	4	[21]	2002	1999
49	USA	Towanda Creek (Applachians)**	550	240-733	0.78	8.3	3	6	[45]	1998	1990, 1993,94
50	Spain	Garona en Pont de Rei (Pyrenees)	558	1420-3080	0.72	2.7	1	5	[23]	2002	1999
51	USA	South Fork (Colorado)	559	2506-3914	0.89	1.8	7	3	[69, 70]	1980, 1981	1973-79
52	Spain	Noguera Ribagorzana en Pont de Suert (Pyrenees)	573	920-3380	0.91	-0.6	1	6	[22]	2002	1999
53	Argentina	Las Cuevas en Los Almendros (Andes)	600	2500-7000	N/A	N/A	N/A	N/A	[41]	1989	1981
54	USA	Independence R. (Adirondacks)	618	261-702	0.81	5.0	1	1	[42]	1990	1987
55	Chile	Mapocho (Andes)	630	1024-4450	0.42	29.9	1	3	[15]	1992	1987
56	Poland	Dunajec (High Tatra)	700	577-2301	0.73	3.8	1	3	[19]	1986	1975
57	India	Saing (Himalayas)	705	1400-5500	N/A	N/A	N/A	N/A	[33]	1991	---
58	USA	Conejos (Rocky Mts)	730	2521-4017	0.87	1.1	7	3	[69]	1981	1973-1979
59	Switzerland	Ilanz (Alps)	776	693-3614	0.53	8.6	2	5	[6]	1987	1982, 1985
60	Spain	Cinca en Laspuña (Pyrenees)	798	1120-3380	0.78	5.6	1	5	[21]	2002	1999
61	China	Toutunhe	840	1430-4450	0.81	2.0	3	6	[77]	1994	1984-1986
62	Austria	Ötztaler Ache (Alps)	893	670-3774	0.84	9.18	1	6	[1]	1998	<1998
63	Argentina	Lago Alumin (Andes)	911	1145-2496	N/A	N/A	N/A	N/A	[43]	1985	1985
64	China	Gongnisi (Tien Shan)	939	1776-4200	0.8	0.97	1	5	[35]	2000	<1999
65	China	Urumqi (Tien Shan)	950	1880-4200	0.62	2.78	1	6	[35]	2000	<1999
66	Uzbekistan	Angren	1082	1200-3800	0.63	2.3	3	6	[4]	2002	---
67	India	Parbati (Himalayas)	1154	1500-6400	0.73	7.5	1	5	[33]	1991	1986~1991
68	Canada	Illecillewaet (Rocky Mts)*	1155	509-3150	0.86	7.0	4	4	[50, 53, 54]	1988, 1994, 2000	1976, 1981, 1983,84
69	Spain	Segre en Seo d'Urgel (Pyrenees)	1217	360-2900	N/A	N/A	N/A	5	[24]	1997	1996
70	India	Buntar (Himalayas)	1370	1200-5000	N/A	N/A	N/A	N/A	[33]	1991	1985~1991
71	Chile	Tinguiririca Bajo Briones (Andes)	1460	520-4500	0.88	-0.3	1	3	[15]	1992	1987
72	New Zealand	Hawea (S. Alps)	1500	300-2500	N/A	N/A	N/A	N/A	[18]	1991	1989
73	Switzerland	Ticino-Bellinzona (Alps)	1515	220-3402	0.86	-0.6	1	5	[62]	2000	1994
74	USA	Spanish Fork (Utah)	1665	1484-3277	0.85	1.0	1	4	[68]	1987	1983

#	Country	Basin	Size (km^2)	Elevation Range (m a.s.l.)	R^2	D$_V$ [%]	Years seasons	Zones	Ref	Publ	Year appl
75	Switzerland	Inn at Tarasp (Alps)	1700	1235-4005	0.77	8.0	---	1	[59]	2000	1996
76	Argentina	Tupungato (Andes)	1800	2500-6000	0.63	6.4	1	8	[41]	1989	1981
77	Switzerland	Inn-Martina (Alps)	1943	1030-4049	0.82	4.3	1	2	---	1995	1990
78	Argentina	Chico (Tierra del Fuego)	2000	N/A	N/A	N/A	N/A	N/A	[34]	1991	N/A
79	USA	Boise (Rocky Mts.)	2150	983-3124	0.84	3.3	3	3	[55]	1985	1976-1978
80	France	Durance (Alps)	2170	786-4105	0.85	2.6	5	5	[79]	1986	1975-1979
81	USA	Madison (Montana)	2344	1965-3234	0.89	1.5	2	2	[56]	1984	1976, 1978
82	Uzbekistan	Pskem	2448	1000-4200	0.97	-1.0	3	7	[4]	2002	<2002
83	Morocco	Tillouguit (Atlas)	2544	1050-3411	0.84	0.5	1	3	[2]	1989	1979
84	Austria	Salzach-St.Johann (Alps)	2600	570-3666	N/A	N/A	N/A	N/A	---	---	>1991
85	USA	Henry's Fork (Idaho)	2694	1553-3125	0.91	1.5	2	3	[56]	1984	1976, 1979
86	USA	Cache la Poudre (Colorado)	2732	1596-4133	N/A	N/A	1	3	[27]	1984	1983
87	Chile	Aconcagua en Chababuquito (Andes)	2900	900-6100	0.91	0.9	1	3	[15]	1992	1987
88	USA	Sevier River (Utah)	2929	1923-3260	0.75	5.1	1	4	[68]	1987	1983
89	Switzerland	Rhine-Felsberg (Alps) *	3249	562-3425	0.70	7.2	7	5	[16, 65]	1998	1982, 85, 88, 89, 92,94, 96
90	Switzerland	Rhône-Sion (Alps) ***	3371	491-4634	0.97	-2.1	1	7	[61]	2000	1985
91	USA	Rio Grande (Colorado) *	3414	2432-4215	0.84	3.8	13	3	[50, 52]	1997, 2000	1976-77, 1979
92	USA	Kings River (California) *	4000	171-4341	0.82	3.2	5	7	[50, 36]	1982, 2000	1973-75, 82,88
93	Chile	Maipo en el Manzano (Andes)	4960	850-5600	0.77	0.9	2	3	[15]	1992	1982, 1988
94	India	Beas-Thalot (Himalayas)	5144	1100-6400	0.80	1.5	2	6	[32]	1991	1986-87
95	USA	Upper Yakima (Cascades)	5517	366-2121	0.92	2.8	1	5	[9]	1990	1989
96	Uzbekistan	Chatkal	6591	1000-4000	0.81	1.6	3	7	[4]	2002	---
97	Canada	Sturgeon (Ontario)	7000	N/A	N/A	N/A	N/A	N/A	[10]	1982	1967
98	Argentina	Grande (Tierra del Fuego)	9050	N/A	N/A	N/A	N/A	N/A	[34]	1991	N/A
99	Canada	Iskut (Coast)	9350	200-2556	N/A	N/A	N/A	N/A	[71]	2002	N/A
100	Turkey	Karasu (Upper Euphrates)	10216	1125-3487	0.95	0.25	3	5	[73]	2001	1997-1999
101	Uzbekistan, Kyrgystan	Karadarya	12056	1100-4568	0.87	4.0	4	8	[4, 5]	2002	1996, 98, 1999
102	Tadjikistan	Zerafshan	12214	410-5500	N/A	N/A	1	8	[4, 8]	1996, 2002	---

#	Country	Basin	Size (km²)	Elevation Range (m a.s.l.)	R²	D_V [%]	Years seasons	Zones	Ref	Publ	Year appl
103	Uzbekistan, Kazakhstan	Kafinirgan *	12369	505-3005	0.57	8.6	3	6	[8]	1996	1988-1991
104	USA	Sevier River (Utah)	13380	1506-3719	0.93	4.0	1	4	[68]	1987	1983
105	USA	Snake River (Idaho)	14897	1524-4196	0.90	0.4	11	N/A	[31]	1986	1972-1982
106	Tadjikistan	Vakhsh *	37759	1791-5291	0.63	2.8	3	8	[8]	1996	1988-1990
107	Kyrgystan	Naryn	53237	800-5000	0.96	1.0	2	8	[4]	2002	---
108	Pakistan	Kabul River (Himalayas)	63657	305-7690	0.66	6.0	1	1	[11]	1989	1975
109	Tadjikistan, Afghanistan	Pyandzh (Pamirs and Hindu Kush)	120534	2141-5564	0.65	5.6	3	8	[8]	1996	1988-1991
110	China	Yellow (Anyemogen Shan)	121972	2500-5224	N/A	N/A	N/A	3	[80]	1994	1993
111	India, Bangladesh	Brahmaputra * (Himalayas)	547346	0-8848	0.75	-7.5	1	7	[64]	2000	1995
112	India, Bangladesh	Ganges * (Himalayas)	917444	0-8848	0.94	8.3	1	7	[64]	2000	1995

If more than one year was evaluated, averages of R² and averages of D_V (single values taken in absolute terms) are listed.

* climate change evaluated   ** land-use zones   *** separate mapping of snow cover and glaciers

Ref = Number of reference, Section 11.2

Publ = Year of publication

Year appl = Hydrological year of model application

The accuracy criteria $\mathbf{R^2}$ and $\mathbf{D_V}$ listed in Table 1 are defined as:

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(Q_i - Q_i')^2}{\sum_{i=1}^{n}(Q_i - \overline{Q})^2} \qquad D_v = \frac{V_R - V_R'}{V_R} \cdot 100$$

where:
R^2 = a measure of model efficiency
Q_i = measured daily discharge
Q_i' = simulated daily discharge
$\overline{Q}$ = average daily discharge for the simulation year or simulation season
n = number of daily discharge values
D_V = percentage difference between the total measured and simulated runoff (%)
V_R = measured runoff volume
V_R' = simulated runoff volume

In addition to the input variables, the area-elevation curve of the basin is required. If other basin characteristics are available (forested area, soil conditions, antecedent precipitation, and runoff data), they are of course useful for facilitating the determination of the model parameters.

SRM can be used for the following purposes:

(1) Simulation of daily flows in a snowmelt season, in a year, or in a sequence of years. The results can be compared with the measured runoff in order to assess the performance of the model and to verify the values of the model parameters. Simulations can also serve to evaluate runoff patterns in ungauged basins using satellite monitoring of snow covered areas and extrapolation of temperatures and precipitation from nearby stations.

(2) Short term and seasonal runoff forecasts. The computer program (WinSRM) includes a derivation of modified depletion curves which relate the snow covered areas to the cumulative snowmelt depths as computed by SRM. These curves enable the snow coverage to be extrapolated manually by the user several days ahead by temperature forecasts so that this input variable is available for discharge forecasts. The modified depletion curves can also be used to evaluate the snow reserves for seasonal runoff forecasts. The model performance may deteriorate if the forecasted air temperature and precipitation deviate from the observed values, but the inaccuracies can be reduced by periodic updating.

(3) In recent years, SRM was applied to the new task of evaluating the potential effect of climate change on the seasonal snow cover and runoff, as explained in Chapter 8. The microcomputer program has been modified and supplemented accordingly.

4 MODEL STRUCTURE

Each day, the water produced from snowmelt and from rainfall is computed, superimposed on the calculated recession flow and transformed into daily discharge from the basin according to Equation (1):

$$Q_{n+1} = [c_{Sn} \cdot a_n (T_n + \Delta T_n) S_n + c_{Rn} P_n] \frac{A \cdot 10000}{86400} (1 - k_{n+1}) + Q_n k_{n+1} \qquad (1)$$

where: Q = average daily discharge $[m^3 s^{-1}]$

c = runoff coefficient expressing the losses as a ratio (runoff/precipitation), with c_S referring to snowmelt and c_R to rain

a = degree-day factor $[cm\ ^oC^{-1}d^{-1}]$ indicating the snowmelt depth resulting from 1 degree-day

T = number of degree-days $[^oC\ d]$

ΔT = the adjustment by temperature lapse rate when extrapolating the temperature from the station to the average hypsometric elevation of the basin or zone $[^oC\ d]$

S = ratio of the snow covered area to the total area

P = precipitation contributing to runoff [cm]. A preselected threshold temperature, T_{CRIT}, determines whether this contribution is rainfall and immediate. If precipitation is determined by T_{CRIT} to be new snow, it is kept on storage over the hitherto snow free area until melting conditions occur.

A = area of the basin or zone $[km^2]$

k   = recession coefficient indicating the decline of discharge in a period without snowmelt or rainfall:

$$k = \frac{Q_{m+1}}{Q_m}$$ (m, m + 1 are the sequence of days during a true recession flow period).

n   = sequence of days during the discharge computation period. Equation (1) is written for a time lag between the daily temperature cycle and the resulting discharge cycle of 18 hours. In this case, the number of degree-days measured on the nth day corresponds to the discharge on the n + 1 day. Various lag times can be introduced by a subroutine.

$$\frac{10000}{86400} =$$ conversion from cm·km^{2}d^{-1} to m^3 s^{-1}

T, S and P are variables to be measured or determined each day, c_R, c_S, lapse rate to determine ΔT, T_{CRIT}, k and the lag time are parameters which are characteristic for a given basin or, more generally, for a given climate. A guidance for determining these parameters will be given in Section 5.3.

If the elevation range of the basin exceeds 500 m, it is recommended that the basin be subdivided into elevation zones of about 500 m each. For an elevation range of 1500 m and three elevation zones A, B and C, the model equation becomes:

$$
\begin{aligned}
Q_{n+1} = &\left\{ \left[c_{SAn} a_{An} \left(T_n + \Delta T_{An} \right) S_{An} + c_{RAn} P_{An} \right] \frac{A_A \cdot 1000}{86400} + \right. \\
&\left[c_{SBn} a_{Bn} \left(T_n + \Delta T_{Bn} \right) S_{Bn} + c_{RBn} P_{Bn} \right] \frac{A_B \cdot 1000}{86400} + \\
&\left. \left[c_{SCn} a_{Cn} \left(T_n + \Delta T_{Cn} \right) S_{Cn} + c_{RCn} P_{Cn} \right] \frac{A_C \cdot 1000}{86400} \right\} \left(1 - k_{n+1} \right) + Q_n k_{n+1}
\end{aligned}
$$

(2)

The indices A, B and C refer to the respective elevation zones and a time lag of 18 hours is assumed. Other time lags can be selected and automatically taken into account as explained in the Section 5.3.7.

In the simulation mode, SRM can function without updating. The discharge data serve only to evaluate the accuracy of simulation. In ungauged basins the simulation is started with a discharge estimated by analogy to a nearby gauged basin. In the forecasting mode, the model provides an option for updating by the actual discharge every 1-9 days.

Equations (1) and (2) are written for the metric system but an option for model operation in English units is also provided in the computer program.

5 NECESSARY DATA FOR RUNNING THE MODEL

5.1 Basin characteristics

5.1.1 Basin and zone areas

The basin boundary is defined by the location of the streamgauge (or some arbitrary point on the streamcourse) and the watershed divide is identified on a topographic map. The basin boundary can be drawn at a variety of map scales. For the larger basins, a 1:250,000 scale map is adequate. After examining the elevation range between the streamgauge and the highest point in the basin (total basin relief), elevation zones can be delineated in intervals of about 500 m or 1500 ft. In addition to drawing the basin and zone boundaries, several intermediate topographic contour lines should be highlighted for later use in constructing the area-elevation curve. Once the boundaries and the contours have been determined, the areas formed by these boundaries should be planimetered manually or automatically. Figure 2 shows the elevation zones and areas of the South Fork of the Rio Grande basin in Colorado, USA. The elevation range of 1408 m dictated the division of the basin into three elevation zones. Once the zones are defined, the various model variables and parameters are applied to each zone for the calculation of snowmelt runoff. To facilitate this application, the mean hypsometric elevation of the zone must be determined through use of an area-elevation curve. Many of these steps can be expedited through the use of computer analysis and a Digital Elevation Model (DEM).
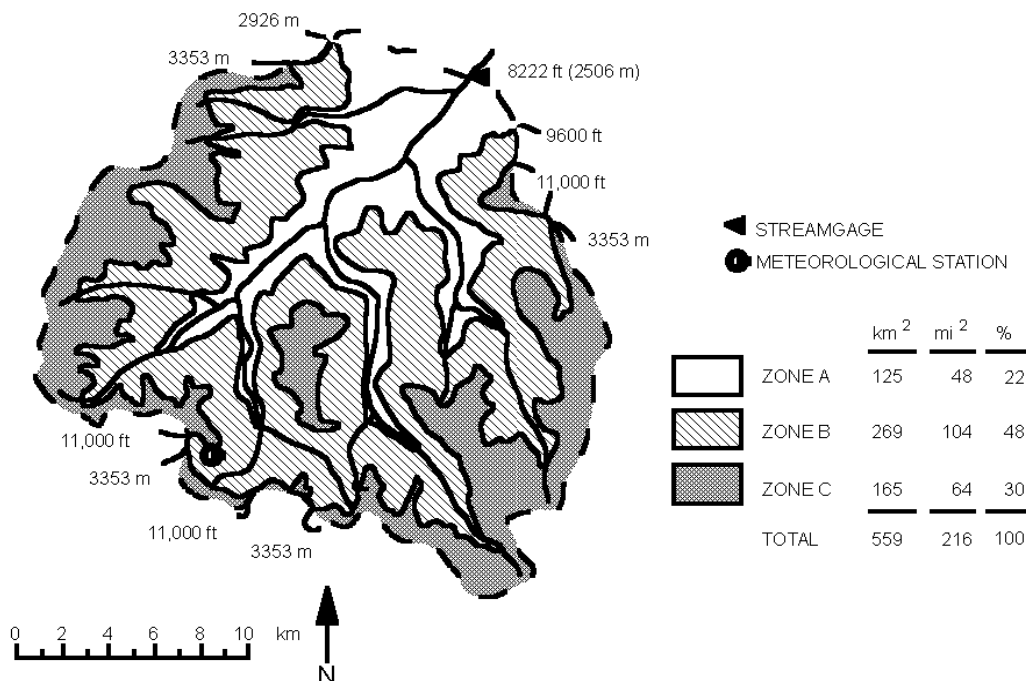
Fig. 2 Elevation zones and areas of the South Fork of the Rio Grande basin, Colorado, USA.

5.1.2 Area-elevation curve

By using the zone boundaries plus other selected contour lines in the basin, the areas enclosed by various elevation contours can be determined by planimetering. These data can be plotted (area vs elevation) and an area-elevation (hypsometric) curve derived as shown in Figure 3 for the South Fork basin. This area-elevation curve can also be derived automatically if the user has access to digital elevation data and computer algorithms used in an image processing system. The zonal mean hypsometric elevation, $\overline{h}$, can then be determined from this curve by balancing the areas above and below the mean elevation as shown in Figure 3. The $\overline{h}$ value is used as the elevation to which base station temperatures are extrapolated for the calculation of zonal degree-days.
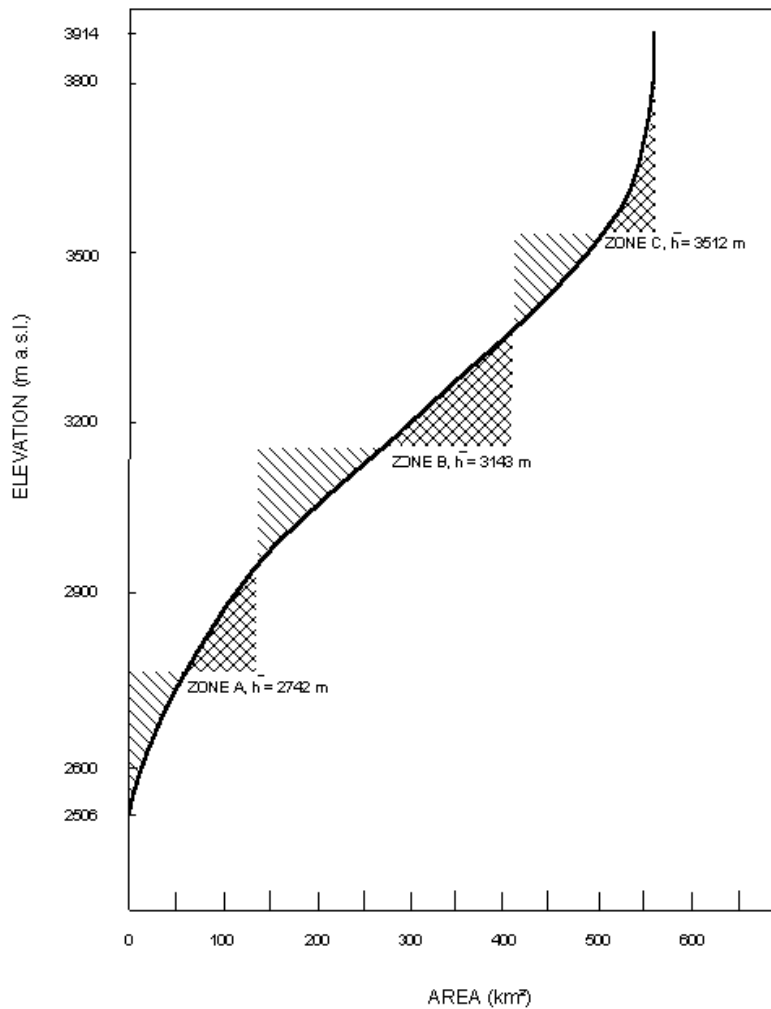
Fig. 3 Determination of zonal mean hypsometric elevations ($\overline{h}$) using an area-elevation curve for the South Fork of the Rio Grande basin.

5.2 Variables

- TEMPERATURE

- PRECIPITATION

- SNOW COVERED AREA

5.2.1 Temperature and degree-days, T

In order to compute the daily snowmelt depths, the number of degree-days must be determined from temperature measurements or, in a forecasting mode, from temperature forecasts.

Temperature average Program options:
    0 = daily mean
    1 = Min, Max

The program accepts either the daily mean temperature (option 0) or two temperature values on each day: T_{Max}, T_{Min} (option 1). The temperatures are extrapolated by the program from the base station elevation to the hypsometric mean elevations of the respective elevation zones. For option 1, the average temperature is computed in each zone as

$$\overline{T} = \frac{T_{Max} + T_{Min}}{2} \tag{3}$$

When using daily means (option 0) or when using T_{Max}, T_{Min} (option 1), it is recommended that negative temperature values (when they occur) be used in the calculation. In line with this recommendation, the original "effective minimum temperature" alternative (automatic change of negative temperatures to 0°C) was removed from the computer program beginning with Version 3.0. If the user still prefers this alternative, the occasional negative temperatures can be changed manually to 0°C when inputting the data to SRM.

Because the average temperatures refer to a 24 hour period starting always at 0600 hrs, they become degree-days T [°C·d]. The altitude adjustment ΔT in Equation (1) is computed as follows:

$$\Delta T = \gamma \cdot (h_{st} - \overline{h}) \cdot \frac{1}{100} \tag{4}$$

where γ = temperature lapse rate [°C per 100 m]
          h_{st} = altitude of the temperature station [m]

          $\overline{h}$ = hypsometric mean elevation of a zone [m]

Whenever the degree-day numbers (T + ΔT in Equation (1)) become negative, they are automatically set to zero so that no negative snowmelt is computed. The values of the temperature lapse rate are dealt with in Section 5.3.3.

Temperature input Program options:
    0 = basin wide
    1 = by zone

The program accepts either temperature data from a single station (option 0, basin wide) or from several stations (option 1, by zone). With option 0, the altitude of the station is entered and temperature data are extrapolated to the hypsometric mean elevations of all zones using the lapse rate. If more stations are available, the user can prepare a single "synthetic station" and still use option 0 or, alternatively, use option 1. With option 1, the user may use separate stations for each elevation zone, however, the temperatures entered for each zone must have already been lapsed to the mean hypsometric elevation of the zone. Although SRM will take separate stations for each zone in this way, it is only optional. The measurement of correct air temperatures is difficult, and therefore one good temperature station (even if located outside the basin) may be preferable to several less reliable stations.

In the forecast mode of the model, it is necessary to obtain representative temperature forecasts for the given region and altitude in order to extrapolate the expected numbers of degree-days for each elevation zone.

5.2.2 Precipitation, P
The evaluation of representative areal precipitation is particularly difficult in mountain basins. Also, quantitative precipitation forecasts are seldom available for the forecast mode, although current efforts in this field are improving this situation. Fortunately, snowmelt generally prevails over the rainfall component in the mountain basins. However, sharp runoff peaks from occasional heavy rainfalls must be given particular attention and the program includes a special treatment of such events (see Section 5.3.6).

Rainfall input Program options:
>   0 = basin wide
>   1 = by zone

The program accepts either a single, basin-wide precipitation input (from one station or from a "synthetic station" combined from several stations, that is, option 0) or different precipitation inputs zone by zone (option 1). If the program is switched to option 1 and only one station happens to be available, for example in the zone A, precipitation data entered for zone A must be copied to all other zones. Otherwise no precipitation from these zones is taken into account by the program. Further program options refer to the rainfall contributing area as explained in Section 5.3.5. In basins with a great elevation range, the precipitation input may be underestimated if only low altitude precipitation stations are available. It is recommended to extrapolate precipitation data to the mean hypsometric altitudes of the respective zones by an altitude gradient, for example 3 % or 4 % per 100 m. If two stations at different altitudes are available, it is possible to assign the averaged data to the average elevation of both stations and to extrapolate by an altitude gradient from this reference level to the elevation zones. It should be noted that the increase of precipitation amounts with altitude does not continue indefinitely but stops at a certain altitude, especially in very high elevation mountain ranges.

A critical temperature (see Section 5.3.4) is used to decide whether a precipitation event will be treated as rain ($T \geq T_{CRIT}$) or as new snow ($T < T_{CRIT}$). When the precipitation event is determined to be snow, its delayed effect on runoff is treated differently depending on whether it falls over the snow-covered or snow-free portion of the basin. The new snow that falls over the previously snow-covered area is assumed to become part of the seasonal snowpack and its effect is included in the normal depletion curve of the snow coverage. The new snow falling over the snow-free area is considered as precipitation to be added to snowmelt, with this effect delayed until the next day warm enough to produce melting.

This precipitation is stored by SRM and then melted as soon as a sufficient number of degree-days has occurred. The following example in Table 2 illustrates a case where 2.20 cm water equivalent of snow fell on day n and then was melted on the three successive days. This procedure is slightly changed in the winter as it will be explained later.

In this example, S is decreasing on consecutive days because it is interpolated previously from the snow-cover depletion curve. In reality it should remain constant as long as the seasonal snowpack is covered with new snow; however, the model currently uses the incremental decrease of S shown in Table 2.

Table 2 Calculation of the melt of new snow on a snow-free area (P_n = 2.20 cm; T_{CRIT} = + 1.0°C).

Day	a [cm·°C^{-1}·d^{-1}]	T [°C·d]	S	P [cm]	Melted Depth a·T [cm]	P Stored [cm]	P contributing to Runoff a·T·(1-S) [cm]
n	0.45	0	0.72	2.20	0	2.20	0
n+1	0.45	0.11	0.70	0	0.05	2.15	0.02
n+2	0.45	2.70	0.68	0	1.22	0.93	0.39
n+3	0.45	3.70	0.66	0	0.93	0	0.32

Sharp peaks of discharge are typical for rainfall runoff as opposed to the relatively regular daily fluctuations of the snowmelt runoff. SRM has been adapted to better simulate these rainfall peaks whenever the average daily rainfall calculated over the whole basin equals or exceeds 6 cm. This threshold can be changed by the user according to the characteristics of the selected basin. The procedure is described in the Section 5.3.6.1 in connection with the recession coefficient. In spite of these precautions, rainfall runoff peaks may cause problems because local rainstorms may be missed if the network of precipitation stations is not dense enough. Also, the timing of rainfalls within the 24 hour period is frequently unknown. Actually, this period (for P_n) usually lasts from 0800 hrs on the day n to 0800 hrs on the day n+1 and is published as precipitation on the day n. In some cases, however, the same precipitation amount is ascribed to the day n+1 on which the measurement period ended. In such case precipitation data must be shifted backwards by one day before input to SRM.

5.2.3 Snow covered area, S

It is a typical feature of mountain basins that the areal extent of the seasonal snow cover gradually decreases during the snowmelt season. Depletion curves of the snow coverage can be interpolated from periodical snow cover mapping so that the daily values can be read off as an important input variable to SRM. The snow cover can be mapped by terrestrial observations (in very small basins), by aircraft photography (especially in a flood emergency) and, most efficiently, by satellites. The minimum area which can be mapped with an adequate accuracy depends on the spatial resolution of the remote sensor. Examples are listed in Table 3.

Figure 4 shows the snow cover in the alpine basin Felsberg mapped from Landsat 5-MSS data (Baumgartner, 1987). When the time interval between the subsequent satellite images becomes too long, e.g. due to visibility obscured by clouds, the depletion curves derived from the measured points may be distorted by occasional summer snowfalls.

Table 3 Some of the possibilities of remote sensing for snow cover mapping.

Platform Sensor	Spectral Bands	Spatial resolution	Minimum area size	Repeat period
Aircraft Orthophoto	Visible/NIR	2 m	1 km^2	flexible
IRS				
Pan	Green to NIR	5.8 m	2 km^2	24 days
LISS-II	1 – 3 Green to NIR	23 m	2.5 – 5 km^2	24 days
WiFS	1 Red / 2 NIR	188 m	10 – 20 km^2	5 days
SPOT				
HRVIR	1 – 3 Green to NIR	2.5 – 20 m	1 – 3 km^2	26 days
Landsat				
MSS	1 – 4 Green to NIR	80 m	10 – 20 km^2	16 – 18 days
TM	1 – 4 Green to NIR	30 m	2.5 – 5 km^2	16 – 18 days
ETM-Pan*	Visible to NIR	15 m	2 – 3 km^2	16 – 18 days
Terra/Aqua				
ASTER	1 – 3 Visible to NIR	15 m	2 – 3 km^2	16 days **
MODIS	1 Red / 2 NIR	250 m	20 – 50 km^2	1 day
	3 – 8 Blue to MIR	500 m	50 – 100 km^2	1 day
NOAA				
AVHRR	1 Red / 2 NIR	1.1 km	10 – 500 km^2	12 hr
Meteosat				
SEVIRI	1 – 3 Red to NIR	3 km	500 – 1000 km^2	30 min
	12 Visible	1 km	10 – 500 km^2	30 min

Acronyms:

ASTER = Advanced Spaceborne Thermal Emission and Reflection Radiometer • AVHRR = Advanced Very High Resolution Radiometer • HRVIR = High Resolution Visible and Near Infrared • IRS = Indian Remote Sensing • LISS = Linear Imaging Self-scanning Sensor • MIR = Middle Infrared • MODIS = Moderate Resolution Imaging Spectroradiometer • MSS = Multi-Spectral Scanner • NIR = Near Infrared • Pan = Panchromatic • SEVIRI = Spinning Enhanced Visible and Infrared Imager • SPOT = Satellite Pour l'Observation de La Terre • TM = Thematic Mapper • WiFS = Wide Field Sensor • ETM-Pan = Enhanced Thematic Mapper - Panchromatic

(*) Landsat 6 and 7 only   (**) Depends on availability
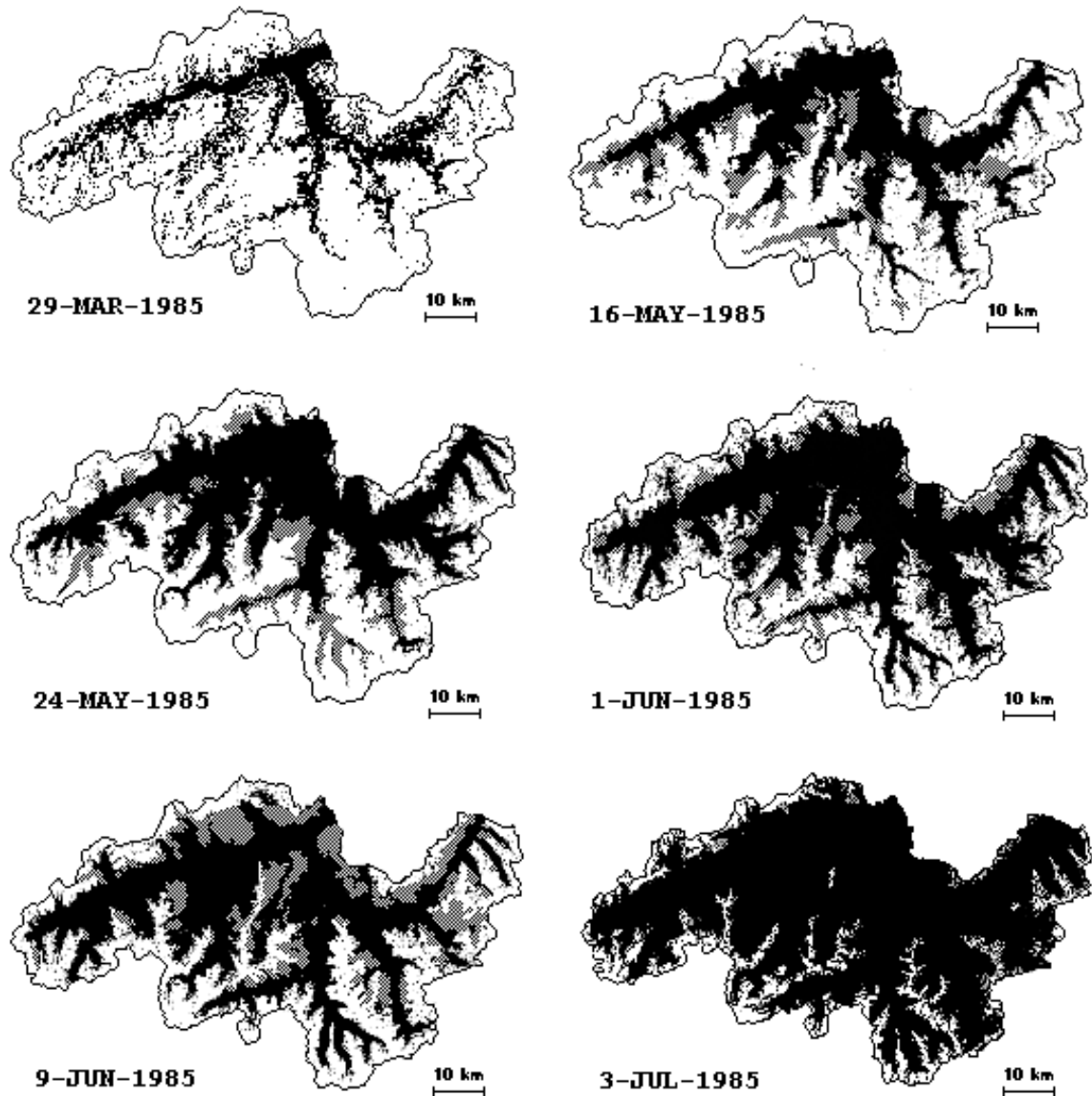
Fig. 4 Sequence of snow cover maps from Landsat 5-MSS, Upper Rhine River at Felsberg, 3250 km^2, 560-3614 m a.s.l. (Baumgartner, 1987). Black is snow free area, gray is cloud covered area and white is snow covered area.
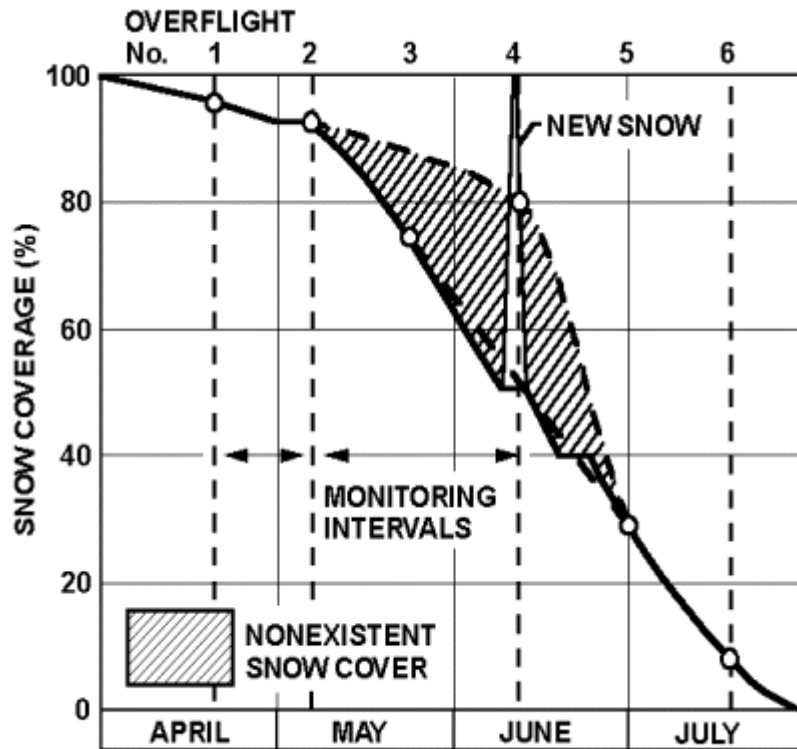
Fig. 5 Example of a possible distortion of a depletion curve due to a temporary increase in the snow coverage by a summer snowfall and to missing Landsat data from the preceding overflight (Hall & Martinec, 1985).
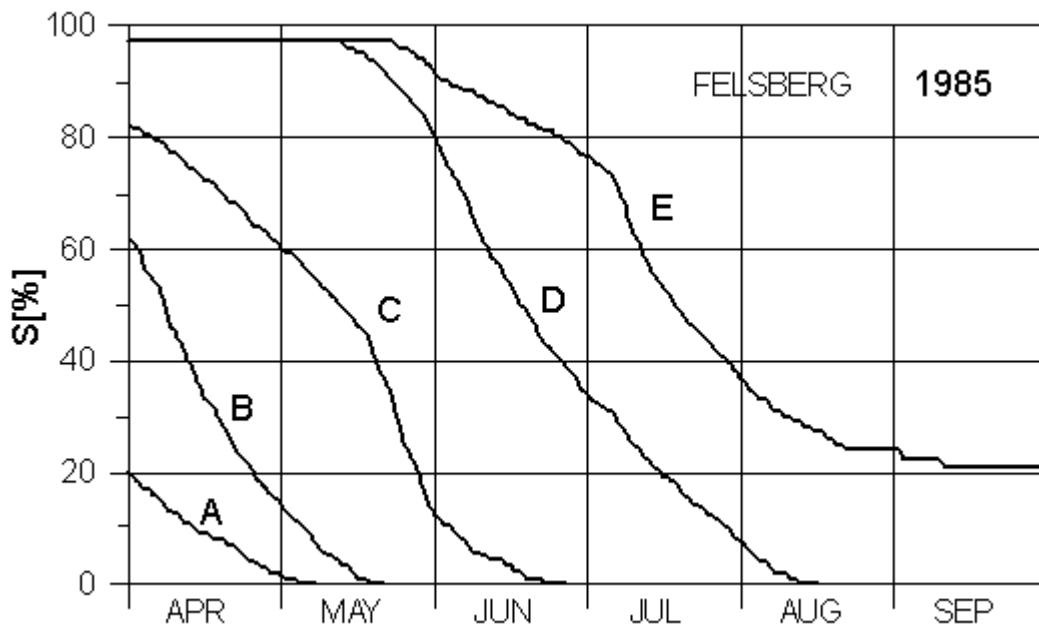
Fig. 6 Depletion curves of the snow coverage for 5 elevation zones of the basin Felsberg, derived from the Landsat imagery shown in Figure 4. A: 560 - 1100 m a.s.l., B: 1100 - 1600 m a.s.l., C: 1600 - 2100 m a.s.l., D: 2100 - 2600 m a.s.l., E: 2600-3600 m a.s.l. (Baumgartner, 1987).

As a result, excessive meltwater production would have been calculated. To avoid such errors, satellite images showing the short-lived snow cover from the summer snowfalls must be disregarded when deriving the depletion curves. In order to identify the new snow events, coincident precipitation and temperature data should be consulted. The transitory new snow is accounted for as stored precipitation eventually contributing to runoff as explained in the Section 5.2.2.

As an example, Figure 6 shows depletion curves of the snow coverage derived for five elevation zones of the alpine basin Felsberg from the Landsat imagery (Baumgartner, 1987, Baumgartner & Rango, 1995). Together with temperature and precipitation data, such depletion curves enable SRM to simulate runoff in a past year. In September, the depletion curve in zone E refers to the glacier which prevents it from decreasing any further.

For real-time runoff forecasts; however, it is necessary to know the snow covered area within days after a satellite overflight and also to extrapolate the depletion curves of the snow coverage to the future weeks. This procedure is explained in the Section 7.

5.3 Parameters

-   RUNOFF COEFF. SNOW   -   CRITICAL TEMPERATURE
-   RUNOFF COEFF. RAIN   -   RAINFALL CONTRIBUTING AREA
-   DEGREE DAY FACTOR   -   RECESSION COEFF.
-   TEMPERATURE LAPSE RATE   -   TIME LAG

The SRM parameters are not calibrated or optimized by historical data. They can be either derived from measurement or estimated by hydrological judgment taking into account the basin characteristics, physical laws and theoretical relations or empirical regression relations. Occasional subsequent adjustments should never exceed the range of physically and hydrologically acceptable values.

5.3.1 Runoff coefficient, c

The runoff coefficient accounts for the losses, which are the difference between the available water volume (snowmelt + rainfall) and the outflow from the basin. On a long term basis, it should correspond to the ratio of the measured precipitation to the measured runoff. In fact, comparison of historical precipitation and runoff ratios provide a starting point for the runoff coefficient values. However, these ratios are not always easily obtained in view of the precipitation gauge catch deficit which particularly affects snowfall and of inadequate precipitation data from mountain regions. At the start of the snowmelt season, losses are usually very small because they are limited to evaporation from the snow surface, especially at high elevations. In the next stage, when some soil becomes exposed and vegetation grows, more losses must be expected due to evapotranspiration and interception. Towards the end of the snowmelt season, direct channel flow from the remaining snowfields and glaciers may prevail in some basins which leads to a decrease of losses and to an increase of the runoff coefficient. In addition, c is usually different for snowmelt and for rainfall. The computer program accepts separate values for snow, c_S, and rain, c_R, and allows for half-monthly (and, if required, daily) changes of values in each elevation zone. Examples of seasonal trends of runoff coefficients are given in Figures 7 and 8, with the half-monthly values connected by straight lines. The runoff coefficients can even reach lower values in certain semiarid basins; particularly in the lowest elevation zone of such basins. Of the SRM parameters, the runoff coefficient appears to be the primary candidate for adjustment if a runoff simulation is not at once successful.

5.3.2 Degree-day factor, *a*

The degree-day factor *a* [cm °C^{-1} d^{-1}] converts the number of degree-days T [°C·d] into the daily snowmelt depth M [cm]:

$$M = a \cdot T \tag{5}$$

Degree-day ratios can be evaluated by comparing degree-day values with the daily decrease of the snow water equivalent which is measured by radioactive snow gauge, snow pillow or a snow lysimeter. Such measurements (Martinec, 1960) have shown a considerable variability of degree-day ratios from day to day. This is understandable because the degree-day method does not take specifically into account other components of the energy balance, notably the solar radiation, wind speed and the latent heat of condensation.

If averaged for 3-5 days, however, the degree-day factor is more consistent and can represent melting conditions. The effect of daily fluctuations of the degree day values on the runoff from a basin as computed by SRM is greatly reduced because the daily meltwater input is superimposed on the more constant recession flow (Equation (1)).

The degree-day method requires several precautions:

(1)   The degree-day factor is not a constant. It changes according to the changing snow properties during the snowmelt season.

(2)   If point values are applied to areal computations, the degree-day values must be determined for the hypsometric mean elevation of the snow cover in question and not, for example, for the altitude of the snow line.

(3)   If the snow cover is scattered, a correctly evaluated degree-day factor will produce less meltwater than if a 100 percent snow cover were assumed. A meltwater difference that arises from erroneous snow cover information should not be compensated for by "optimizing" the degree-day factor. Instead, the correct areal extent of the snow cover should be determined and used.

(4)   In large area extrapolations, point measurements should be weighted depending on how well a specific station represents the hydrological characteristics of a given zone (Shafer *et al.*, 1981).

In the absence of detailed data, the degree-day factor can be obtained from an empirical relation (Martinec, 1960):

$$a = 1.1 \cdot \frac{\rho_s}{\rho_w} \tag{6}$$

where a = the degree-day factor [cm °C^{-1}d^{-1}]
ρ_s = density of snow
ρ_w = density of water

When the snow density increases, the albedo decreases, and the liquid water content in snow increases. Thus the snow density is an index of the changing properties which favor the snowmelt.
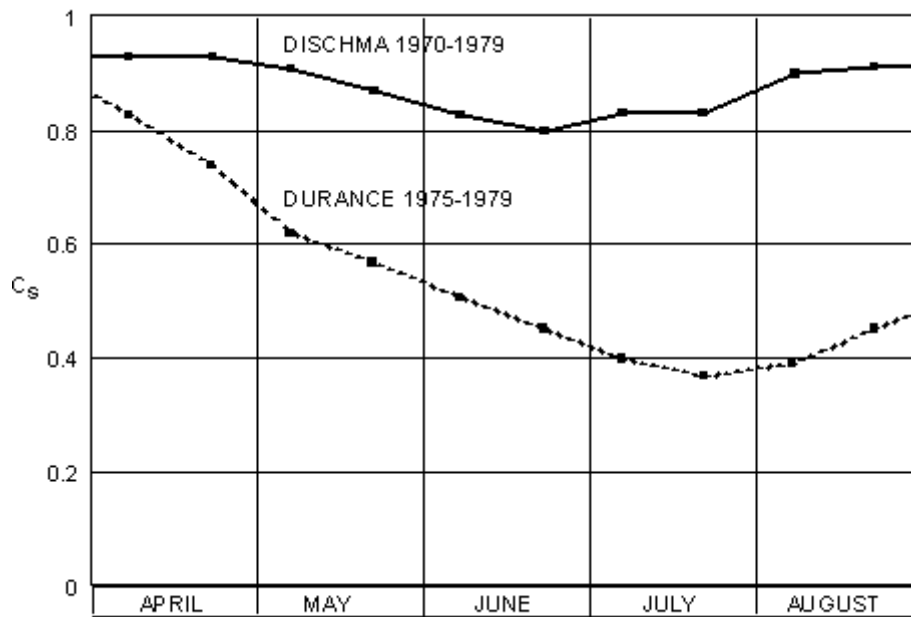
Fig. 7 Average runoff coefficient for snow (c_S) for the alpine basins Dischma (43.3 km^2, 1668-3146 m a.s.l.) and Durance (2170 km^2, 786-4105 m a.s.l.) (Martinec & Rango, 1986).
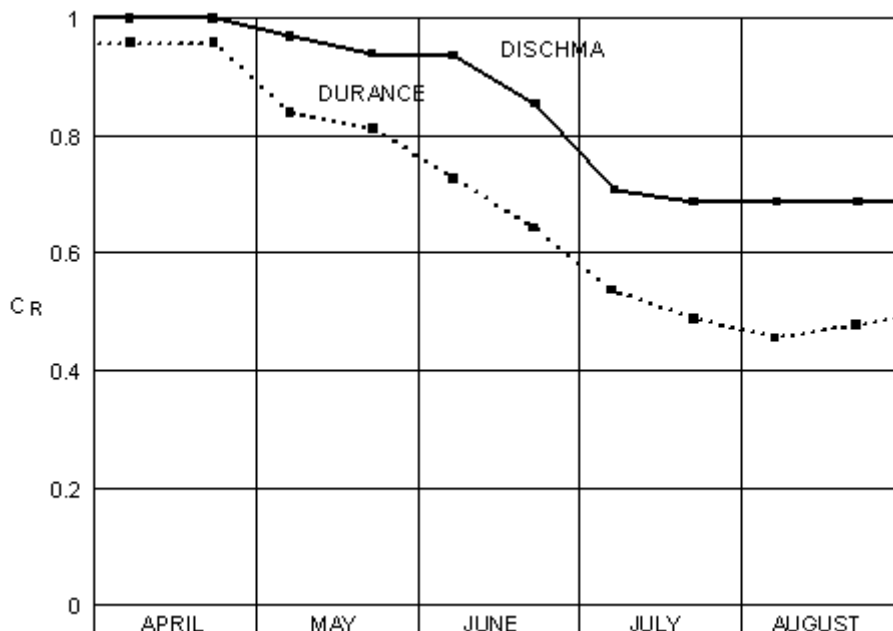
Fig. 8 Average runoff coefficient for rainfall (c_R) for the alpine basins Dischma (43.3 km^2, 1668-3146 m a.s.l.) and Durance (2170 km^2, 786-4105 m a.s.l.) (Martinec & Rango, 1986).

Figure 9 illustrates the seasonal trend of the degree-day factor in the Alps and in the Rocky Mountains. Because the geographic latitude of a basin influences the solar radiation, it may be advisable to adjust the degree-day factors accordingly. In glacierized basins, the degree-day factor usually exceeds 0.6 cm $C^{-1}d^{-1}$ towards the end of the summer when ice becomes exposed (Kotlyakov & Krenke, 1982). The computer program accepts different degree-day factors for up to 16 elevation zones which are usually changed twice a month (although daily changes are possible).

Sometimes the occurrence of a large, late season snowfall will produce depressed *a*-values for several days due to the new low-density snow. The *a*-values in the model can be manually modified and inserted to reflect these unusual snowmelt conditions.

As is evident from Equation (1), the degree-day method could be readily replaced by a more refined computation of snowmelt without changing the structure of SRM. Such refinement appeared to be imperative in a study of outflow from a snow lysimeter (Martinec, 1989) but is not considered to be expedient for hydrological basins until the necessary additional variables and their forecasts become available. The degree-day method is explained in more detail in a separate publication (Rango & Martinec, 1995).

5.3.3 Temperature lapse rate, γ

If temperature stations at different altitudes are available, the lapse rate can be predetermined from historical data. Otherwise it must be evaluated by analogy from other basins or with regard to climatic conditions. In SRM simulations, a lapse rate of 0.65°C per 100 m was usually employed. Slightly higher, seasonally changing values appeared to be adequate in the Rocky Mountains.
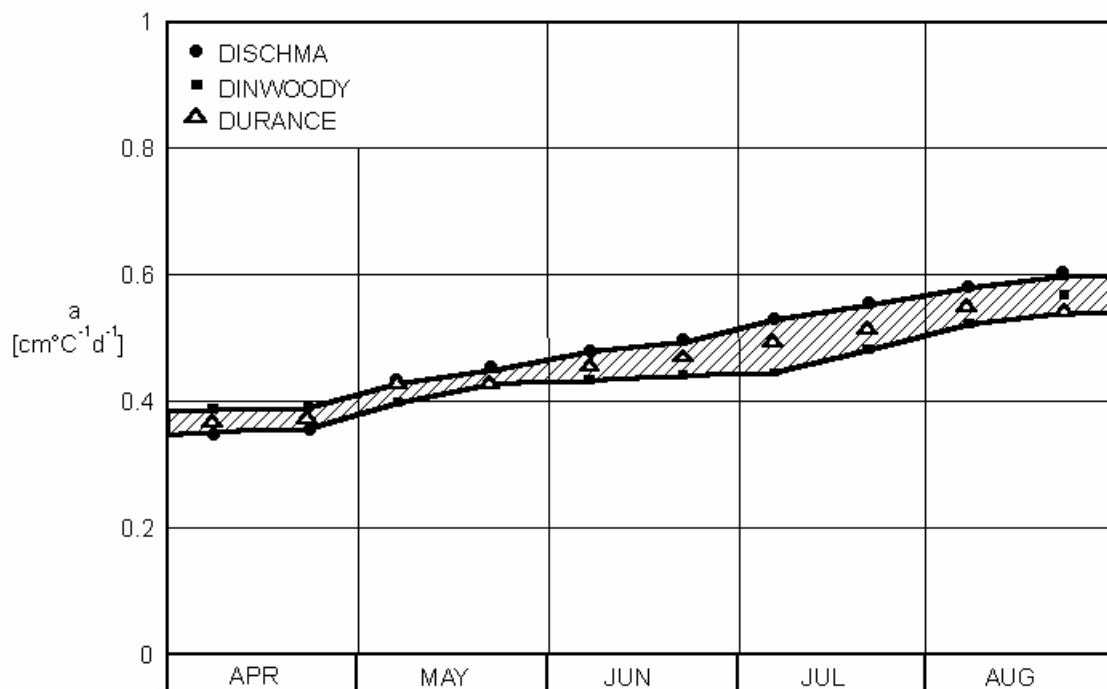
Fig. 9 Average degree-day ratio (*a*) used in runoff simulations by the SRM model in the basins Dischma (10 years), Durance (5 years) and Dinwoody (228 km^2; 1981-4202 m a.s.l., Wyoming, 2 years) (Martinec & Rango, 1986).

The computer program accepts either a single or a basin wide lapse rate (option 0) or different rates for each zone (option 1). Seasonal variations can also be accommodated by inputting predetermined lapse rates every 15 days, and the lapse rate can be changed manually on selected days if a special meteorological situation (for example, a temperature inversion) requires a different value:

Temperature lapse rate Program options:
      0 = basin wide
      1 = by zone

If the temperature station is situated near the mean elevation of the basin, possible errors in the lapse rate are to some extent canceled out because the extrapolation of temperature takes place upwards as well as downwards. If, on the other hand, the temperature station is at a low altitude, SRM becomes sensitive to the lapse rate. For some basins in Wyoming, for example, the closest temperature station was more than 100 km away and 2000 m lower than the highest snow-covered parts of the basins. In such a case, an error in the lapse rate of only 0.05°C per 100 m causes a deviation of 1 degree-day from the correct degree-day value which corresponds to an error of about 0.5 cm of the computed daily meltwater depth late in the snowmelt season.

Such situations sometimes necessitate an adjustment of the originally selected lapse rate taking into account the course of the depletion curves of snow coverage. If high temperatures result from extrapolation by a certain lapse rate but no change in the snow areal extent is observed, then probably no appreciable snowmelt is taking place at this altitude. The high temperatures result from a false lapse rate which must be increased or decreased, depending on whether the temperature station is lower or higher than the mean zone elevation.

5.3.4 Critical temperature, T_{CRIT}

The critical temperature determines whether the measured or forecasted precipitation is rain or snow. Models which simulate the build-up of the snow cover, first in order to simulate the runoff, depend heavily on this parameter not only in the ablation period; but particularly, in the accumulation period. SRM needs the critical temperature only in order to decide whether precipitation immediately contributes to runoff (rain), or, if $T < T_{CRIT}$, whether snowfall took place. In this case, SRM automatically keeps the newly fallen snow in storage until it is melted on subsequent warm days, as explained in the Section 5.2.2.

When SRM was applied in the alpine basin Dischma, T_{CRIT} started at + 3°C in April at the beginning of snowmelt and diminished to + 0.75°C in July. This seasonal trend with a narrower range appears to be applicable in other basins. At certain times, SRM may not take notice of a sharp rainfall runoff peak because the corresponding precipitation is determined to be snow, the extrapolated temperature being just slightly below the critical temperature. In such cases the assignment of critical temperature and the temperature lapse rate values should be reviewed and logical adjustments made in order to change snow to rain. It is of course difficult to distinguish accurately between rain and snow because the temperature used is the daily mean while precipitation may occur at any time, day or night, i.e., in the warmer or colder portion of the daily temperature cycle.

As a possible refinement, formulas have been proposed (Higuchi *et al.*, 1982) to determine the proportion of rain and snow in mixed precipitation conditions.

5.3.5 Rainfall contributing area, RCA

When precipitation is determined to be rain, it can be treated in two ways. In the initial situation (option 0), it is assumed that rain falling on the snowpack early in the snowmelt season is retained by the snow

which is usually dry and deep. Rainfall runoff is added to snowmelt runoff only from the snow-free area, that is to say the rainfall depth is reduced by the ratio snow-free area/zone area. At some later stage, the snow cover becomes ripe (the user must decide on which date) and the computer program should be switched to option 1. Now, if rain falls on this snow cover, it is assumed that the same amount of water is released from the snowpack so that rain from the entire zone area is added to snowmelt. The melting effect of rain is neglected because the additional heat supplied by the liquid precipitation is considered to be small (Wilson, 1941).

5.3.6 Recession coefficient, k

As is evident from Equation (1), the recession coefficient is an important feature of SRM since (1-k) is the proportion of the daily meltwater production which immediately appears in the runoff. Analysis of historical discharge data is usually a good way to determine k. Figure 10 shows such an evaluation for the alpine basin Dischma (43.3 km^2, 1668-3146 m a.s.l.). Values of Q_n and Q_{n+1} are plotted against each other and the lower envelope line of all points is considered to indicate the k-values. Based on the relation $k = Q_{n+1}/ Q_n$, it can be derived that for example $k_1 = 0.677$ for $Q_n = 14$ m^3s^{-1} and $k_2 = 0.85$ for $Q_n = 1$ m^3s^{-1}. This means that k is not constant, but increases with the decreasing Q according to the equation:

$$k_{n+1} = x \cdot Q_n^{-y} \tag{7}$$

where the constants x and y must be determined for a given basin by solving the equations:

$$k_1 = x \cdot Q_1^{-y}$$
$$k_2 = x \cdot Q_2^{-y}$$
$$\log k_1 = \log x - y \log Q_1 \tag{8}$$
$$\log k_2 = \log x - y \log Q_2 \tag{9}$$

In the given example,

$$\log 0.677 = \log x - y \log 14$$
$$\log 0.85 = \log x - y \log 1$$

$$x = 0.85$$
$$y = 0.086$$

As a formal change from the SRM User's Manual of 1983 (Martinec *et al.*, 1983), a negative sign appears in the exponent of Equation (7) so that the numerical values of x and y are positive.
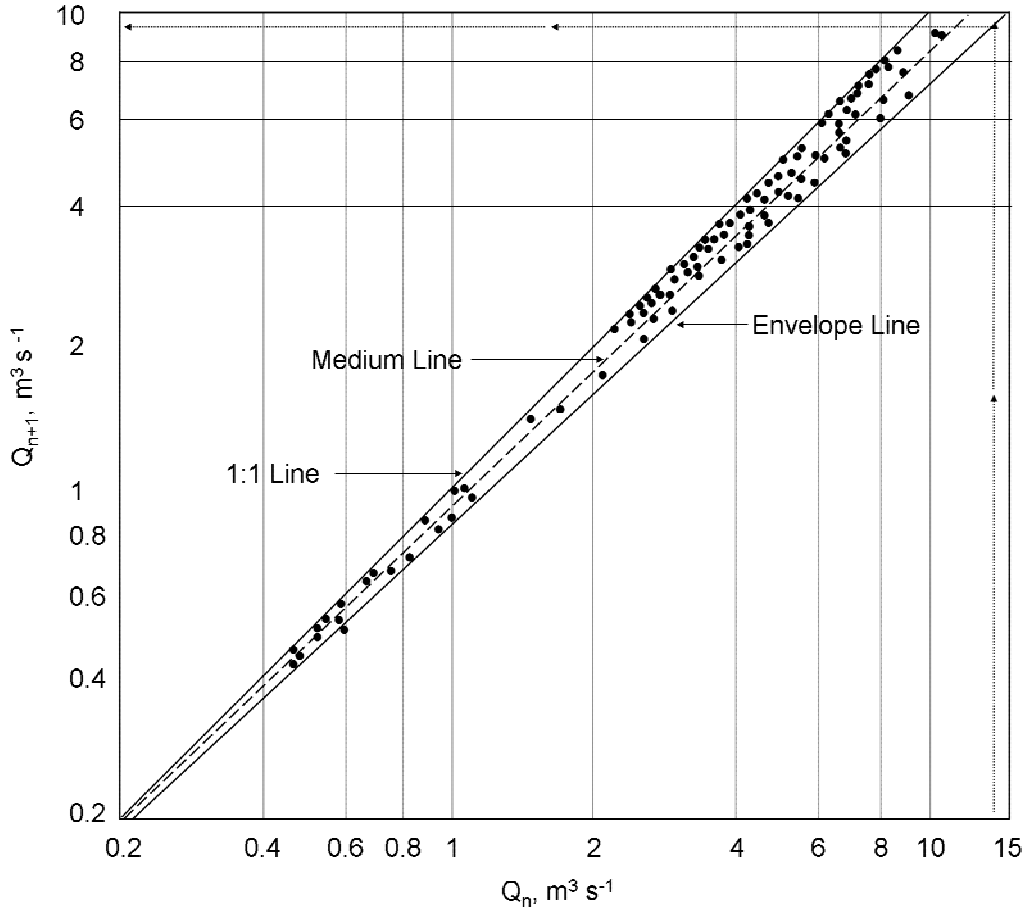
Fig. 10 Recession flow plot Q_n vs Q_{n+1} for the Dischma basin in Switzerland. Either the solid envelope line or the dashed medium line is used to determine k-values for computing the constants x and y in Equation (7) (Martinec & Rango, 1986).

The variability of k according to Equation (7) was also confirmed in other basins. This means that the recession does not exactly follow the usual equation:

$$Q_n = Q_0 \cdot k^n \tag{10}$$

where Q_0 = the initial discharge

$\qquad$ Q_n = the discharge after n days

but the following equation (Jaccard, 1982)

$$Q_n \;=\; x^{\frac{1}{y}} \left(\frac{Q_0}{x^{\frac{1}{y}}} \right)^{(1-y)^n} \tag{11}$$

where x and y are the constants of Equation (7).

The envelope line in Figure 10 and the resulting values of x and y must be determined for each basin. For ungauged basins and when historical discharge data are insufficient, x and y can be derived indirectly from the size of the basin as follows:

$$k_{Nn} = \left[x_M \left(\frac{\overline{Q}_M}{\overline{Q}_N} \cdot Q_{Nn-1} \right)^{-y_M} \right]^{\sqrt[4]{A_M/A_N}} \qquad (12)$$

where: x_M, y_M are the known constants for the basin M; $\overline{Q}_M, \overline{Q}_N$ are average discharge values from the basin M and the new basin N; and A_M, A_N are the areas of the respective basins. Equation (12) indicates that recession coefficients are generally higher in large basins than in small basins.

If the increase in k with size appears to be too large, the exponent may be replaced with $\sqrt[8]{A_M/A_N}$. Even if the envelope line in Figure 10 can be reliably derived in a basin, it is possible that the resulting k-values may be too low to represent average conditions during the snowmelt season, especially in large basins. In such cases the SRM model will react too quickly to any change of the daily input. The simulated peaks would be too high and the simulated recession too fast. A quick improvement is possible by deriving a new x and y, not from the envelope line, but from an intermediate or medium line between the envelope and the 1:1 line. This modification may especially be needed if the runoff simulation is extended to the whole year. Recession coefficients which may be right for the snowmelt period are usually too low for the winter months so that the simulated flows drop below the measured minimum values.
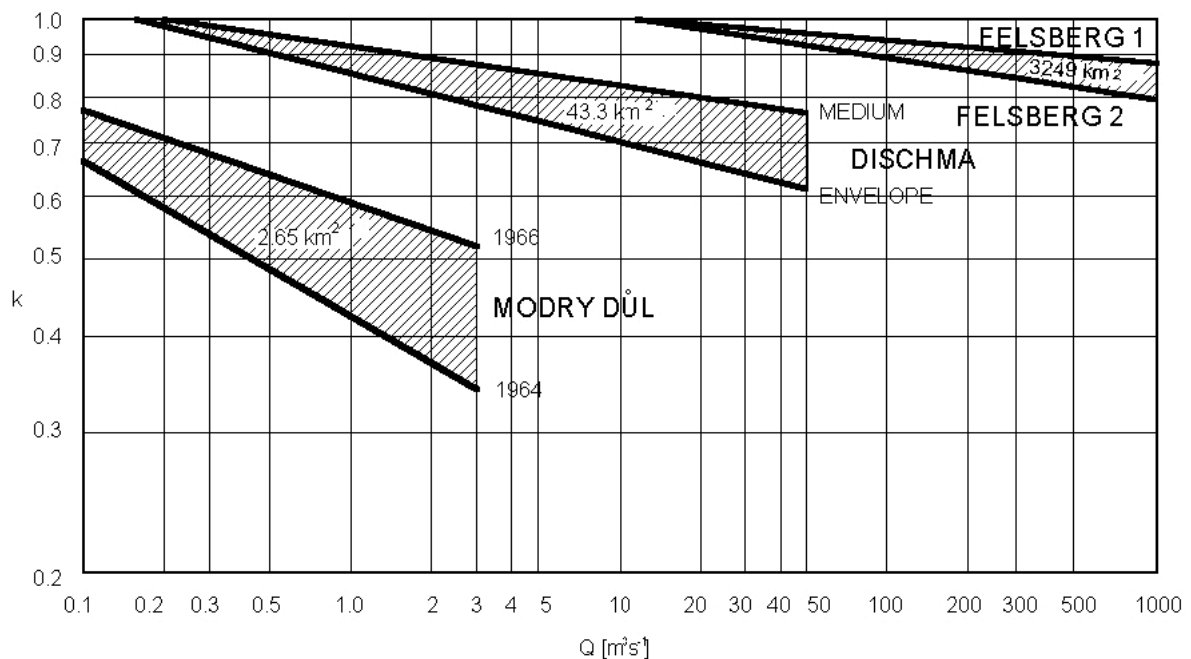
Fig. 11 Range of recession coefficients, k, related to discharge Q resulting from various evaluations: In Dischma, the range results from using either the envelope line or the medium line in Figure 10. In Modry Dul, the relation varies in different years. In Felsberg, the relations (1) and (2) are derived from the size of the basin by two alternative formulas (Martinec & Rango, 1986).

In very small basins, noticeable differences in the recession flow conditions and the k-values may occur from year to year. Figure 11 illustrates the range of k-values for varying basin size and for the mentioned

different years (Martinec, 1970). For a larger alpine basin, the limits refer to the envelope line and to the medium line in Figure 10. For the largest basin, the higher limit (1) of the indicated range was derived by substituting the constants x = 0.085, y = 0.086 derived for the Dischma basin into Equation (12). The lower limit (2) was obtained by replacing $\sqrt[4]{A_M / A_N}$ in Equation (12) with $\sqrt[8]{A_M / A_N}$.

Figure 11 shows that k can theoretically exceed 1 for very small discharges in large basins. This does not really happen because such small discharges do not occur there. Such a situation could be produced, however, by the user inadvertently taking over the x and y values derived in a large basin and using them for a small basin without modification. In this case, if the daily snowmelt input exceeds the previous day's runoff, SRM computes a runoff decrease instead of increase. In order to avoid this error, the computer program prevents k from exceeding 0.99. However, it is advisable to avoid approaching this limiting situation by checking the x and y values with regard to the lowest flow to be expected. Recalling Equation (11), it follows for n = ∞, because y > 0 and (1-y) < 1:

$$Q_\infty \ = \ x^{\frac{1}{y}} \left(\frac{Q_0}{x^{\frac{1}{y}}} \right)^{(<1)^\infty} \ = \ x^{\frac{1}{y}} \tag{13}$$

Therefore the values x and y should fulfill the condition

$$Q_{Min} \ > \ x^{\frac{1}{y}} \tag{14}$$

where Q_{Min} = the minimum discharge in the given basin.

5.3.6.1 Adjustment of the recession coefficient for heavy rainfalls

The formula (7) for computing the recession coefficient reflects the usual conditions characterizing the snowmelt runoff in the given basin. When a heavy rainfall occurs, the input is concentrated in a short time interval creating an abrupt rise and subsequent decline of the hydrograph. In order to simulate such events, the computer program automatically adjusts the recession coefficient whenever the daily rainfall averaged over the whole basin equals or exceeds 6 cm:

$$\text{If P (rain)}_n \geq 6 \text{ cm} \ \longrightarrow \ k_{n+1} = x \, (4 \, Q_n)^{-y}$$
$$k_{n+2} = x \, (4 \, Q_{n+1})^{-y}$$
$$k_{n+3} = x \, (4 \, Q_{n+2})^{-y}$$
$$k_{n+4} = x \, (4 \, Q_{n+3})^{-y}$$
$$k_{n+5} = x \, (4 \, Q_{n+4})^{-y} \tag{15}$$

after which it returns to the normal formula (7). In this way, k gets lower so that the basin response to input becomes faster. If the precipitation is recognized by T_{CRIT} as snow and not rain, the mechanism will not be activated. If there is partly rainfall and partly snowfall in the respective elevation zones according

to T_{CRIT}, the rainfall value is determined as a total of rainfall volumes from the zones with rainfall, divided by the entire basin area:

$$\overline{P}\,(rain) = \frac{\sum P\,(rain) \cdot A\,(rain)}{A} \qquad (16)$$

(Note that in the following examples, the type and amount of precipitation varies with zone from example to example.)

Example (a):

Precipitation input option 0; P = 10 cm
Rainfall contributing area option 1

Zone A: 100 km², P (rain)   = 10 cm
Zone B: 100 km², P (snow) = 10 cm
Zone C: 100 km², P (snow) = 10 cm

$$\overline{P}\,(rain) = \frac{10\ cm \cdot 100\ km^2}{300\ km^2} = 3.3\ cm \rightarrow k = x\,Q^{-y}$$

Example (b):

Precipitation input option 0; P = 10 cm
Rainfall contribution area option 1

Zone A: 100 km², P (rain)   = 10 cm
Zone B: 100 km², P (rain)   = 10 cm
Zone C: 100 km², P (snow) = 10 cm

$$\overline{P}\,(rain) = \frac{10\ cm \cdot 200\ km^2}{300\ km^2} = 6.7\ cm \rightarrow k = x\,(4Q)^{-y}\ \text{on 5 consecutive days}$$

Example (c):

Precipitation input option 1; P_A = 7 cm, P_B = 10 cm, P_C = 13 cm
Rainfall contributing area option 1

Zone A: 100 km², P (rain)   = 7 cm
Zone B: 100 km², P (rain)   = 10 cm
Zone C: 100 km², P (snow) = 13 cm

$$\overline{P}\,(rain) = \frac{7\ cm \cdot 100\ km^2 + 10\ cm \cdot 100\ km^2}{300\ km^2} = 5.7\ cm \rightarrow k = x\,Q^{-y}$$

These examples refer to the rainfall contributing area option 1, that is to say rainfall contributes to runoff from snow-free as well as snow-covered parts of the basin. For rainfall contributing area option 0, with rain retained in the snowpack, the adjustment of the recession coefficient is less likely to be activated:

Example (d):

Precipitation input option 0; P = 10 cm
Rainfall contributing area option 0

Zone A: 100 km^2, P (rain)   = 10 cm, S_A = 0.4
Zone B: 100 km^2, P (rain)   = 10 cm, S_B = 0.6
Zone C: 100 km^2, P (snow)   = 10 cm, S_C = 0.8

$$\overline{P}\,(rain) \;=\; \frac{10\ cm \cdot (1 - S_A) \cdot 100\ km^2 \;+\; 10\ cm\ \cdot (1 - S_B) \cdot 100\ km^2}{300\ km^2} \;=\; 3.33\ cm \;\rightarrow\; k = x\,Q^{-y}$$

but it can still take place if a very heavy rain falls over the whole basin (Example e).

Example (e):

Precipitation input option 1, P_A = 14 cm, P_B = 16 cm, P_C = 18 cm
Rainfall contributing area option 0

Zone A: 100 km^2, P (rain) = 14 cm, S_A = 0.4
Zone B: 100 km^2, P (rain) = 16 cm, S_B = 0.6
Zone C: 100 km^2, P (rain) = 18 cm, S_C = 0.8

$$\overline{P}\,(rain) \;=\; \frac{14\ cm \cdot (1 - S_A) \cdot\ 100\ km^2 \;+\; 16\ cm \cdot (1 - S_B) \cdot 100\ km^2 \;+ 18\ cm \cdot (1 - S_C) \cdot 100\ km}{300\ km^2}$$

$$=\; 6.1\ cm \rightarrow\; k = x\,(4Q)^{-y} \text{ on 5 consecutive days}$$

The threshold value can be changed in order to activate the rainfall peak program for smaller rainfall amounts or to delay activation until higher rainfall amounts are reached. By putting the threshold to 0 cm, the program will be activated on each day with rainfall (in an earlier version of the computer program, the threshold 0 cm resulted in automatic switching to a threshold of 6 cm). With a 0 cm threshold, the recession coefficient will be continuously decreased, and SRM is likely to overestimate the runoff. By putting the threshold higher than the highest daily precipitation, Equation (15) is eliminated, and SRM will probably underestimate the sharp runoff peaks from heavy rainfall.

5.3.7 Time Lag, L

The characteristic daily fluctuations of snowmelt runoff enable the time lag to be determined directly from the hydrographs of the past years. If, for example, the discharge starts rising each day around noon, it lags behind the rise of temperature by about 6 hours. Consequently, temperatures measured on the nth day correspond to discharge between 1200 hrs on the nth day and 1200 hrs on the n+1 day. Discharge data, however, are normally published for midnight-to-midnight intervals and need adjustments in order to be compared with the simulated values. Conversely, the simulated values can be adjusted (Shafer *et al.,* 1981) to refer to the midnight-to-midnight periods. Figure 12 illustrates the procedure for different time lags. For L = 6 hours, 50 % of input computed for temperature and precipitation on the nth day (I_n) plus 50 % of I_{n+1} results in the n+1 day's runoff after being processed by the SRM computer program:

$$L = 6 \text{ h} \qquad 0.50 \cdot I_n + 0.50 \cdot I_{n+1} \qquad \rightarrow \quad Q_{n+1} \tag{17}$$

Similarly:

$$L = 12 \text{ h} \qquad 0.75 \cdot I_n + 0.25 \cdot I_{n+1} \qquad \rightarrow \quad Q_{n+1} \tag{18}$$

$$L = 18 \text{ h} \qquad I_n \qquad\qquad\qquad\qquad \rightarrow \quad Q_{n+1} \tag{19}$$

$$L = 24 \text{ h} \qquad 0.25 \cdot I_n + 0.75 \cdot I_{n+1} \qquad \rightarrow \quad Q_{n+2} \tag{20}$$

This procedure is preferable, at least in mountain basins smaller than 5000 km^2, to evaluations of L by calculating the velocity of overland flow and channel flow. It has been shown by environmental isotope tracer studies (Martinec, 1985) that overland flow is not a major part of the snowmelt runoff as previously believed. There is increasing evidence that a major part of meltwater infiltrates and quickly stimulates a corresponding outflow from the groundwater reservoir. With this runoff concept in mind, the seemingly oversimplified treatment of the time lag in the SRM model is better understood.
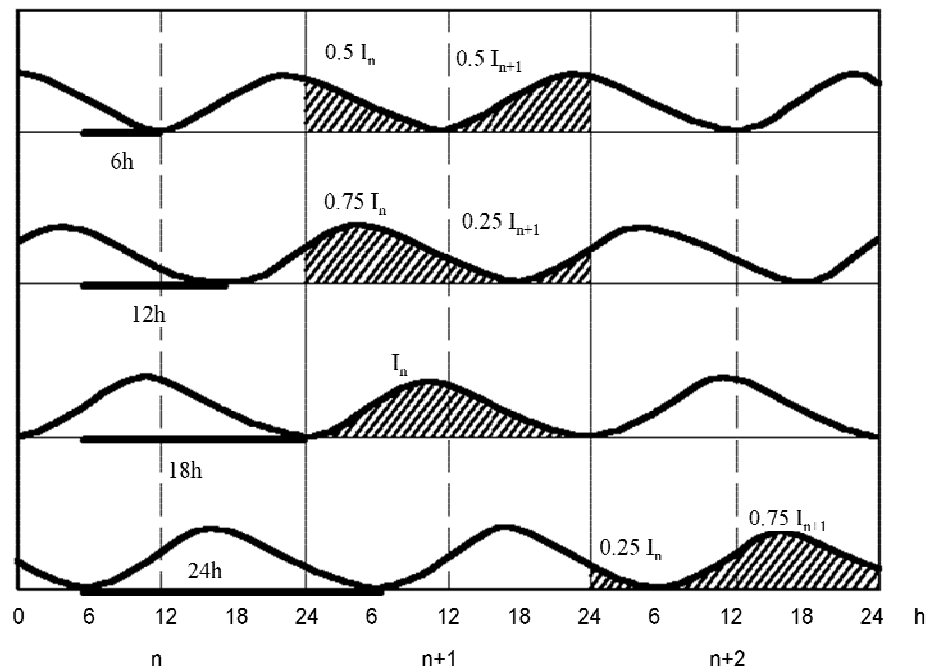
Fig. 12 Snowmelt hydrographs illustrating the conversion of computed runoff amounts for 24 hour periods to calendar day periods. The various time lags (bold lines) are taken into account by proportions of the daily inputs (Martinec & Rango, 1986).

If the hydrographs are not available, or if their shape is distorted by reservoir operations, the time lag can be estimated according to the basin size and by analogy with other comparable basins. Generally, the time lag in a basin increases as the snow line retreats.

In the WMO intercomparison test (WMO, 1986), most models calibrated the time lag. However, these results appear to be of little help to determine the proper values. Contradictory time lags have been calibrated by different models. However, if the time lags for all models participating in the WMO intercomparison test are averaged for each basin, the resulting values support the expected relation between L and basin size:

Basin W-3 (8.42 km^2)   :   3.0 h
Dischma (43.3 km^2)   :   7.2 h
Dunajec (680 km^2)   :   10.5 h
Durance (2170 km^2)   :   12.4 h

If there is some uncertainty, L (percentages in Equations (17)-(20)) can be adjusted in order to improve the synchronization of the simulated and measured peaks of average daily flows. It should be noted that a similar effect results from an adjustment of the recession coefficient.

6 ASSESSMENT OF THE MODEL ACCURACY

6.1 Accuracy criteria

The SRM computer program includes a graphical display of the computed hydrograph and of the measured runoff. A visual inspection shows at first glance whether the simulation is successful or not. SRM uses two well established accuracy criteria; namely, the coefficient of determination, R^2, and the volume difference, D_v for a more objective assessment of how well the simulation has been carried out.

The coefficient of determination is computed as follows:

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(Q_i - Q_i')^2}{\sum_{i=1}^{n}(Q_i - \overline{Q})^2} \tag{21}$$

where: Q_i is the measured daily discharge
Q_i' is the computed daily discharge
$\overline{Q}$ is the average measured discharge of the given year or snowmelt season
n is the number of daily discharge values

Equation (21) also corresponds to the Nash-Sutcliffe coefficient in which case $\overline{Q}$ is a long-term average measured discharge applied to the respective years or seasons. The deviation of the runoff volumes, D_v, is computed as follows:

$$D_v\ [\%] = \frac{V_R - V_R'}{V_R} \cdot 100 \tag{22}$$

where: V_R is the measured yearly or seasonal runoff volume
V_R' is the computed yearly or seasonal runoff volume

Numerical accuracy criteria are never perfect, as illustrated by Figure 13. From the visual judgment both simulations look good because the fundamental difference between two extreme years is well reproduced. However, $R^2 = 0.95$ in 1979 while it amounts only to 0.48 in 1977. In spite of this unfavorable value, the simulation (or forecast) in 1977 would certainly be useful for water management because it correctly reveals an extremely low runoff.

For the year 1977, with $\overline{Q}$ as a long-term average substituted into Equation (21) (Nash-Sutcliffe) instead of the average for the specific year, a much more favorable (but deceptive) value for R^2 (0.97) is realized. This value is high because the long-term $\overline{Q}$ is much higher than any Q in 1977. Consequently, the daily deviations of the simulated runoff become relatively insignificant although in absolute terms they are not negligible.

In addition to these criteria which are automatically computed and displayed after each model run, the coefficient of gain from daily means, DG, could be computed by the user as follows:

$$DG = 1 - \frac{\sum_{i=1}^{n}(Q_i - Q_i^{'})^2}{\sum_{i=1}^{n}(Q_i - \overline{Q}_i)^2} \qquad (23)$$

where: Q_i is the measured daily discharge

$Q_i^{'}$ is the computed daily discharge

$\overline{Q}_i$ is the average measured discharge from the past years for each day of the period

n is the number of days

Thus, R^2 compares the performance of a model with "no model" (average discharge) and DG with a "seasonal model" (long term average runoff pattern). Negative values signal that the model performed worse than "no model" or worse than the "seasonal model".
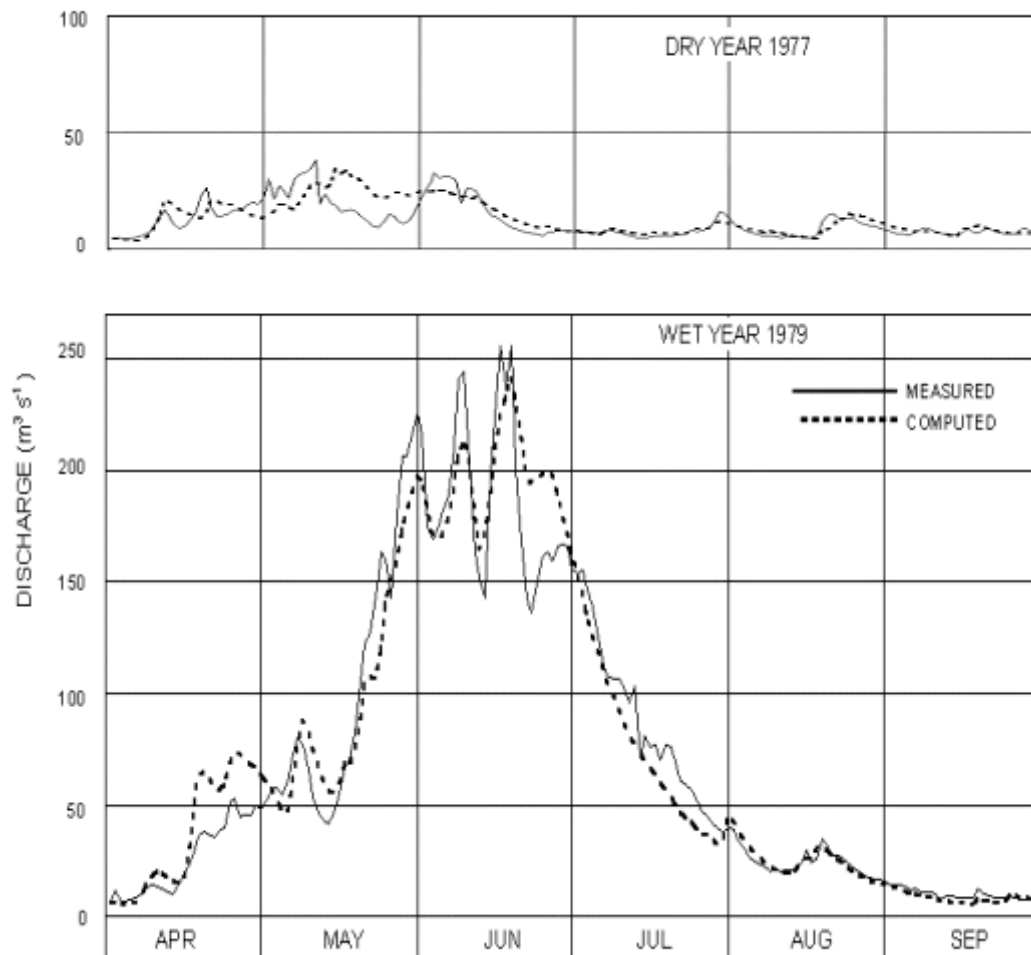
Fig. 13 Runoff simulations in the basin of the Rio Grande near Del Norte, Colorado (3419 km², 2432-4215 m a.s.l.) (Martinec & Rango, 1989).

6.1.1 Accuracy criteria in model tests

The World Meteorological Organization (WMO) organized an international comparison of snowmelt runoff models in which hundreds of model runs were performed in six selected test basins. Figure 14 shows a summary of all numerical values of R^2, DG and D_v published by WMO (1986). Each prism refers to a tested model. The length along the x-axis corresponds to the arithmetic mean of all $(1-R^2)$ values, length along the y-axis to the arithmetic mean of all (1-DG) values, and length along the z-axis to the arithmetic mean of all D_v values as achieved in the snowmelt seasons of 10 test years.

Inaccurate results mean low values of R^2 and DG, thus longer dimensions along the x and y axis. Volume deviations prolong the dimension along the z-axis. Consequently, the volume of a prism is proportional to an overall average inaccuracy of a model.

In Figure 15, the dimensions of the prisms are determined by the worst results of each model for R^2, DG and D_v, i.e., $(1-R^2)_{MAX}$, $(1-DG)_{MAX}$ and D_{vMAX}. All available data for the individual years and snowmelt seasons as listed in the WMO tables (WMO, 1986) are thus contained within each prism. The differences between models are larger than in Figure 14 which means that some calibrating models had difficulties in the years with unusual runoff conditions but improved their average results (Figure 14) by the more normal years.

A more detailed assessment of accuracy criteria with regard to the needs of the model user is published elsewhere (Martinec & Rango, 1989). Prisms in Figures 14 and 15 labeled "G" refer to SRM. Table 4 compares the numerical results of each model in the WMO project. In Table 4, columns 1-3 refer to Figure 14 and columns 4-6 refer to Figure 15.

Table 4 Results of model performances in the WMO project (10 years, snowmelt season)

Model	$\overline{D_v}$ %	$\overline{1-R^2}$	$\overline{1-DG}$	$D_{v\,max}$ %	$1-R^2_{min}$	$1-DG_{min}$
A **UBC**	8.13	0.269	0.370	-23.2	1.898	1.533
B **CEQ**	7.37	0.334	0.558	-24.7	1.371	2.337
C **ERM**	15.34	0.695	0.906	65.7	5.831	3.266
D **NAM**	10.85	0.308	0.487	51.0	1.750	2.803
E **TANK**	7.90	0.239	0.356	45.9	1.223	2.286
F **HBV**	6.82	0.286	0.501	23.2	0.955	4.489
G **SRM**	5.97	0.189	0.292	-27.9	0.391	0.786
H **SSARR**	7.30	0.294	0.510	25.4	0.756	1.447
I **PRMS**	10.58	0.367	0.570	24.2	0.898	2.516
J **NWS**	7.43	0.230	0.254	28.1	0.684	1.239
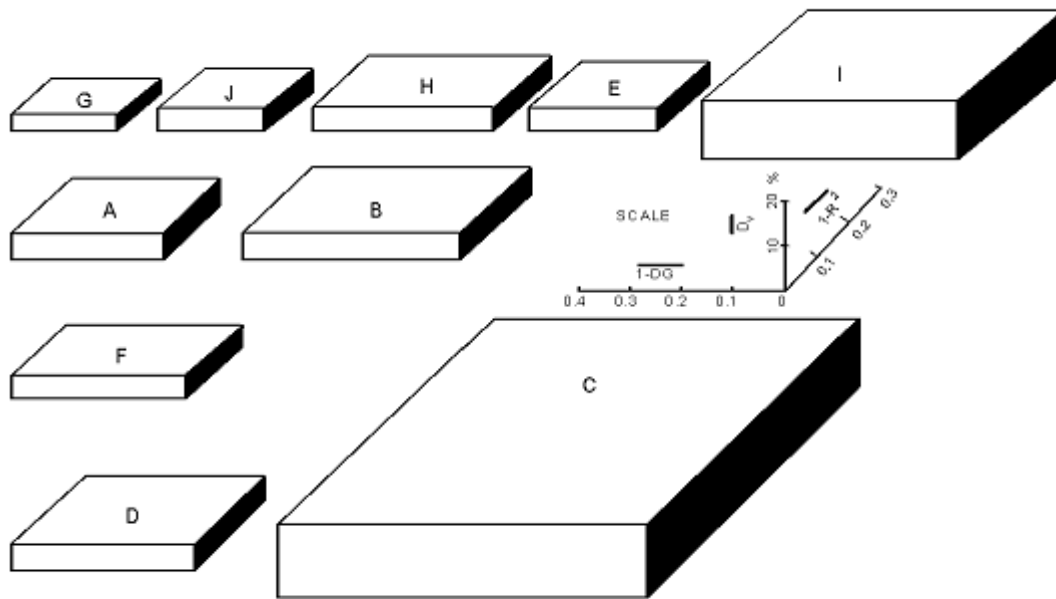
Fig. 14 Combined representation of model performance using three criteria: R^2, DG and D_v. The volumes of the prisms indicate the *average* inaccuracies of the tested models from all results for snowmelt seasons reported in the WMO project (Rango & Martinec, 1988).
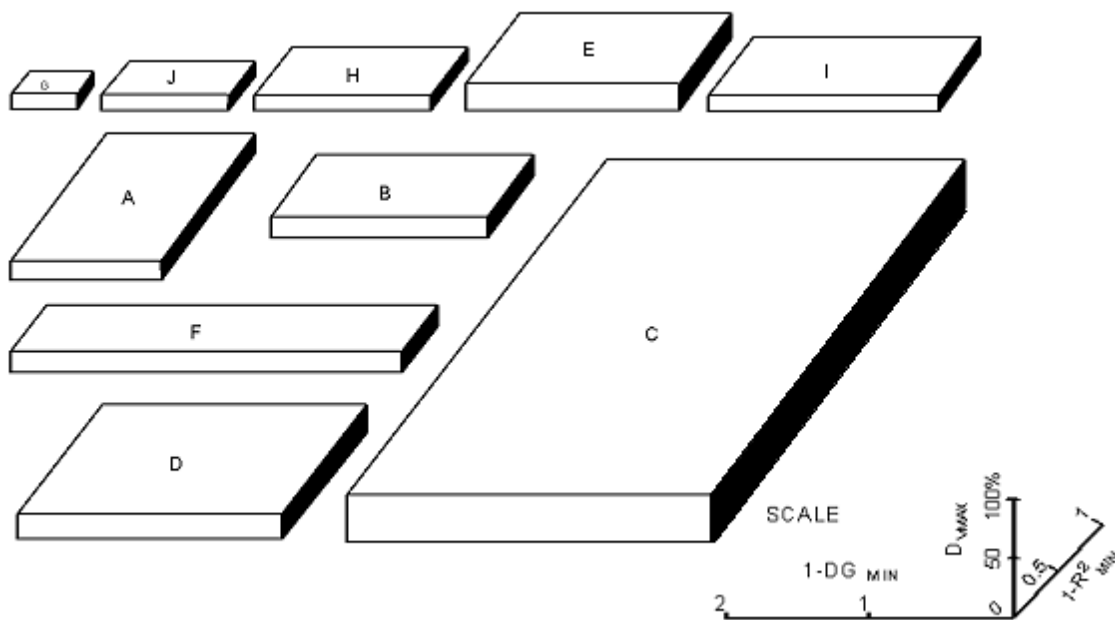
Fig. 15 Combined representation of model performance using three criteria: R^2, DG and D_v. The volumes of the prisms indicate the *maximum* inaccuracies of the tested models from all results as listed for snowmelt seasons and individual years in the WMO tables (Martinec & Rango, 1989).

6.1.2 Model accuracy outside the snowmelt season

SRM has been designed to compute runoff during the snowmelt season, but it can be run for the whole year if required. According to the mentioned WMO intercomparison test (WMO, 1986), about the same accuracy as for the snowmelt season can be achieved for the entire year in mountain basins with a low winter runoff. An example in Figure 16 shows that SRM can even be run without updating for 10 years.
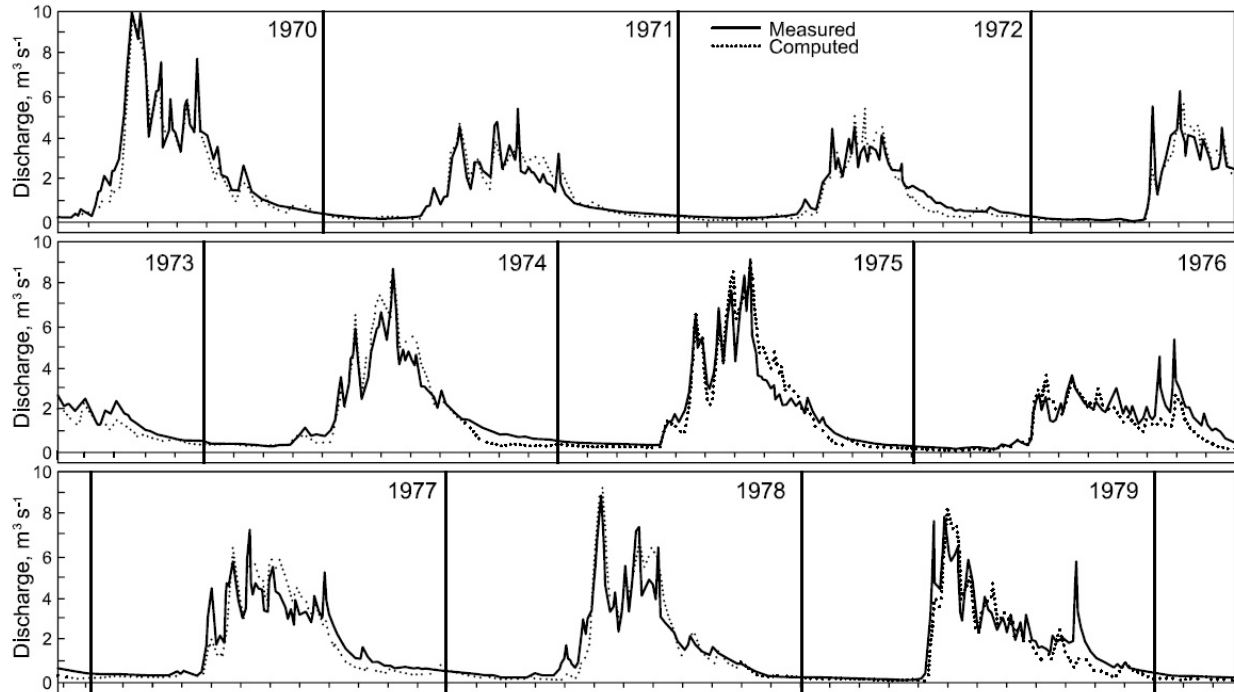
Fig. 16 Runoff simulations in the basin Dischma (43.3 km^2, 1668-3146 m a.s.l.). Computation of daily flows is extended to 10 years without updating (Martinec & Rango, 1986).

6.2 Elimination of possible errors

It is not possible to give threshold values of accuracy criteria which would determine whether a model run is successful or whether something must be changed. With good data, a value like $R^2 = 0.80$ might still be improved. In unfavorable conditions, with incomplete data, a user may be satisfied even with lower R^2 values. Sometimes, however, the graphical display as well as the numerical criteria indicate that something went definitely wrong. Before adjusting one or the other parameter, it is recommended to check several probable sources of error first. Examples in Table 5 are based on the actual experience of various users.

Table 5 Errors experienced by SRM users and their correction.

Error:	Cause:
1 Runoff simulation went too high (Dinwoody, 1976, Dischma, 1977).	Snow cover depletion curves distorted by summer snowfall (see Figure 5): Eliminate satellite observation after a snowfall event and redraw the depletion curves.
2 Runoff simulation suddenly deteriorated (Dischma).	Input of snow coverage data S shifted by 1 month: Correct the S-input.
3 The simulated runoff hydrograph declined uncontrollably in September (Illecillewaet basin).	Input of snow coverage data broken off by the end of August: Complete the S-input.
4 Runoff simulation far below the measured runoff (Illecillewaet).	Decimal point in the measured precipitation and discharge data shifted and thereby increasing the measured runoff 10x, but the simulated runoff only slightly: Correct the decimal point.
5 After the start of snowmelt, the simulated runoff kept decreasing in spite of snowmelt input (small tributary basins of upper Rhine, 1985).	Values x, y for the recession coefficient formula (Equation (7)) were taken over from a much larger basin so that k exceeded 1.0 for low Q: Correct x, y with regard to the basin size. Possibility of this error was eliminated in the computer program Version 2.01 and later versions (3.0, 3.1, 3.11, and 4.0).
6 Frequent deviations from the measured runoff, periodical lows of the hydrograph not simulated (Felsberg 1982).	SRM simulates natural runoff while the measured runoff was influenced by storage (on weekends) and release from artificial reservoirs for hydropower. These interventions must be corrected in order to compare simulated and measured runoff.
7 Rainfall peaks inadequately simulated (Illecillewaet).	Rainfall input is concentrated to shorter periods than snowmelt input which accelerates the basin response. Program Versions 2.01 and later versions take this feature automatically into account whenever rainfall exceeds a preselected threshold.
8 Rainfall peak inadequately simulated even with the special rainfall peak program (small tributary basins of upper Rhine 25 August 1985).	Temperature extrapolated from station 800 m a.s.l. to zone D 2380 m a.s.l. by 0.65°C/100 m → T = + 0.43°C while T_{CRIT} is + 0.75°C. By decreasing T_{CRIT}, snowfall was converted to rainfall and the runoff peak was better simulated.
9 Rainfall peak inadequately simulated because the daily amount was below the special program automatic threshold. Threshold was lowered but the peak simulation deteriorated further. (small tributary basins of upper Rhine, 1985).	Only 1 precipitation station was available but the "by zone" option was switched on. Consequently precipitation input took place only in 1 zone. With 1 station, select option "basin wide".

Table 5 (cont.)

10	Runoff simulation went very high in a basin with a large elevation range of 7400 m. (Kabul River, 1976).	Compact snow cover was assumed above the snow line so that the snow covered area was exaggerated. Temperature was extrapolated by too low a lapse rate. Snowmelt was not computed separately for elevation zones but for the entire basin. This usually leads to overestimation of meltwater input. Simulation was improved by re-evaluating the snow coverage and selecting a higher temperature lapse rate corresponding to the climate. With regard to the large elevation range, the basin should have been divided in several elevation zones.
11	Distorted runoff simulation (outflow from a snow lysimeter).	Values of recession coefficient false: Negative y values used with the equation $k = x \cdot Q^{-y}$ so that the exponent became positive. Consequently, k increased with the increasing Q while it should have decreased. Use equation $k = x \cdot Q^{-y}$ and positive values of y, so that the exponent is always negative.
12	Difficulties with the timing of rainfall-runoff peaks (WMO test for simulated operational forecasts, Illecillewaet basin).	Precipitation data from one of the stations were ascribed to the date on which it was measured at 0800. Data had to be shifted one day backwards. See also Section 5.2.2.
13	Forecasted runoff for hydroelectric stations Sedrun and Tavanasa too low in April-June 1994. In one run, snow cover was not completely melted by the end of September.	Snowmelt was computed by smooth long term average temperature thus decreasing the number of degree days. Reintroduce the daily fluctuations of temperatures.
14	Discrepancies in runoff simulations for Rio Grande near Del Norte.	Erratic precipitation data. Automatic extrapolation by altitude gradients from two stations resulted in negative precipitation amounts in the highest zone when gradient was negative. Extrapolate averaged precipitation data by a uniform gradient as recommended in Section 5.2. Always visually inspect input precipitation data.
15	Discrepancies in runoff simulations for Rio Grande near Del Norte	Occasionally missing temperature data were interpreted by the computer program as $0 = 0°C$. Inspect temperature data and complete missing values by interpolation.
16	Effect of climate change (see Section 8.3): Decrease of runoff computed by an increased temperature (Rio Grande near Del Norte)	The "winter deficit" was exceeded on a warm day with a high snowmelt depth, so that too much was cut off from MDC_{EXCL}. Consequently CDC_{CLIM} was shifted too much and less runoff resulted. Cut off MDC_{EXCL} by the value of the previous day ("nearly equaled").
17	Overestimation of runoff in the Rhine-Felsberg basin 1-15 May 1993 with usual temperature lapse rate of 0.65°C/100 m.	Frequent föhn-wind in this period, temperature differences between Weissfluhjoch (2693 m a.s.l.) and Davos (1560 m a.s.l.) correspond to a lapse rate as high as 0.95°C/100 m. The value of 0.8°C/100 m was used.

Table 5 (cont.)

18	Evaluation of the climate effect in the Kings River basin 1973: For a temperature increase +4°C, snow cover on 1 April disappears in the C zone (1700-2300 m.a.s.l.) but still exists in the lower B zone (1100-1700 m.a.s.l.)	The decrease of the snow water equivalent on 1 April due to warming is evaluated from uniform amounts of precipitation and snowmelt depths in winter in each zone (Figs. 25, 26). The snow in the B zone was completely melted for T ^{o}C on 1 April so that no winter deficit resulted for T+4°. However, in reality, some snow survived for T ^{o}C due to variable snow depths as seen by satellites (S=27% on 1 April). With no computed snow for T ^{o}C as well as for T+4°, no winter deficit resulted and therefore the existing snow cover was falsely preserved for T+4°. A manual correction (elimination of CDC$_{CLIM}$) was necessary. In the C zone there was enough snow to avoid the error from uniform, instead of variable, snow depths in winter, so that the snow cover duly disappeared as a result of the evaluated winter deficit. This error can occur only with very little snow in a zone on 1 April and can be readily corrected. Whenever satellites see some snow on 1 April and the winter accumulation of snow from precipitation and snowmelt is zero, eliminate CDC$_{CLIM}$.
19	Failure of runoff simulations in the basin Pskem: the derived constant y in the recession formula (Eq. 7) is negative, so that the recession is steeper for low flows than for high flows. The envelope line in Fig. 10 was derived taking into account evidently false points in the low range of flows. Such points may occur, for example, when the river flow is artificially stopped by freezing.	The recession of the natural runoff slows down with a decreasing discharge. To this effect, y must be > 0. In a log-log representation (Fig. 10), the points outside the range between the 1:1 line and a parallel line for points in the range of high flows (below the dashed line in Fig. 10) must be disregarded. With this measure, the problem of the runoff simulation was eliminated.

7 OPERATION OF THE MODEL FOR REAL TIME FORECASTS

In order to be applied for real-time discharge forecasts, a model should be able to simulate the runoff not only in selected test basins with good data or in specially equipped experimental basins where a particular calibration model was developed, but also in basins where such forecasts are required by the user. SRM has relatively modest requirements for input variables (temperature, precipitation, and snow covered area) and therefore it was easily possible perform runoff simulations for the basins delivering water for hydroelectric projects, as required by an electric company. Examples of such simulations are shown in Figures 17 and 18.

As mentioned in Section 3, SRM can be used for short term (for example weekly) forecasts of daily flows as well as for longer time period forecasts such as monthly runoff volumes or seasonal runoff volumes. For short term forecasts, temperature, precipitation and snow covered area must be forecasted or predetermined for the coming days and substituted into the model. Temperature and even precipitation forecasts are becoming increasingly available from meteorological services, but the snow covered areas must be extrapolated by the model user. The forecasts of input variables is still an important challenge for all snowmelt runoff models.

7.1 Extrapolation of the snow coverage

The future course of the depletion curves of the snow coverage can be evaluated from the so-called modified depletion curves (MDC). These curves are automatically derived by SRM from the conventional curves (CDC) by replacing the time scale with cumulative daily snowmelt depths as computed by the model. Consequently, if SRM is run in a whole hydrological year, the derivation of MDC from CDC starts with the summer half year and not earlier. The decline of the modified depletion curves depends on the initial accumulation of snow and not on the climatic conditions, as is the case with the conventional depletion curve.
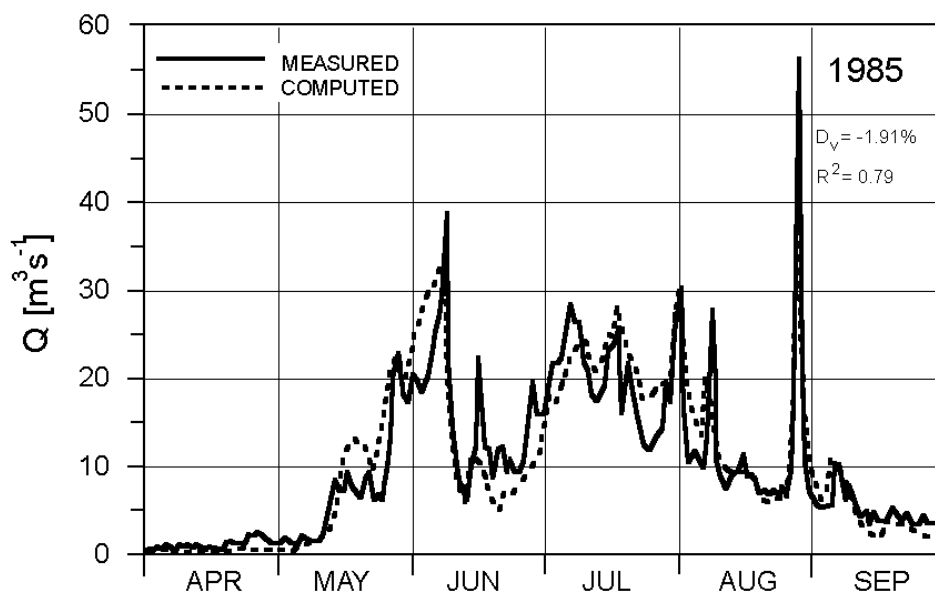
Fig. 17 Runoff simulation in the catchment area of the hydroelectric station Sedrun (Swiss Alps, 108 km^2, 1840-3210 m a.s.l.) (Baumann *et al*., 1990).
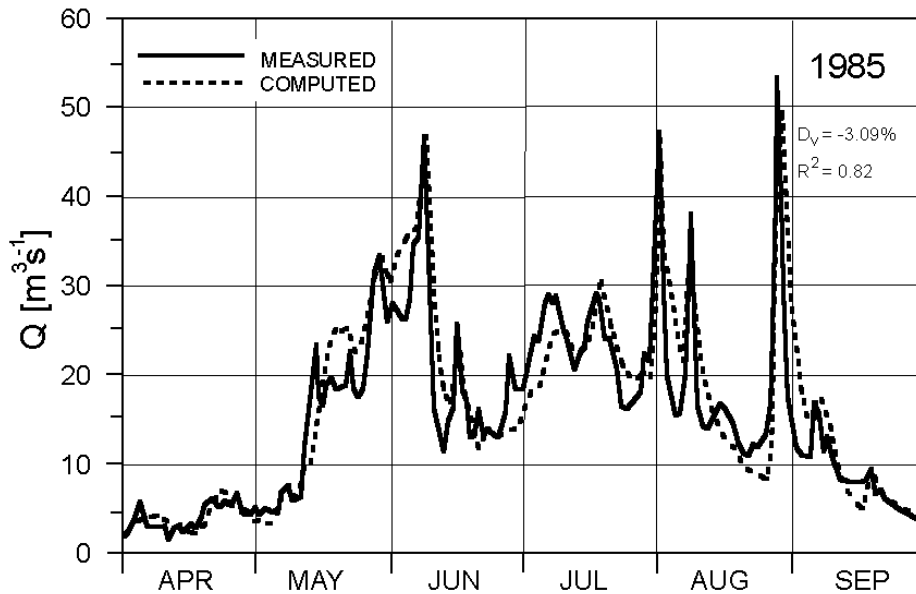
Fig. 18 Runoff simulation in the catchment area of the hydroelectric station Tavanasa (Swiss Alps, 215 km^2, 1277-3210 m a.s.l.) (Baumann *et al.*, 1990).

Procedure for weekly forecasts of daily flows:
Assumption: A family of modified depletion curves has been derived from the past snow cover monitoring and temperature measurements in the given basin. Two of these curves representing the initial water equivalents H_W = 20 cm and H_W = 60 cm are plotted in Figure 19.

Example 1 - Snow accumulation in the basin unknown, snow coverage measured by satellite on 15 May, S = 80 %, cumulative snowmelt depth (from degree-days and degree-day ratios) to date: 30 cm. Temperature forecast: 30 degree days for the next week, converted to meltwater depth M = 15 cm by a degree-day ratio a = 0.5 cm °C^{-1}d^{-1}. S = 80 % and ΣM = 30 cm indicate that the curve for H_W = 60 cm is applicable. The snow coverage will drop to 64 % in 7 days. Extrapolated conventional depletion curve indicates values for day-to-day discharge computations.

Example 2 - As above, but the cumulative snowmelt depth to date is only 10 cm. Consequently, the curve for H_W = 20 cm is applicable and the snow coverage will drop to 33 % in 7 days, which leads to a different extrapolation of the conventional depletion curve and to a different weekly total of forecasted daily runoff volumes. If the initial water equivalent is known, for example from SNOTEL (a system of data transmission using meteor paths for reflecting the signals and operated in the USA), the appropriate modified depletion curve can be selected at the start of the snowmelt season. Otherwise, the average curve (dashed line in Figure 19) is used until the correct curve can be identified by satellite data.

Figure 20 illustrates the effect of new snow prior to the date of forecast. In this example, S (1 May) = 74 percent and ΣM = 35 cm seem to indicate that the maximum modified depletion curve (H_W = 60 cm, Figure 19) should be used. The subtraction of the melt depth of the new snow reveals however that the seasonal snow cover is only average, corresponding to the dashed curve in Figure 19. By this curve, if the forecasted snowmelt depth M = 15 cm is added to ΣM = 35 cm, S drops from 60 % to 33 %. These auxiliary values are then transferred to the equidistant dashed curve in Figure 20 and the real snow covered areas are obtained: 74 % on the date of forecast and 50 % after one week. These values, together with the interpolated data for the intermediate days, are used for runoff computations. Figure 20 shows just one snowfall but the computer program takes into account each new snowfall during the snowmelt period.
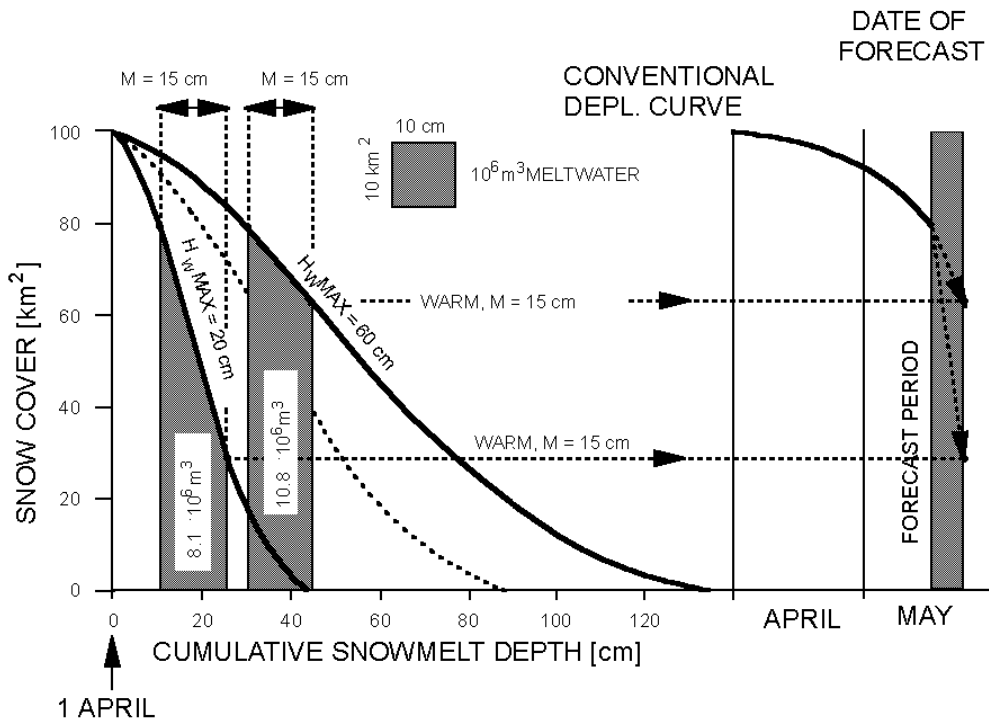
Fig. 19 Extrapolation of snow cover depletion curves in real-time from modified depletion curves with the use of temperature forecasts. $H_{W\,MAX}$ is the water equivalent of the snow cover at the beginning of the snowmelt season (Hall & Martinec, 1985).
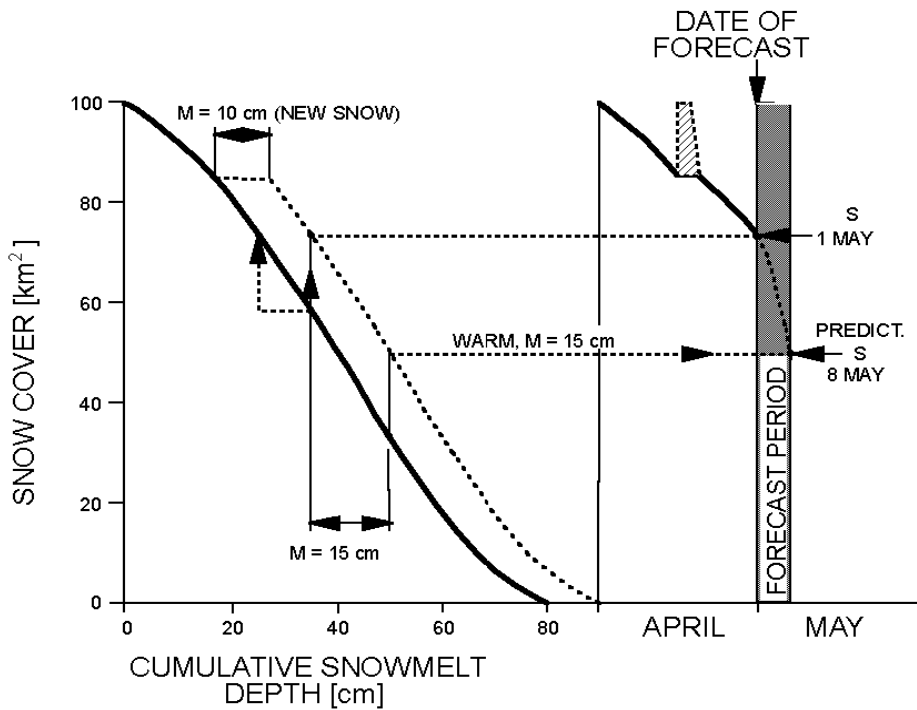
Fig. 20 Elimination of the effect of antecedent snowfall on the extrapolation of depletion curves of snow coverage (Hall & Martinec, 1985).

Figure 21 shows that it is possible to derive a nomograph of modified depletion curves (Rango & van Katwijk, 1990) for a given basin from the past years. As noticed in Figure 19, the area below a modified depletion curve indicates the water volume stored in the snow cover if the y-axis scale is in km^2. If the y-axis scale is in percent snow coverage, it indicates the water equivalent of the snow cover as an areal average. Therefore each curve in Figure 21 can be labeled by the water equivalent which it indicates. The rectangular shaded area means 0.1 x 10 cm = 1 cm. Because the area below the highest curve is 83 times larger, this curve indicates that at the beginning of computations of the cumulative snowmelt depth (usually on 1 April), the snow accumulation corresponded to the water equivalent of 83 cm. The values for each curve are automatically determined by the computer program.

The nomograph is used for real time forecasts as follows: In a current year, the snow covered area is monitored from the start of the snowmelt season and simultaneously the cumulative snowmelt depth is computed. The snow covered area must be evaluated as quickly as possible after each satellite overflight. The degree-days necessary for melting the temporary snow cover from intermittent snowfalls are disregarded. If, after some time, for example on 15 May, the snow coverage amounts to 80 % and the cumulative snowmelt depth amounts to 15 cm, the modified depletion curve labeled by 37 cm is identified to be valid for that year. This curve can be used for extrapolating the snow covered area. For example, if another 15 cm will be melted in the next week according to temperature forecasts (total 30 cm), the snow coverage will drop to 55 %. The snow covered areas thus extrapolated are used for real time forecasts of daily flows. The modified curve also indicates the water equivalent of snow (37 cm) at the start of the snowmelt season for seasonal runoff forecasts. If, in another future year, the cumulative computed snowmelt depth coincides for example with the snow coverage of only 36 %, the curve labeled 13 cm is valid. The appropriate curve can thus be identified but with a certain time delay. If the initial water equivalent of the snow cover can be evaluated from point measurements, the proper curve can be selected at the start of the snowmelt season with no time delay.

The computer program also provides an option for plotting a modified depletion curve in which the total melt depth includes new snow that falls occasionally during the snowmelt period. It appears in Figure 20 as the dashed line equidistant from the new snow-excluded modified depletion curve. While the new snow-excluded MDC is used to evaluate the water equivalent of the seasonal snow cover at the start of the snowmelt period, the new snow-included MDC can be used to evaluate the shifting of the conventional depletion curves by changed temperatures, as will be explained in the Section 8. The depletion curves of snow covered areas are dealt with in more detail in an earlier publication (Hall & Martinec, 1985).

Figure 22 shows a simulated runoff forecast for the Rio Grande basin in which the forecasted temperatures were replaced by seasonal average temperatures, the precipitation was 110 % of the average precipitation randomly distributed over each month, and the snow covered area was forecasted by using temperatures and the appropriate modified depletion curve. Evidently the seasonal average temperatures do not show the cold spell in the second half of May 1987 and therefore the runoff decline is not simulated.

The difference between the runoff simulation and short-term forecast is illustrated by Figure 23. The temperature T_n, precipitation P_n, and snow covered area S_n are used to compute Q_{n+1} with L = 18 h. At the time of simulation, these values are known. When Q_{n+1} is forecasted in the morning of the day n, T_n and P_n are not yet known and forecasted values must be used. In order to forecast further ahead (Q_{n+2}, Q_{n+3}), the forecasted values T_{n+1} and P_{n+1}, T_{n+2} and P_{n+2} are used. The snow covered areas S_n, S_{n+1}, S_{n+2} are extrapolated by using temperature forecasts and the modified depletion curve MDC.
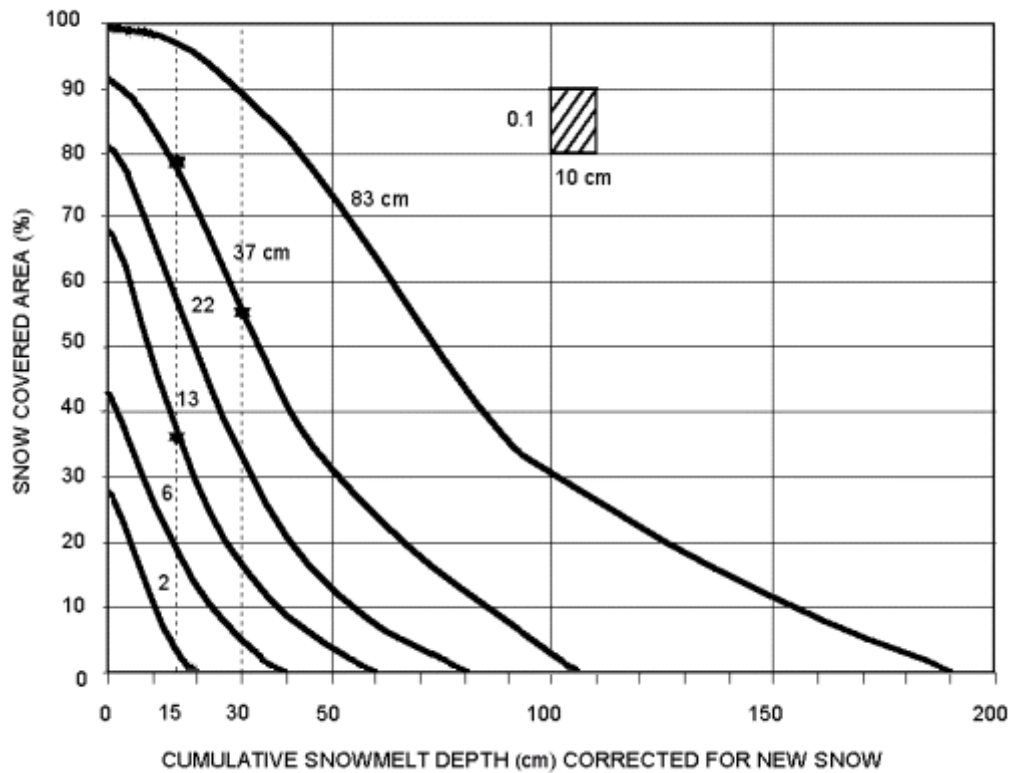
Fig. 21 Nomograph of modified depletion curves for the elevation zone B (1284 km², 2926-3353 m a.s.l.) of the Rio Grande basin near Del Norte, Colorado. The curves are labeled with the areal average water equivalent (1 April) of the snow cover which they represent (Rango & van Katwijk 1990).
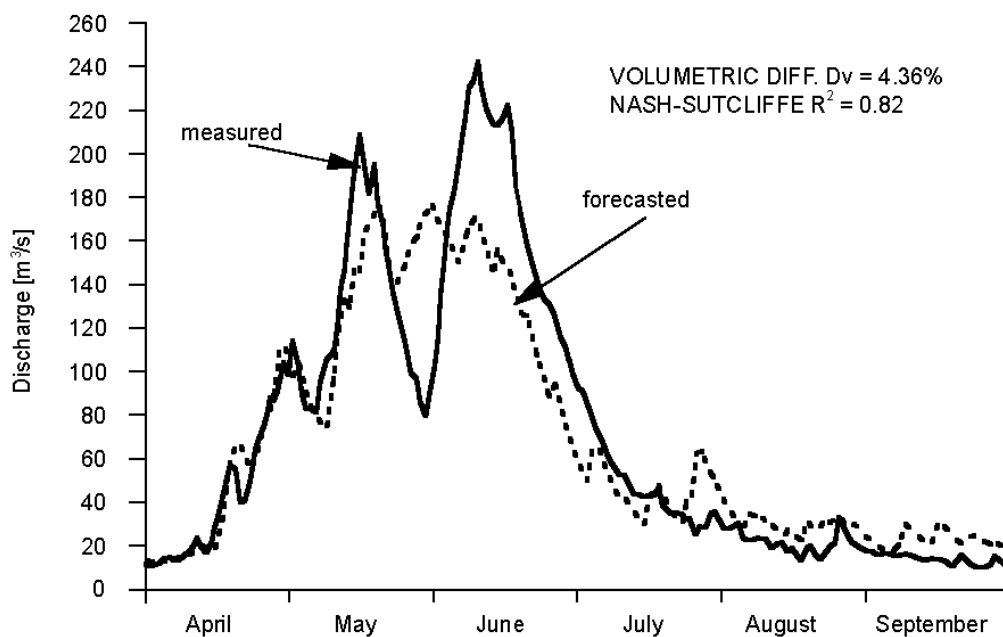
Fig. 22 Simulated real-time runoff forecast for the Rio Grande basin using long-term average temperatures instead of temperatures for the year 1983 (Rango & van Katwijk, 1990).
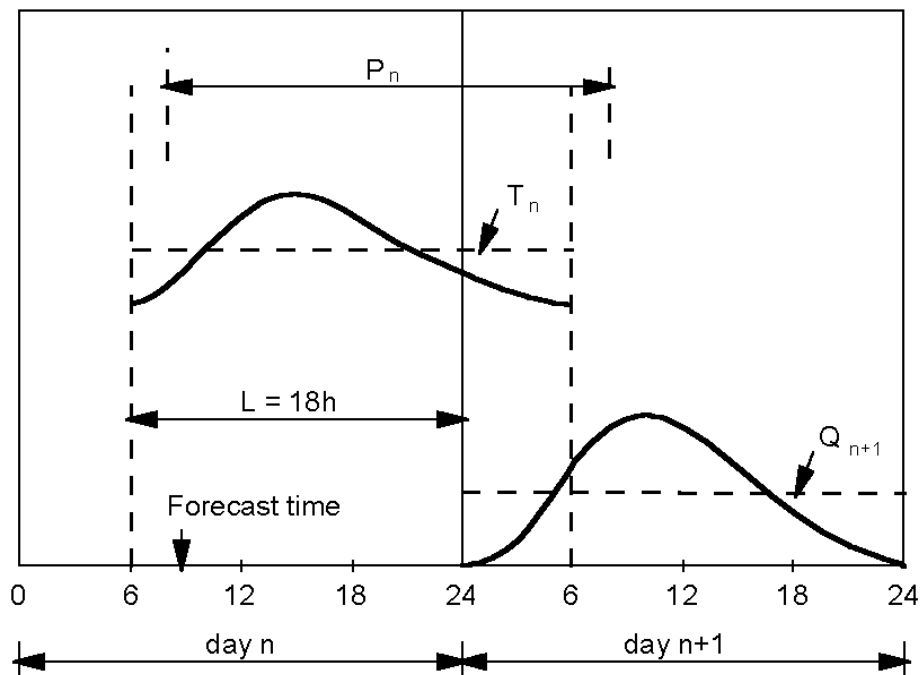
Fig. 23 Real-time availability of temperature and precipitation data for short-term runoff forecasts in contrast to runoff simulation.

For other lag times, SRM automatically combines Q in the appropriate proportions of two subsequent inputs, as explained in Section 5.3.7. For example, if L = 24 h, the input from T_{n-1} and P_{n-1} (which might be already known at the time of the forecast) is represented by 25% and the input from T_n and P_n (forecasted values) by 75 %.

In the absence of temperature and precipitation forecasts, runoff forecasts can be issued on condition, for example, that long-term average values or extreme values (maxima, minima) will occur. It is also possible to use fictitious values as will be shown in the section dealing with climate change.

The feasibility of real-time forecasts was demonstrated for two hydroelectric stations in the Swiss Alps (Brüsch, 1996). With the use of snow cover monitoring by Landsat as well as of temperature and precipitation forecasts from the Swiss Meteorological Office, the daily runoff was forecasted always for four subsequent days. The runoff volume from April through September was forecasted and updated with the use of modified depletion curves (Martinec & Rango, 1995).

The climate part of the WinSRM program facilitates the real time runoff forecasts as explained in Section 8.6.

7.2 Updating

The model performance in the forecasting mode is naturally affected by the reduced accuracy and reliability of temperature and precipitation forecasts. The propagation of errors can be avoided by periodic updating. In the more recent versions of the computer program (Versions 3.11 and 3.2), the computed discharge can be replaced every 1-9 days by the measured discharge which becomes known for the corresponding day so that each subsequent forecast period is computed by using a correct discharge value.
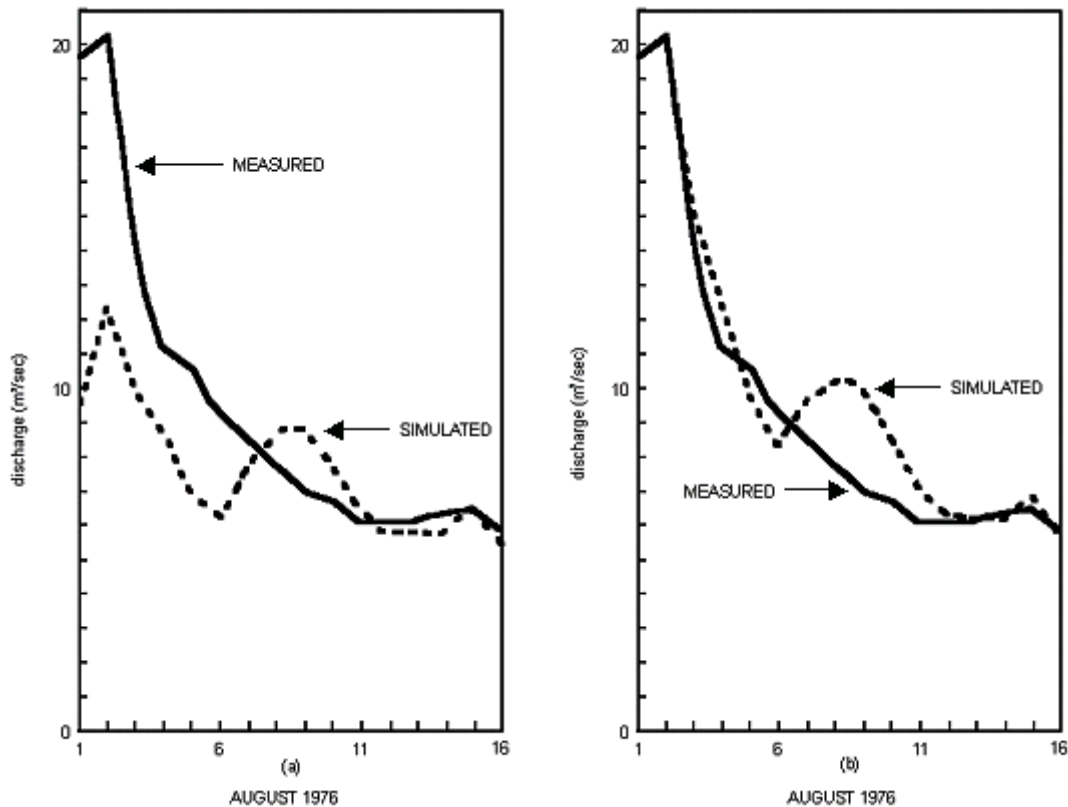
Fig. 24 Discharge simulation in the Dinwoody Creek basin (228 km², 1981-4202 m a.s.l.) in Wyoming, (a) without updating, and (b) with updating by actual discharge on 1 August.

Even without this updating, SRM prevents persistent large errors by a built-in self adjusting feature which is efficient if Equation (7) is carefully assessed: Figure 24a shows a model runoff simulation starting with computed discharge of only one half of the correct value. Updating by actual discharge improves the simulation as shown in Figure 24b. Even without updating, however, the initial discrepancy is soon eliminated automatically.

Further possibilities of updating will be made available to users when more experience in real time situations is accumulated. For example, it should be possible to adjust some parameters (e.g., the runoff coefficient) in the progress of the forecast, but only within hydrologically and physically acceptable limits. In any case, false forecasts of temperature and precipitation should be updated whenever a correction by new data is indicated.

What is generally called "updating" can be thus divided into 3 categories:

(1) Updating the computed discharge by the measured discharge when it becomes known, i.e., checking with the measured discharge to avoid carry-over of errors when the next forecast is issued.

(2) Adjustment of model parameters in the process of forecast.

(3) Correction of temperature, precipitation, and snow cover forecasts according to actual observations.

Short-term discharge forecasts can be updated as frequently as each day (Baumann *et al.,* 1990).

8 YEAR-ROUND RUNOFF SIMULATION FOR A CHANGED CLIMATE

SRM uses a real snow cover from satellite monitoring in the present climate in order to produce a snow cover and runoff in a changed climate. This requires a rather detailed procedure, but uncertainties arising from a fictitious snow cover simulated from precipitation and arbitrary threshold temperatures are avoided. In any event, the SRM program finishes this task, including printout of figures, tables, numerical results and hydrographs, within minutes. Another advantage is the independence from calibration, enabling the model parameters to be meaningfully shifted in time or adjusted if so indicated by climate scenarios.

If SRM is used only to predict snow covered areas and regional snow accumulation in a changed climate, for example, in mountain areas which are not hydrologically defined basins, the computer program requires the following data:

- Number of elevation zones, their areas, and hypsometric mean elevations

- Current snow covered areas, daily values (S)

- Daily average or Max/Min temperatures (T)

- Precipitation, daily (P)

- Degree-day factor (a)

- Temperature lapse rate (γ)

- Critical temperature (T_{CRIT})

For runoff computation, the remaining SRM parameters are required: c_S c_R, RCA, k, L and the initial Q.

Originally, SRM was applied to simulate and forecast runoff only during the snowmelt season. It was later run year-round for international tests of model performance (WMO, 1986). The first evaluation of the effect of climate change of SRM dates back to 1980 (Martinec, 1980). At that time there was no consensus yet whether temperature will increase or decrease. Therefore, the runoff in the snowmelt season was computed for +1°C and –1°C. Since then, climate scenarios anticipating increasing temperatures have become available for the whole year. Consequently, the SRM climate program has been extended to handle the winter half year as well.

8.1 Snowmelt runoff computation in the winter half year

In the winter half year (usually October-March in the Northern hemisphere), the evaluation of the snow coverage is more difficult than during the snowmelt season, because of persistent cloudiness and low sun angles. Satellite data, if available, are not frequent enough to distinguish the stable snow cover from frequent transitory snowfalls which are subsequently melted. An assumption of a stable snow cover between two available satellite measurements may lead to an overestimation of the snow coverage. Two options are available to handle this problem during the winter months:

Option 1: Put S = 0 so that each precipitation event recognized by T_{CRIT} as snow is automatically stored and subsequently melted over the whole area (1 - S = 1). This method is applicable only if precipitation data are good enough to represent the input or if they can be adequately adjusted. This is in many cases not possible due to the well known catch deficit of precipitation gauges and due to the lack of measurements in the high elevations of mountain regions. It is for this reason that SRM uses the snow covered area whenever possible for computing the runoff input.

Option 2: Assume a stable snow cover (S = 1 or a little less in a rugged terrain) in January and February, for example, and S = 0 in October - December. If S = 1 on 1 April from satellite data, assume S = 1 in March as well. If it is less than 1 on 1 April, the snow coverage in March is put to 0 or, which may be more accurate, it is interpolated from 1 on 1 March to the S-value on 1 April. Naturally, S = 1 can be assumed for a longer part of the winter in higher elevation zones while in the lowest zone option 1 may be preferable. The present program keeps the snow coverage estimated for the present climate unchanged for climate runs. It is therefore recommended to assume a complete snow coverage only in months in which it is expected to last in a warmer climate as well.

Whenever S = 1 is introduced, the SRM program cancels any existing storage of preceding temporary snowfalls because such snow becomes a part of the seasonal snow cover. Snow storage is also automatically canceled on the 1 April date because all existing snow is then accounted for by the depletion curve of the seasonal snow coverage.

With the variables thus accounted for, SRM is run as usual. Because the estimated snow coverage is less accurate than measured CDC in the summer, the water equivalent of new snow is reduced at once by the simultaneous (1 - S) to prevent an inadequate S from influencing the computation on a later melt day. This deviates from the summer procedure explained in Section 5.2.2, Table 2.

The model parameters should be adapted to winter conditions. In particular, the constants x, y for the recession formula (Equation (7)) derived usually for summer conditions sometimes allow the discharge to decrease too low so that a slower recession formula is indicated. By using the Equation (14):

$$Q_{Min} > x^{\frac{1}{y}} \tag{14}$$

x, y can be adjusted in order to prevent the discharge from sinking below a selected level after a long recession period.

In view of frequent snowfalls, values of the degree-day factor lower than those used in the summer are recommended. Values of c_S and c_R higher than in summer can be expected.

The main purpose of the winter runoff simulation is the evaluation of the runoff redistribution between the winter and summer half years. Consequently, it is more important to compute the winter runoff volume as accurately as possible rather than to try to improve the daily accuracy (R^2).

8.2 Change of snow accumulation in the new climate

As the first step, the effect of a climate change on snow covered areas and runoff was evaluated in the summer half year only, assuming an unchanged initial snow cover on 1 April (Martinec *et al.,* 1994). For a year-round temperature increase, the seasonal snow cover on 1 April is deprived of a certain snow water equivalent (and perhaps snow cover) by additional snowmelt and by a conversion of some precipitation events from snow to rain in October through March.

This decrease of the snow water equivalent is computed by rewriting the input part of the SRM formula as follows:

$$\Delta H_W = \sum_{n=1}^{182} \left[a_n \cdot T_n \cdot S_n + a_n \cdot T_n \left(1 - S_n\right) + P_{Rn} \right]$$

$$- \sum_{n=1}^{182} \left[a_n \cdot T'_n \cdot S'_n + a_n \cdot T'_n \left(1 - S'_n\right) + P'_{Rn} \right] \tag{24}$$

where

ΔH_W = difference between the present and future areal water equivalent of the
snow cover on 1 April [cm].

a = degree-day factor [cm °C^{-1}·d^{-1}]

T = temperature in the present climate at mean hypsometric elevation, as degree-days [°C·d]

T' = temperature in a warmer climate as degree-days [°C·d]

S = ratio of snow covered area to total area, present climate

S' = ratio of snow covered area to total area, warmer climate

P_R = rain according to T_{CRIT}, present climate

P'_R = rain according to T_{CRIT}, warmer climate

182 = number of days October through March

Equation (24) thus summarizes the SRM input to runoff which consists of snowmelt from the stable snow cover (S), melting of snow which temporarily covers the snow free area (1 - S), and rain.

The distinction between a stable and temporary snow cover during the snow accumulation in winter is rather arbitrary due to insufficient satellite monitoring, but the total of both snowmelt inputs always equals 100 % of the occurring snowmelt M:

$$M \cdot S + M \left(1 - S\right) = M \left(S + 1 - S\right) = M \tag{25}$$

In March, however, if S is put to 0 while there is a stable snow cover, and there happens to be little snowfall, the snowmelt input may be underestimated.

Figure 25 illustrates the areal water equivalent of the snow cover on 1 April as a difference between the winter precipitation and the winter input to runoff (left side of Figure 25). This water equivalent can also be computed by accumulating the daily zonal melt depths (right side of Figure 25). In this hypothetical example there is an agreement of the water equivalent determined either way. In natural conditions, discrepancies are to be expected mainly due to difficulties in evaluating the areal precipitation value for mountainous regions. In such cases, it is recommended that the value from the accumulated zonal melt be considered as more reliable. The accumulated zonal melt value might even be used to correct the winter precipitation data and to estimate the altitude precipitation gradient. Another advantage of this method is that it takes into account a possible redeposition of snow by wind during the accumulation season.
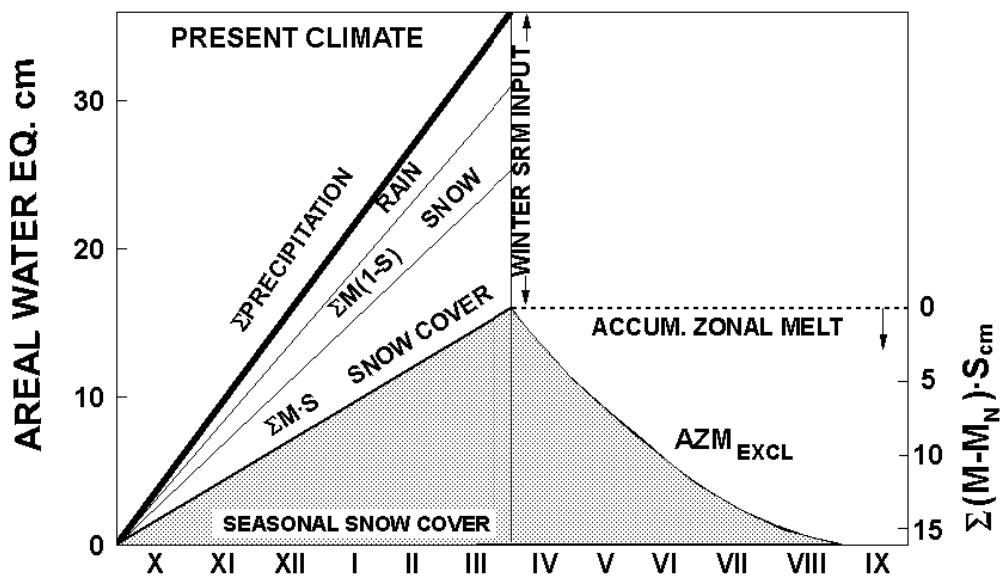
Fig. 25 Illustration of the snow accumulation in the winter and snowmelt in the summer in the present climate (hypothetical example).

On the other hand, no losses are normally considered (losses indicated by the runoff coefficient are assumed to take place after meltwater has left the snow cover). This may lead to underestimation of the retrospectively computed water equivalents if significant evaporation from the snow surface takes place. However, if degree-day ratios are used which have been derived from lysimeter measurements under similar evaporation conditions, this error is eliminated. In a warmer climate, the winter input to runoff increases, as shown in Figure 26, so that there is less snow on 1 April if winter precipitation remains unchanged. A combined effect of a warmer climate and increased winter precipitation can result in rare cases (low temperatures in high mountains with little or no effect of the temperature increase) in an increased snow accumulation.
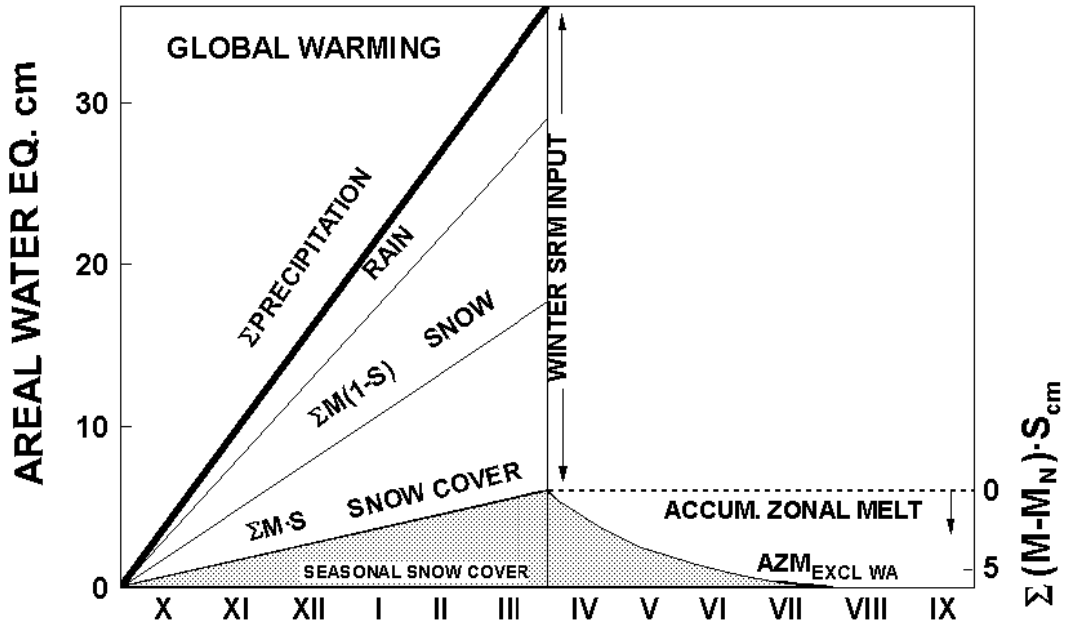
Fig. 26 Illustration of the snow accumulation in the winter and snowmelt in the summer in a warmer climate (hypothetical example).

8.3 Runoff simulation for scenarios of the future climate

In order to evaluate the effect of a warmer climate on runoff in mountain basins, the SRM program uses the real seasonal snow cover of the present as monitored by satellites and models a climate-affected seasonal snow cover.

The future snow conditions in terms of snow covered areas and areal water equivalents in different elevation zones constitute useful information for planning water management and winter tourism. Using snow coverage data as model input, the climate-affected runoff during the whole hydrological year is computed. It allows examination of the changes of daily runoff peaks and the redistribution of runoff volumes in the winter and summer half years.

The procedure is illustrated by evaluating the effect of a temperature increase of + 4°C on runoff in the Rio Grande basin near Del Norte, Colorado (3419 km², 2432 - 4215 m a.s.l., elevation zones A, B and C) in the hydrological year 1979 (Figure 27). The following symbols are used:

CDC = conventional depletion curve of snow covered area interpolated from periodical snow cover mapping.

MDC$_{INCL}$ = modified depletion curve of snow covered area with new snow included. This curve is derived from CDC by relating the snow coverage to the accumulated computed snowmelt depth. It indicates how much snow, including new snow falling during the snowmelt period, must be melted (in terms of computed snowmelt depth) in order to decrease the snow covered area to a certain proportion of the total area and ultimately to zero. The shape of this curve depends on the initial water equivalent of the snow and on the amount of new snow.

MDC_{EXCL} = modified depletion curve of snow covered area with new snow excluded. This curve is derived from MDC_{INCL} by deducting the melt depths of new snow from the accumulated snowmelt depth. The shape of this curve depends on the initial water equivalent of the snow cover and is independent of subsequent snowfalls. The area below this curve indicates the areal water equivalent of the initial snow cover.

AZM_{INCL} = accumulated zonal melt with new snow included. This curve accumulates daily computed snowmelt depths multiplied by the respective snow coverage (as decimal number) and shows the totals on a time scale.

AZM_{EXCL} = accumulated zonal melt with new snow excluded. This curve is derived from AZM_{INCL} by deducting the zonal melt of new snow from the accumulated zonal melt. Again it relates the successive totals to time. The final total is the areal water equivalent of the initial snow cover (as also indicated by MDC_{EXCL}).

MDC_{CLIM} = modified depletion curve of snow covered area for a changed climate. This curve takes into account the amount of snowfalls changed by the new climate. If there is no change, it is identical with MDC_{INCL}.

CDC_{CLIM} = conventional depletion curve of snow covered area in a changed climate.

$CDC_{CLIM\,MA}$ = conventional depletion curve of snow covered area in a changed climate (derived from MDC_{INCL}) adjusted for the input to SRM runoff computation (model adjusted). It appears in publications disregarding the winter effect of a changed climate.

$MDC_{EXCL\,WA}$ = winter adjusted curve. The effect of a warmer winter is taken into account by decreasing the curve according to the "winter deficit". With a simultaneous increase of winter precipitation a positive balance of the winter snow accumulation may result in which case the curve is increased. The area below this curve indicates the areal water equivalent of the initial snow cover in a changed climate.

$AZM_{EXCL\,WA}$ = winter adjusted curve. The effect of a warmer winter and, if necessary, of a changed precipitation is taken into account. The final total is the water equivalent of the initial snow cover in a changed climate.

$MDC_{CLIM\,WA}$ = winter adjusted curve. It is derived from $MDC_{EXCL\,WA}$ by taking into account snowfalls "surviving" in the new climate.

$CDC_{CLIM\,WA}$ = conventional depletion curve of snow covered area in a changed climate. The curve is derived from $MDC_{CLIM\,WA}$.

$CDC_{CLIM\,WA,\,MA}$ = curve adjusted for the model input (model adjusted). If the derivation from $MDC_{CLIM\,WA}$ results in more than one S-value on a date, the first (highest) value is used. If there is no new S-value on a date, the previous day′s S-value is repeated until there is a new S-value. With this adjustment $CDC_{CLIM\,WA,\,MA}$ can be used as input to SRM which requires one S-value on each day, as is provided by the original CDC. This curve is used to compute the year-round climate-affected runoff.
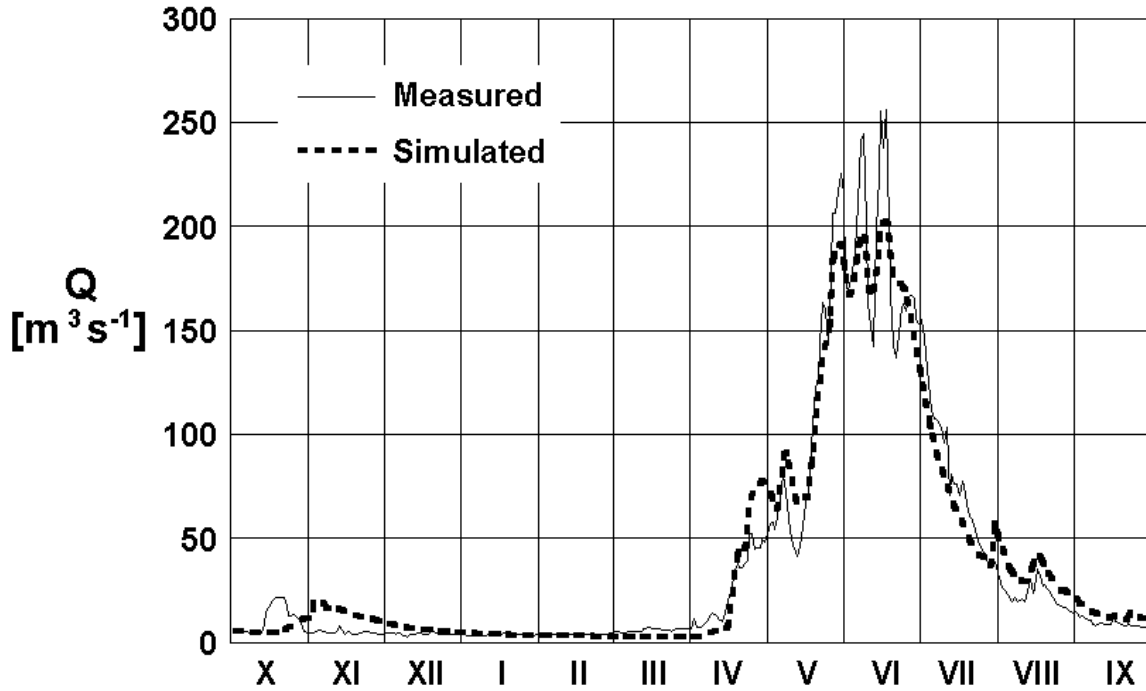
Fig. 27 Measured and simulated runoff in the Rio Grande basin near Del Norte, Colorado in the hydrological year 1979.

Due to the time shift by the changed climate, the derivation of $S_{CLIM\ WA}$ values from $MDC_{CLIM\ WA}$ may stop before the end of the computation period. In case of $S_{CLIM\ WA} < S$, the program decreases the depletion curve $CDC_{CLIM\ WA,\ MA}$ to the last S-value of the original CDC, which is typically zero, and repeats it for the missing days. If an elevation zone contains glaciers or permanent snow cover, $CDC_{CLIM\ WA,\ MA}$ drops to the residual snow or ice coverage, again taken over from the original CDC. In less frequent cases (no effect of temperature increase in a high elevation zone, increased precipitation), $S_{CLIM\ WA} > S$. The program then determines $\Delta S = S_{CLIM\ WA} - S$ and extrapolates $CDC_{CLIM\ WA}$ as $CDC + \Delta S$ on the missing days. In order to evaluate the effect of a temperature increase on the Rio Grande basin, the following steps were taken:

(1) Runoff in the whole hydrological year is simulated (Figure 27) in order to verify the preselected parameters and the estimated snow coverage in winter.

(2) Conventional depletion curves of the snow coverage (CDC) used as input variable in the summer are plotted (Figure 28).

(3) Winter runoff is simulated separately for T and T + 4°C in order to obtain the respective runoff volumes (hydrographs are printed).

(4) The decrease of the snow water equivalent on 1 April due to the increased snowmelt in winter ("winter deficit" or "negative winter adjustment") is computed as explained in Section 8.2.

(5) Summer runoff is simulated separately for T in order to obtain the runoff volume (hydrographs are printed).

At this point, the climate-affected conventional depletion curves, CDC_{CLIM}, which are needed as an input variable for computing the summer part (since they do not exist in the accumulation period in the winter) of the climate-affected runoff, are derived as follows:

(6) The modified depletion curve MDC_{INCL} is derived from the CDC. This curve relates the snow coverage with cumulative snowmelt depths including new snow in the summer (Figure 29).

(7) MDC_{EXCL} is derived by eliminating melt depths referring to new snow from cumulative snowmelt depth (Figure 29). The area below this curve indicates the initial areal water equivalent of the snow cover, as shown in Section 7.

(8) The climate effect is taken into account by depriving MDC_{EXCL} of the "winter deficit" computed in step (4), and $MDC_{EXCL\ WA}$ (winter adjusted) is derived. The program prints both MDC_{EXCL} and $MDC_{EXCL\ WA}$. In zone A, $\Delta H_W = -36.94$ cm was computed so that MDC_{EXCL} is cut off on the day when this value was equaled or exceeded. This happened on 27 April, when ΣM for MDC_{EXCL} was 42.04 cm (not reduced by S, therefore higher). $MDC_{EXCL\ WA}$ thus derived is shifted to start on 1 April.

(9) The cumulative snowmelt is printed in relation to time as zonal snowmelt, that is to say, reduced each day by the respective percentage of the snow coverage. The accumulated zonal melt curve AZM_{EXCL} indicates graphically (Figure 30) that the "winter deficit", in this example $\Delta H_W = -36.94$ cm, was exceeded on 27 April, when the accumulated zonal melt amounted to 37.69 cm. The previous day′s total 35.9 cm is also printed so that the user can cut off the MDC_{EXCL} at the previous day′s value if the next day′s value is much higher than the computed ΔH_W.

(10) After melt depths of new snow of the present climate and the winter deficit had been taken out of MDC_{INCL} to derive $MDC_{EXCL\ WA}$, melt depths of new snow "surviving" in the warmer climate are put back to derive $MDC_{CLIM\ WA}$ as illustrated for zone A in Figure 31.

(11) The climate-affected conventional depletion curves adjusted for the "winter deficit", $CDC_{CLIM\ WA}$, are derived as follows: $MDC_{CLIM\ WA}$ indicates, for example, that a snowmelt depth of 22 cm is needed to decrease the snow coverage to 50 % (Figure 31). This occurs in the present climate, according to CDC in Figure 28 on 5 May. In a warmer climate (T + 4°C in this example) a cumulative snowmelt depth of 22 cm and a corresponding decrease of the snow coverage to 50 % are reached already on 9 April, so that the 50 % point is shifted to that date (Figure 32). The program takes the cumulative snowmelt depth computed by present temperatures on each day and searches for the date, on which this snowmelt depth was equaled or exceeded when the higher temperatures are used for computation. If the new climate implies changes of the degree-day factor (see Section 8.4), the cumulative snowmelt depth must be computed not only by higher temperatures, but also by changed (usually higher) a-values. The computer program takes care of this matter. Comparable snowmelt depths are reached about one month earlier so that $CDC_{CLIM\ WA}$ is shifted in time against the original CDC as illustrated in Figure 32 for all elevation zones. The method of CDC shifting in the summer is also explained by a numerical example elsewhere (Rango & Martinec, 1994). In view of the stepwise character of the cumulative snowmelt depths, a slightly higher snow water equivalent than the "winter deficit" may be cut off to derive $MDC_{EXCL\ WA}$ (see Step (9) above) which would ultimately accelerate the decline of $CDC_{CLIM\ WA}$. On the other hand, searching for cumulative snowmelt depths equaled or exceeded in deriving $CDC_{CLIM\ WA}$ may result in a very slight delay of the decline.

(12) $CDC_{CLIM\ WA}$ is used to compute the climate-affected runoff in the summer half year. It should be noted that in contrast to the model runs in the simulation mode, R^2 in the climate change runs does not indicate the model accuracy, but results from the difference between the hydrographs computed for the present and changed climate.
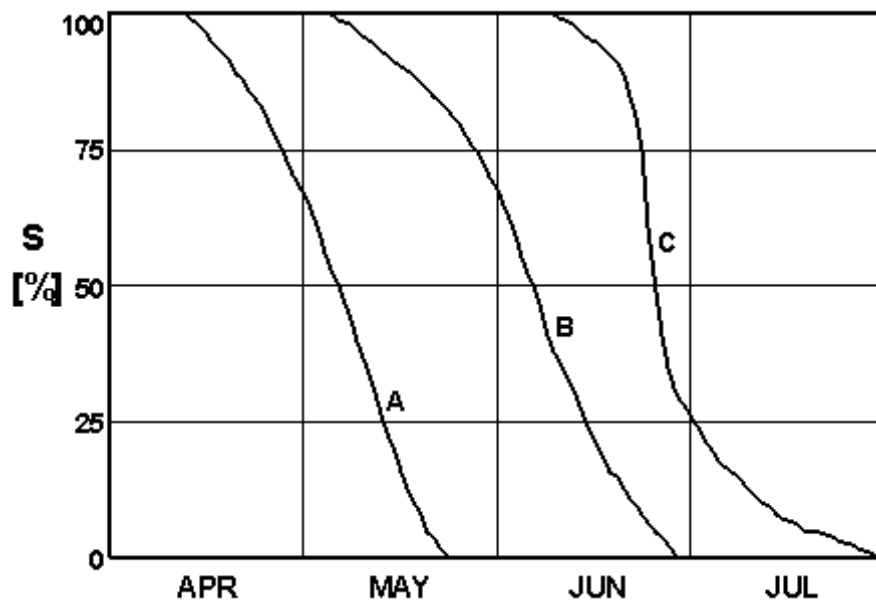
Fig. 28 Conventional depletion curves of the snow coverage from Landsat data in the elevation zones A, B and C of the Rio Grande basin near Del Norte, Colorado in 1979.
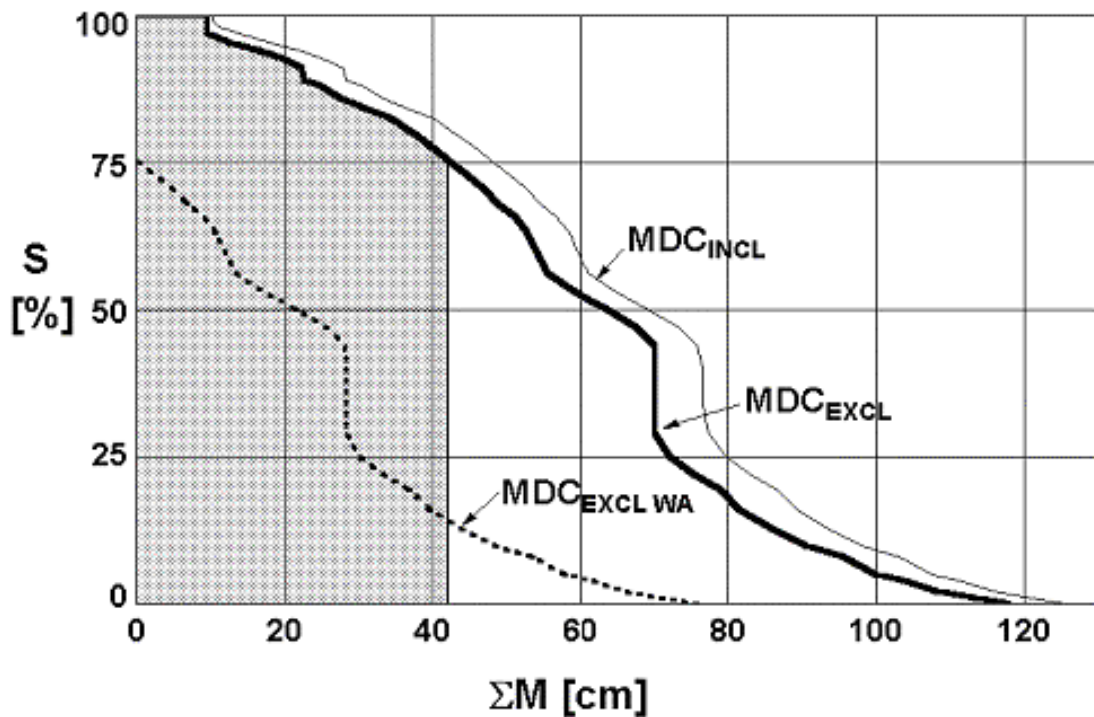
Fig. 29 Modified depletion curves for zone A: MDC$_{INCL}$ derived from CDC, therefore including new snow, MDC$_{EXCL}$ with new snowmelt excluded, MDC$_{EXCL\ WA}$ with "winter deficit" (shaded area) cut off.
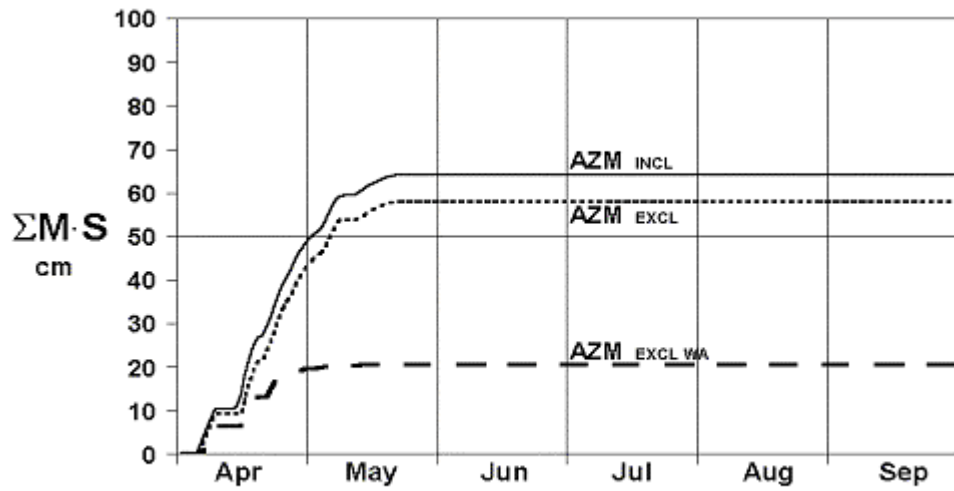
Fig. 30 Accumulated zonal melt curves for zone A: AZM$_{INCL}$: computed daily melt depth multiplied by S from CDC (= zonal melt). AZM$_{EXCL}$ with new snow zonal melt excluded and AZM$_{EXCL\ WA}$ derived from AZM$_{EXCL}$ by cutting it off on 27 April and transferring it to 1 April.
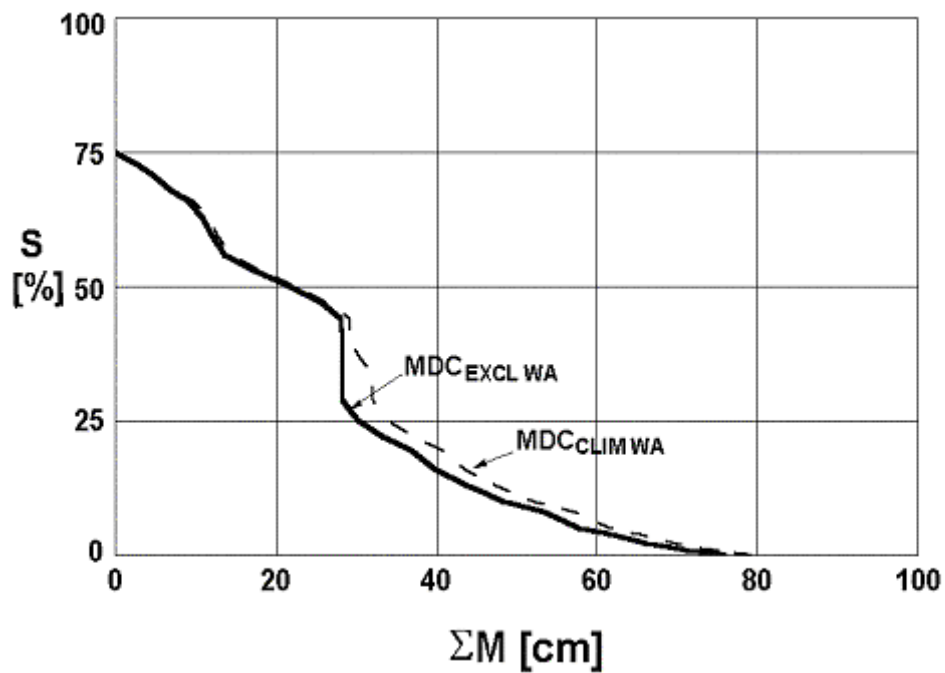
Fig. 31 Modified depletion curve, adjusted for the "winter deficit" and including new snow of the changed climate (MDC$_{CLIM\ WA}$) derived from MDC$_{EXCL\ WA}$ for zone A.
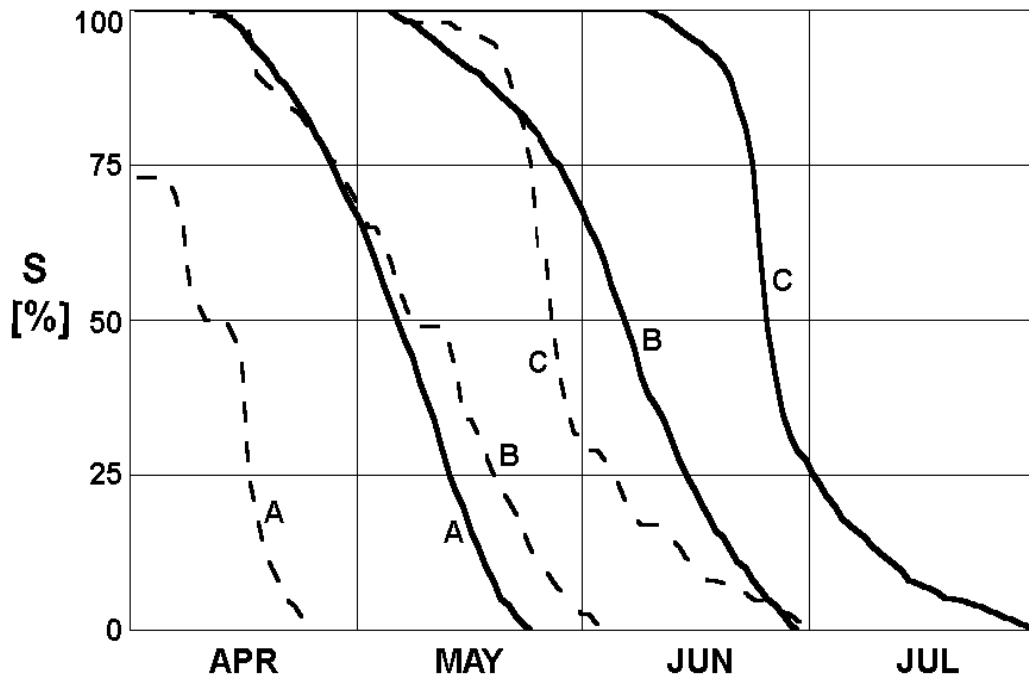
Fig. 32 Effect of a changed climate (T + 4°C) on snow covered areas of 1979 in elevation zones A, B and C of the Rio Grande basin near Del Norte, Colorado. $CDC_{CLIM\,WA}$ is shifted from the original CDC due to a reduced snow cover on 1 April and due to increased temperatures in the snowmelt season.
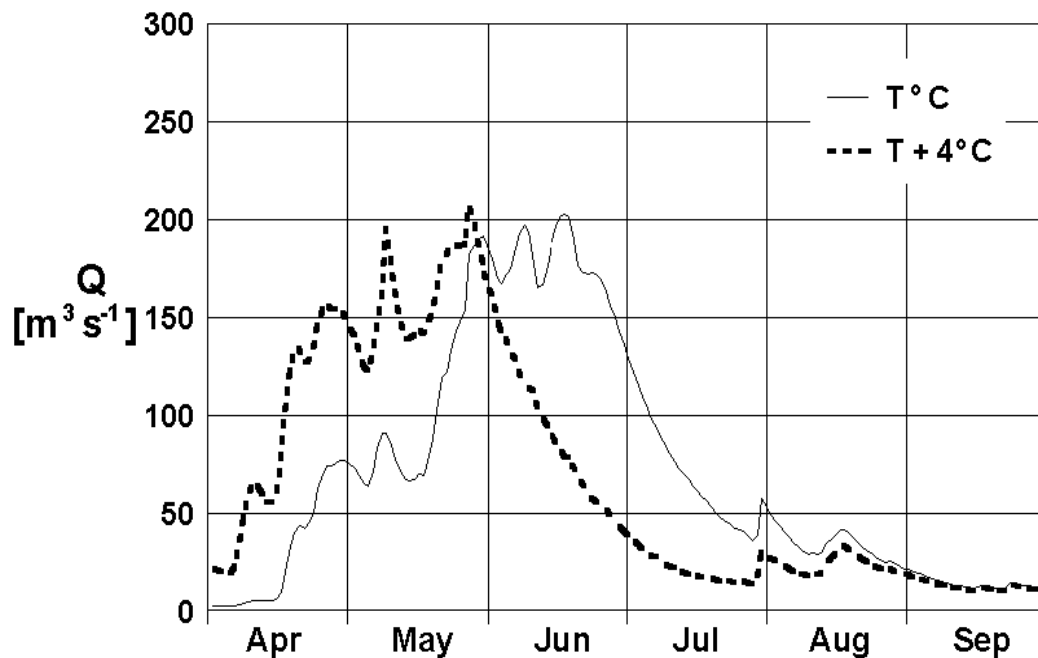
Fig. 33 Climate-affected runoff (T + 4°C) in the Rio Grande basin near Del Norte, Colorado, compared with the runoff simulated by data of 1979 (as shown in Figure 27) for April-September.
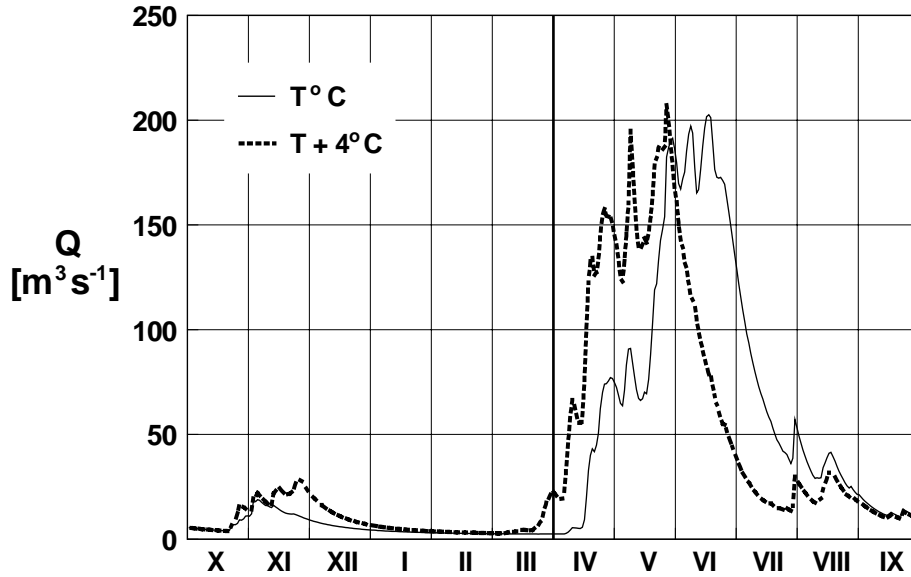
Fig. 34 Simulated runoff in the Rio Grande basin near Del Norte, Colorado in the hydrological year 1979 and climate-affected runoff computed by increased temperatures (T+4°C) and correspondingly changed snow conditions.

Figure 33 shows the climate-affected runoff computed by original precipitation, temperature T + 4°C and snow covered areas according to $CDC_{CLIM\ WA}$ compared with the original runoff simulation in Figure 27. The run is started by discharge computed on 31 March with T + 4°C (see Step (3)). The year-round climate-affected hydrograph thus consists of a winter simulation with T + 4°C and estimated S and of a summer computation by the climate program with T + 4°C and S from $CDC_{CLIM\ WA}$.

Figure 34 shows year-round hydrographs computed with temperatures of 1979 and with temperatures increased by + 4°C. As listed in Table 6, the future winter runoff would be increased at the expense of the summer runoff. The actual effect is greater because the increased climate-affected runoff in late March is carried over to April as recession flow as explained elsewhere (Rango & Martinec, 1997). Proportionally the redistribution of runoff is relatively small because the cold winter of 1979 did not allow much snowmelt even with the increased temperatures (see Section 8.5 about normalization).

In the given example, precipitation was not changed in the new climate but the climate program can also handle the combined effect of changed temperatures and changed precipitation. Usually the temperature effect prevails but, as mentioned in Section 8.2, increased precipitation and absence of melting conditions in high altitudes in winter may convert the "winter deficit" to "winter gain" or "positive winter adjustment". In this case, the computer program derives $MDC_{EXCL\ WA}$ by stretching MDC_{EXCL} proportionally to this gain:

$$g = \frac{P' - I'}{P - I} \qquad (26)$$

where: P, P′ = precipitation in the present and changed climate.
                  I, I′ = winter input (see Equation 24) in the present and changed climate.

Re-writing Equation (24): $\Delta H_W = I - I'$ (27)

If there is no winter input in either case due to low temperatures, a precipitation increase by 20 % results in g = 1.2. The x-coordinates of MDC_{EXCL} (cumulative snowmelt depth) are multiplied by g to derive $MDC_{EXCL\ WA}$ which conforms to the increased water equivalent of the snow cover on 1 April. In the summer half year, the position of $CDC_{CLIM\ WA}$ as opposed to CDC results from the balance of the contradictory effects of an increased initial snow cover and of increased melting.

Table 6 Seasonal redistribution of runoff for 1979 in the Rio Grande near Del Norte, Colorado basin due to climate change

1979	winter		summer		hydrological year	
	10^6 m^3	%	10^6 m^3	%	10^6 m^3	%
Measured	86.53	7.2	1122.43	92.8	1208.96	100
Computed, T	91.87	7.6	1120.15	92.4	1212.02	100
Computed, T + 4°C	146.76	12.3	1046.16	87.7	1192.92	100

8.4 Model parameters in a changed climate

SRM parameters are predetermined which requires more hydrological judgment than mechanical calibration or optimizing. However, as has been pointed out elsewhere (Klemes, 1985, Becker & Serban, 1990, Nash & Gleick, 1991), calibration models are not suitable for climate effect studies because the parameters cannot be meaningfully adapted to the conditions of a changed climate. In the given example from the Rio Grande basin near Del Norte, the seasonal change of the degree-day factor *a* and of the runoff coefficient for snow c_S was taken into account.

The degree-day factor gradually increases in line with snow density while c_S reflects the decline of the snow coverage and the stage of vegetation growth. Since the original CDC′s are moved by about one month earlier (see Figure 32), the values of both parameters were shifted accordingly by 31 days in the climate run. For example, $a = 0.45$ cm·°C^{-1}·d^{-1} selected for May in the present climate was used in April in the warmer climate. The climate program provides for automatic shifting by any number of days. When September values are shifted to August, the value of 30 September is repeated in September. The shifting is stopped in January in order to prevent winter conditions being transferred to the autumn. There is no consensus yet whether a warmer climate will increase losses in which case the values of c_S and c_R would be generally decreased, because a decreased evapotranspiration due to the CO_2 increase might offset the temperature effect (Carlson & Bunce, 1991, Gifford, 1988).

Selected parameters can be shifted or changed in accordance with the expected conditions of a future climate. Future versions will also enable the constants *x, y* for the recession formula to be adjusted if, for example, a steeper recession would be indicated by drier soil conditions.

8.5 Normalization of data to represent the present climate

The climate effect is evaluated by comparing present conditions with conditions modeled by a climate scenario. The present conditions can be represented by precipitation, temperatures, snow covered areas and simulated runoff of a single year, especially if this year appears to be a nearly average year. Apparently, averaging data from a number of years would be more representative. However, using long term average temperatures (which smooths out daily fluctuations) for snowmelt runoff computations, for example, may result in a considerable underestimation of snowmelt and runoff as mentioned in Table 5, case 13. The following procedure is recommended (see also Appendix A, Example 6):

1. Select a hydrological year.

2. Determine deviations of monthly average temperature of the selected year from long term means of monthly average temperatures (see the example ahead):

$$\Delta T = \overline{T}_{year} - \overline{T}_{(long\ term\ average)} \qquad (\Delta T \text{ different in each month})$$

3. Adjust daily temperatures of the selected year to obtain daily normalized values with daily fluctuations preserved:

$$T_{norm} = T_{year} - \Delta T \qquad (\Delta T \text{ different in each month})$$

4. Determine ratios of the monthly mean precipitation of the selected year to long term monthly mean precipitation:

$$r = \frac{\overline{P}_{(long\ term\ average)}}{\overline{P}_{year}} \qquad (r \text{ different in each month})$$

5. Adjust daily precipitation of the selected year to obtain daily normalized values:

$$P_{norm} = P_{year} \cdot r \qquad (r \text{ different in each month})$$

The third variable, the snow cover S, is evaluated differently in the winter half and in the summer half of the year.

Winter (October – March in the Northern hemisphere)

6. Estimate S in the selected year, S_{year}, as described in Section 8.1.

7. Simulate the runoff with S_{year}, T_{year}, and P_{year} to verify whether the estimated S and model parameters are realistic.

8. Adjust S_{year} to ΔT to obtain the normalized S_{norm}.

9. Run SRM with P_{norm}, T_{norm}, and S_{norm} to obtain the normalized winter runoff, representing the present climate.

10. Adjust S_{norm} to T_{CLIM} to obtain S_{CLIM} (see Section 8.1.).

11. Run SRM with P_{CLIM}, T_{CLIM}, S_{CLIM} to obtain the climate-affected runoff.

The difference between the "Norm run" and the "Clim run" is the effect of the climate change on the winter runoff.

Summer (April – September in the Northern hemisphere)

12. Simulate runoff with S_{year}, T_{year}, and P_{year} to verify whether the model parameters are realistic (in summer S_{year} is obtained from satellite data).

13. Run the SRM climate program (see Section 8.4.) with T_{norm}, P_{norm} (in other words, consider T_{norm}, P_{norm} as a new climate) to derive $S_{norm,WA} = CDC_{norm,WA}$ taking into account ΔH_W obtained from winter runs.

14. Continue climate run with P_{norm}, T_{norm}, and S_{norm} to obtain the normalized summer runoff.

15. Run the SRM climate program with P_{CLIM}, T_{CLIM} to derive $S_{CLIM} = CDC_{CLIM}$.

16. Continue the climate run with P_{CLIM}, T_{CLIM}, and S_{CLIM} to obtain the climate-affected runoff.

As mentioned for the winter half of the year, the difference between the "Norm run" and the "Clim run" in summer is the effect of the climate change on the summer runoff.

In theory, identical P_{norm}, T_{norm}, and S_{norm} should be derived be derived from any selected year of present times. Such a result cannot be expected in view of some uncertainties involved in the procedure. However, a normalized data set of T, P, S may be considered preferable to represent the present climate in comparison with the data set from a year which happens to be available but deviates from normal conditions of the present climate.

Years with little snow are not suitable for derivation of a normalized year: if there is no snow in an elevation zone, the normalized depletion curve of the snow coverage cannot be derived.

The normalized precipitation and temperatures are treated as a "changed climate". In a climate run, a shift of parameters is sometimes advisable as mentioned in Section 8.4. It should be noted that the shift becomes automatically part of the climate scenario. For example, if the seasonably increasing degree-day factors are shifted to earlier months, then higher melt rates result, but at the same time the CDC_{CLIM} curves are decreased. If the users want to adjust the normalized runoff by shifting the degree-day factor, they must cancel this automation as described in chapter 10. By taking this precaution, a parameter can be changed by shifting and the resulting runoff will be adjusted accordingly.

Example using actual normalized year

The procedure, just described, in theory is used to derive a normalized year from the 1979 data set. The long term data are monthly average temperatures and monthly average precipitation totals from the period 1957-1994. The program takes these data into account as a "climate scenario" and derives the normalized snow cover (Figure 35) which serves to compute the normalized runoff (Figure 36). This normalized year is labeled 9979 since it is derived from the year 1979. The climate program is then run with the desired climate scenario, in our example T+4°C. Figure 37 shows the climate-affected snow cover and Figure 38 the climate-affected runoff. Numerical data indicating the redistribution of the winter and summer runoff are listed in Table 7. The climate effect for the normalized year 9979 is greater than the climate effect for the selected single year 1979.

Table 7 Seasonal redistribution of runoff for a normalized year in the Rio Grande basin near Del Norte due to climate change.

Year	winter		summer		hydrological year	
	10^6 m^3	%	10^6 m^3	%	10^6 m^3	%
9979 (NORM)	74.66	11.7	561.66	88.3	636.32	100
9979 (CLIM)	153.06	24.2	479.58	75.8	632.64	100

The extremely cold winter in 1979 reduced the effect of a temperature increase T+4°C so that the winter runoff increased only about 60%. With a normalized year for the present climate (1957-1994) the winter runoff is doubled as a result of the same temperature increase.

The WinSRM program enables sets of precipitation and temperature data from various years to be transferred to an actual year as a changed climate. The climate part of the program can thus transform snow conditions (CDC's) and runoff of a year to CDC's and runoff of another year by using precipitation and temperature data of that year. Figure 39 shows the measured depletion curves of the snow coverage in the Rio Grande basin near Del Norte in the extremely wet year 1979 and in the extremely dry year 1977. The resulting hydrographs are shown in Figure 13.

By applying the precipitation and temperatures of 1977 to the year 1979 as a "new climate", it is possible to derive the CDC's and the runoff in 1977, as illustrated in Figures 40 and 41. The acceptable agreement between the originally simulated hydrograph of 1977 and the "climate-affected" runoff of 1979 is the first available test of the climate part of a program for a hydrological model. So far, such test would be only possible by waiting for a climate scenario to materialize. In the described example, the climate scenario consisted of precipitation and temperatures which really occurred in the year 1977.

Apart from this reassurance that the evaluations of the climate effect are fairly realistic, this new capability provided by the WinSRM program improves the real time runoff forecasts. The measured and predicted precipitation and temperatures in a current year can be considered as a changed climate for a selected historic year or for a normalized year, as will be explained in Section 8.6.
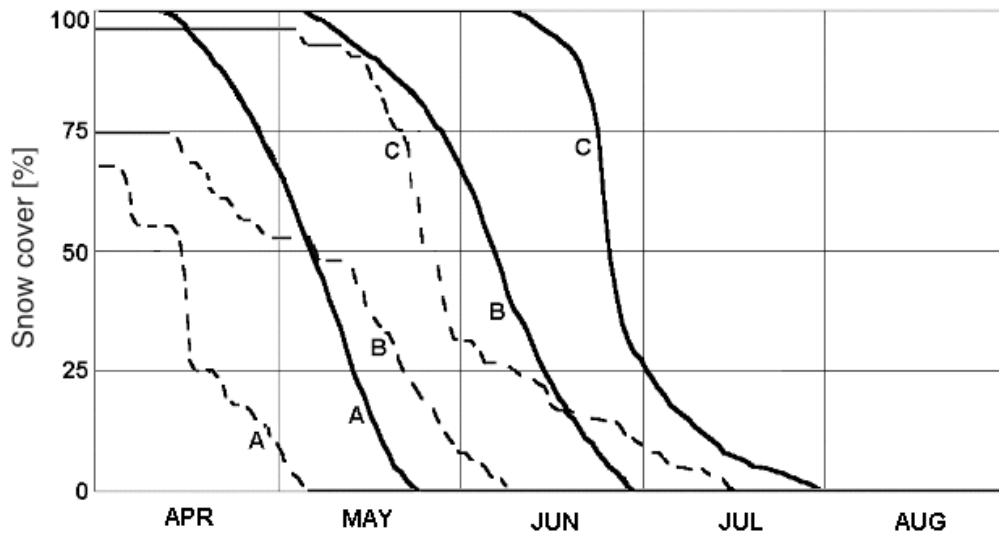
Fig. 35 Normalized depletion curves of the snow coverage (9979) in the Rio Grande basin near Del Norte, Colorado (dashed lines) derived from the measured curves of 1979 (solid lines), zones A, B, and C.
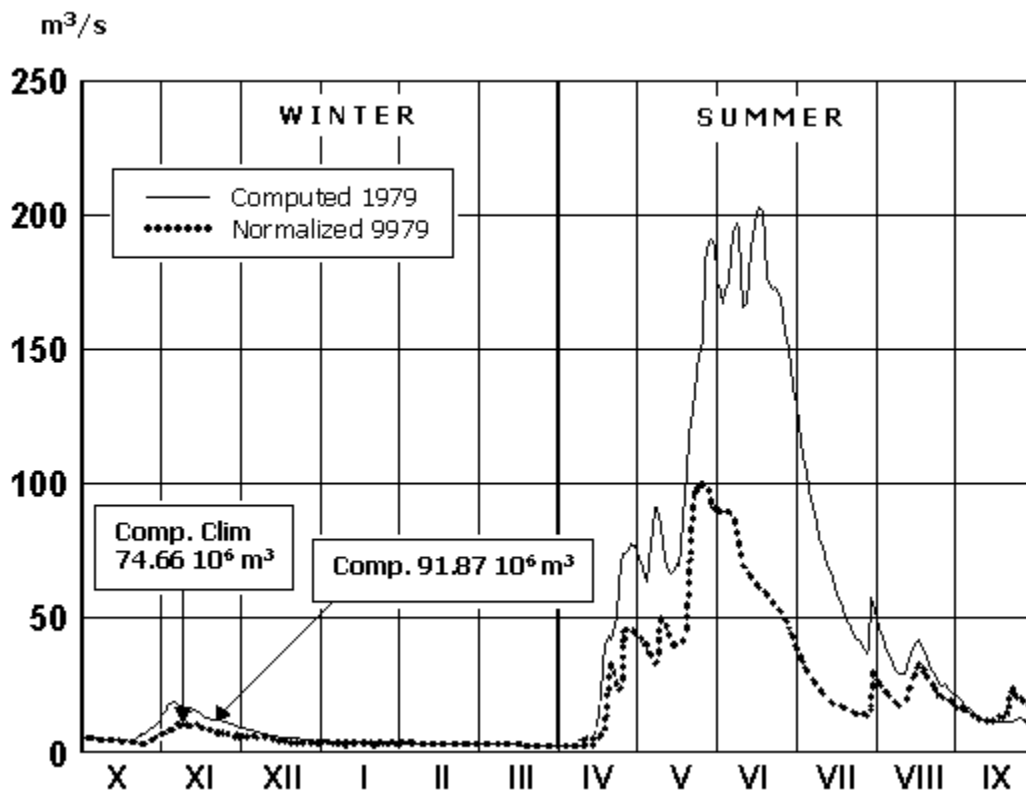
Fig. 36 Normalized runoff (9979) derived from the runoff of 1979 by normalized temperatures and precipitation, Rio Grande basin near Del Norte, Colorado.
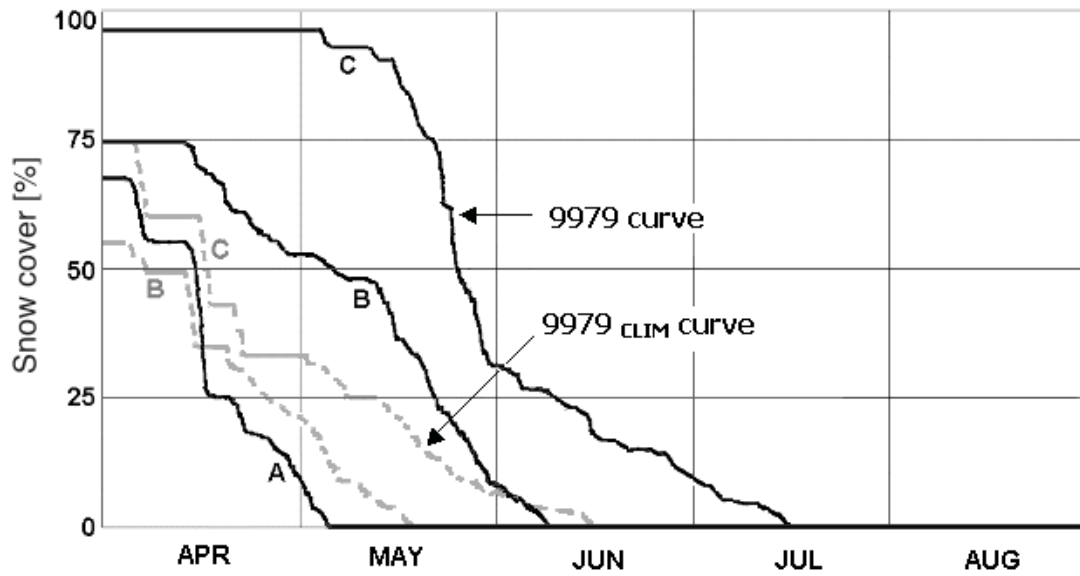
Fig. 37 Effect of a changed climate (T+4 ºC) on the normalized snow covered areas in elevations zones A, B, and C in the Rio Grande basin near Del Norte, Colorado.
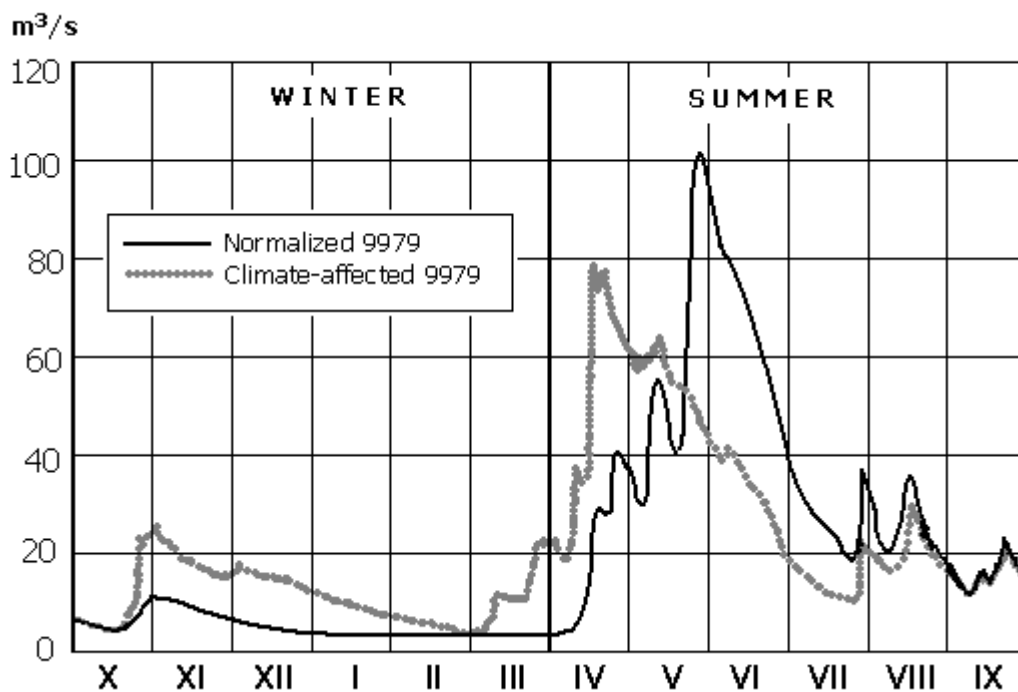
Fig. 38 Effect of a changed climate (T+4 ºC) on the normalized runoff (9979) in the Rio Grande basin near Del Norte, Colorado.
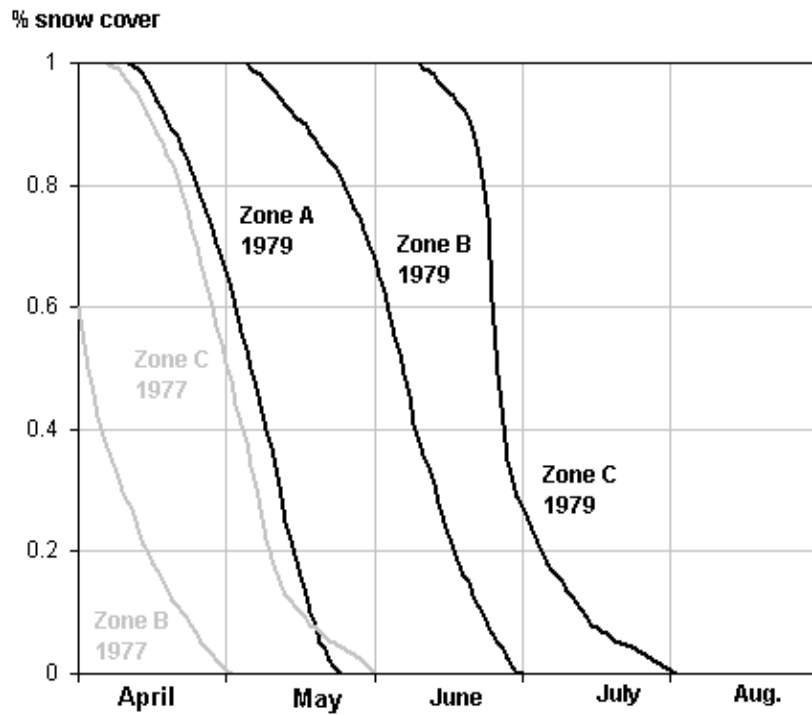
Fig. 39 Conventional depletion curves of the snow coverage (CDC's) in the Rio Grande basin near Del Norte in the years 1977 and 1979.
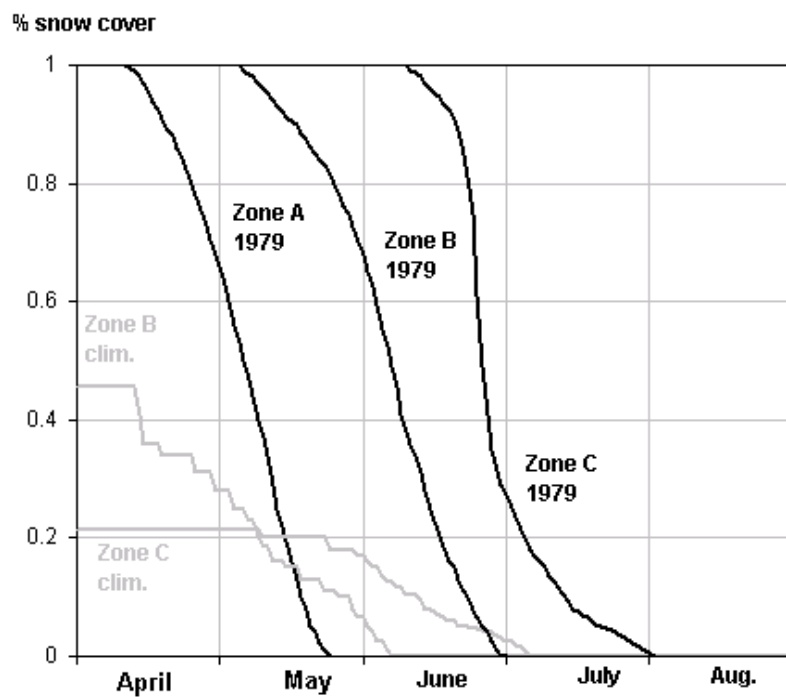
Fig. 40 Depletion curves of the snow coverage (CDC's) in the Rio Grande basin near Del Norte, Colorado measured in 1979 and derived for 1977 by the climate program.
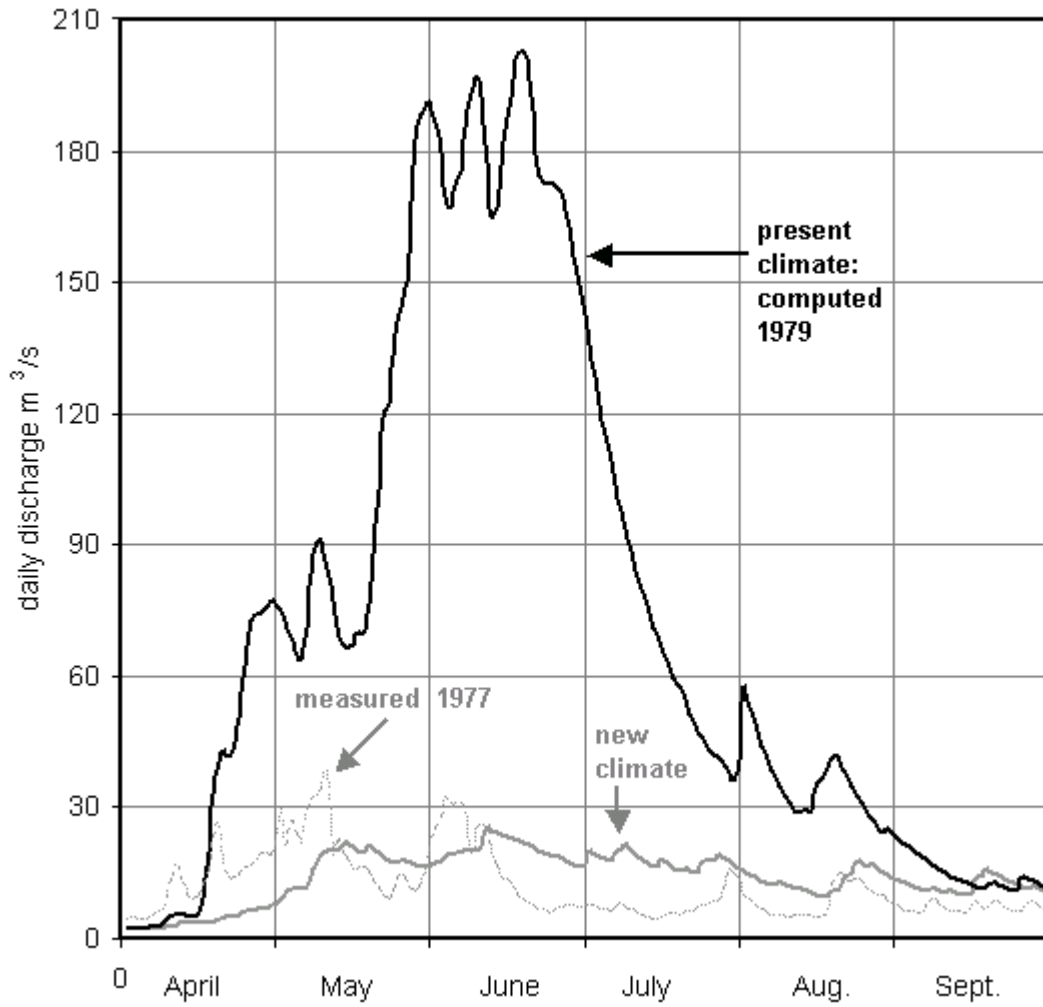
Fig. 41 Transformation of runoff in the Rio Grande basin near Del Norte from runoff in 1979 to runoff in 1977, using temperature and precipitation of 1977 as "new climate" for 1979.

8.6 WinSRM to improve real time runoff forecasts

With WinSRM it is no longer necessary to assemble a set of modified depletion curves, MDC's, as shown in Figure 21 in order to forecast the future course of the conventional depletion curves, CDC's. In a new basin, where these graphs are not yet available, it is sufficient to have one historical year with good satellite data on snow covered areas and the usual daily values of temperature and precipitation.

Based on this data set, runoff starting on 1 April can be forecasted as follows:

1. Runoff is simulated for the available historical year in order to verify the preselected model parameters.

2. The climate program is run for the winter half of the year with the known values of precipitation and temperature, T and P, of the forecast year (F).

3. Snow water equivalent (H_W) on 1 April of the historical year (A) is evaluated using the modified depletion curves $MDC_{EXCL\ A}$

4. Snow water equivalent on 1 April of the forecast year is evaluated from the winter deficit or excess as shown in Equation (24), and the curve $MDC_{EXCL\ F}$ is derived accordingly.

The runoff in the summer half of the year is composed of a guaranteed runoff volume from $MDC_{EXCL\ F}$ (taking into account the losses) and of the forthcoming precipitation. Seasonal runoff forecasts can be issued for different precipitation eventualities.

5. The climate program is run for the summer half of the year considering daily normalized T, P (see Section 8.5) as a "new climate" and $MDC_{CLIM\ WA}$ (in other words $MDC_{INCL\ F}$) is derived.

6. The conventional curve CDC_F is derived from $MDC_{INCL\ F}$.

7. SRM is run with T_{norm} , P_{norm} , and CDC_F .

This is a day-to-day forecast for the next 6 months, assuming normal precipitation and temperature. This forecast can be updated by actual and forecasted temperatures and precipitation.

It is also possible to use as a new climate, instead of T_{norm} ,and P_{norm} , the T and P values of an extremely dry or extremely wet summer, which could occur with a certain probability.

9 RUNOFF MODELING IN GLACIERIZED BASINS

9.1 Runoff increase in a warmer climate from glacier melt

The presence of glaciers (or persistent late-lying snow fields) in an elevation zone is indicated when the decrease of the snow coverage stops at a certain level which corresponds to the glacier area. Approximately from this date on, the daily melt depths (printed out by SRM Version 4 as well as by WinSRM) can be attributed to glaciers instead of the seasonal snow cover, and the total glacier melt depth can be computed.

In a warmer climate the depletion curves of the snow coverage decreases to the glacier area on earlier date and more glacier ice is melted. Again the total amount can be computed from the daily values. For comparison, the glacier melt can also be evaluated from the resulting increase of climate-affected runoff. However, the carry-over from runoff and unmelted snow from the previous hydrological year and to the following hydrological year must be taken into account as follows:

$$R_{CLIM} - R = (P_{CLIM} - P) c + (M_{G\ CLIM} - M_G) c - (ST_{CLIM} - ST) c + (\Delta CO_{CLIM} - \Delta CO) \qquad (28)$$

Where:

$$
\begin{aligned}
R &= \text{runoff depth in a hydrological year [cm]} \\
P &= \text{precipitation [cm]} \\
M_G &= \text{glacier melt depth [cm]} \\
ST &= \text{storage of unmelted snow on 30 September [cm water]} \\
\Delta CO &= \text{difference of carry - overs by recession flow from the} \\
&\quad \text{previous year and to the next year [cm]} \\
c &= \text{runoff coefficient expressing losses}
\end{aligned}
$$

SRM automatically computes the storage of unmelted snow. The carry-over must be separately computed by the recession formula (Equation (7)). The procedure is demonstrated on the basin Illecillewaet, in British Columbia, Canada. Glacier areas estimated from the periodic satellite monitoring are listed in Table 8.

Table 8 Elevation zones and glacier areas in the Illecillewaet basin.

Elevation Zone	Area km²	Elevation Range m.a.s.l.	Glacier Area %	Glacier Area Km²
A	184.8	509 – 1200	---	---
B	408.9	1200 – 1800	---	---
C	468.9	1800 – 2400	4	18.8
D	92.4	2400 – 3150	40	37.0
Total	1155.0			

Figure 42 shows a runoff simulation in the Illecillewaet basin with the following preselected parameters: degree-day factor a = 0.2 to 0.6 cm $^{o}C^{-1}d^{-1}$; snowmelt runoff coefficient c_S = 0.6 to 0.9 ; rain runoff coefficient c_R = 0.6 to 0.9 ; temperature lapse rate γ = 0.65 ^{o}C per 100 m ; critical temperature T_{CRIT} = 0.75 to 3 ^{o}C ; and time lag L = 9 hours. Components of Equation (28) were computed for a hypothetical temperature increase T_{CLIM} = T + 4°C. In the interest of a simple demonstration, we used an average

runoff coefficient, with the same value for snowmelt and for rain, $c_S = c_R = 0.7$ for the period from July to September, and $c_S = c_R = 0.8$ for October. The precipitation remained unchanged.

Figure 43 shows the depletion curves CDC and CDC_{CLIM} for the glacier zones C and D. It appears that the glaciers were covered with snow until the end of September 1984. With T+4°C they became exposed in July and glacier melt took place.

Computed hydrographs for temperatures of 1984 and for T+4°C are shown in Figure 44. In basins without glaciers, for example the Rio Grande near Del Norte (Figure 34), runoff is redistributed by a temperature increase but the runoff total volume remains practically the same: $1,212 \cdot 10^6$ m³ in 1979 and $1,193 \cdot 10^6$ m³ for T+4°C. In the Illecillewaet basin (Figure 44) these total volumes are $1,665 \cdot 10^6$ m³ in 1984 and $1,807 \cdot 10^6$ m³ for T+4°C. This runoff increase can be roughly attributed to glacier melt. For a more accurate result, components of the water balance in Equation (28) can be computed as follows:

$$R_{CLIM} - R_{1984} = 156.44 \text{ cm} - 144.14 \text{ cm} = 12.30 \text{ cm}$$

$$P_{CLIM} - P = 0$$

storage of unmelted snow	1984	T+4°C
zone A	0	0
zone B	0	0
zone C	1.79 cm	0
zone D	10.86 cm	2.03 cm

For the total basin:

$$\textbf{1984} \quad : \quad 1.79 \text{ cm} \ \frac{468.9 \text{ km}^2}{1155.0 \text{ km}^2} \ + \ 10.86 \text{ cm} \frac{92.4 \text{ km}^2}{1155.0 \text{ km}^2} \ = 1.5960 \text{ cm}$$

$$\textbf{T+4°C} \ : \quad 2.03 \text{ cm} \ \frac{92.4 \text{ km}^2}{1155.0 \text{ km}^2} \ = 0.1624 \text{ cm}$$

$$(S_{CLIM} - ST) \ c \ = \ -1.434 \text{ cm} \cdot 0.8 \ = \ -1.147 \text{ cm}$$

The carry-over of runoff is computed by the recession flow formula (Equation (7)), with $x = 1.052$ and $y = 0.037$, as derived in the Illecillewaet basin in the winter.

In the hydrological year 1984, the runoff of the previous day (30 September 1983) was 22.5 m³s⁻¹ and it took 3 days of recession flow, totally 0.453 cm runoff depth, to reach the computed final runoff on 30 September 1984, which was 18.46 m³s⁻¹. Thus, $\Delta CO = +0.453$ cm, a gain from the carry-over balance. For T+4°C the computed final runoff is 22.638 m³s⁻¹ so that a loss, from the carry-over balance, results: $\Delta CO_{CLIM} = -0.017$ cm.

$$\Delta CO_{CLIM} - \Delta CO = -0.017 \text{ cm} - 0.453 \text{ cm} = -0.47 \text{ cm}$$
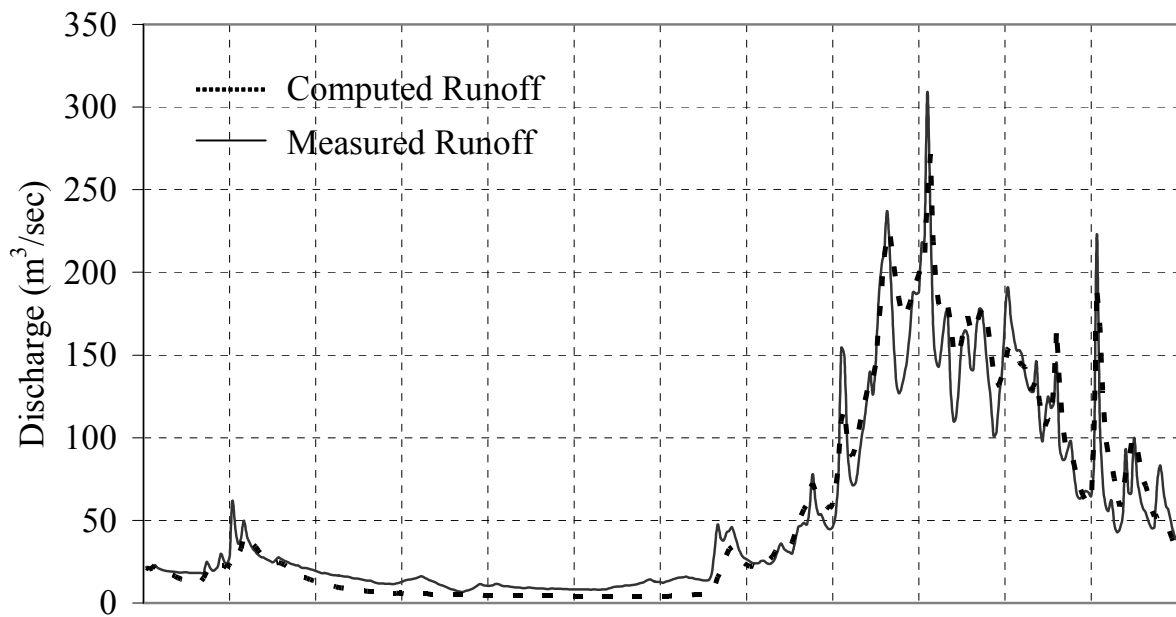
Fig. 42 Measured and computed runoff in the Illecillewaet basin in the year 1984
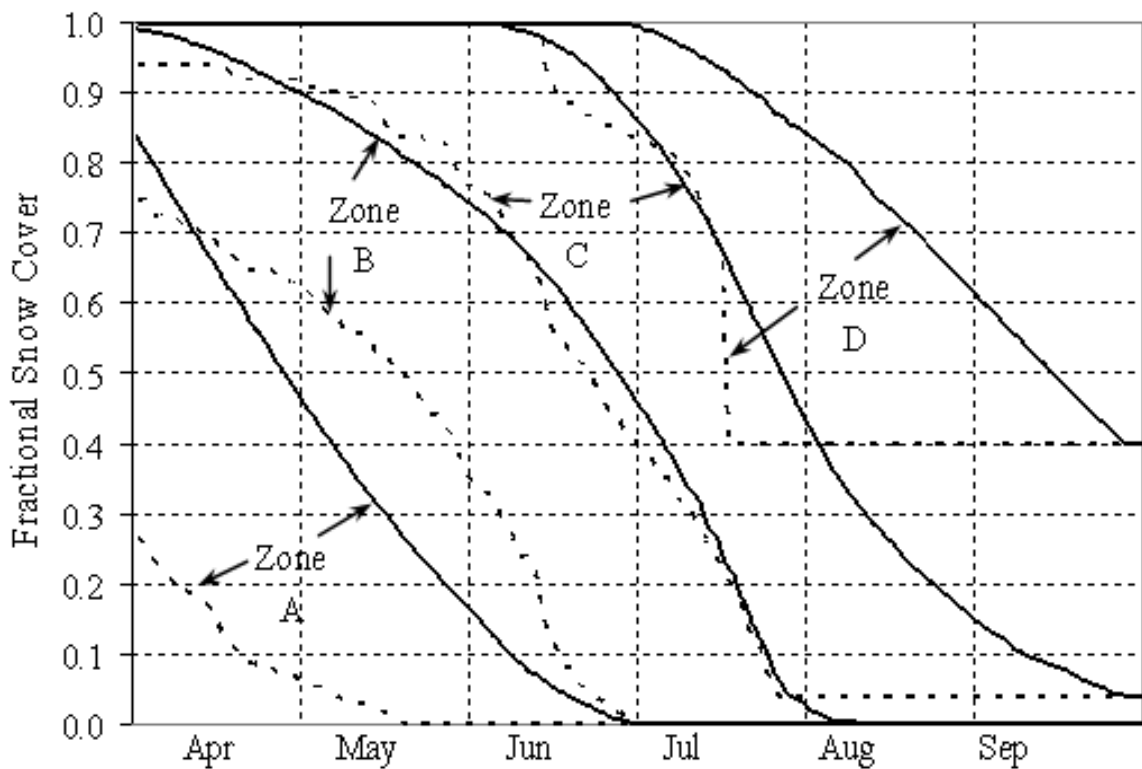
Fig. 43 Measured and climate-affected (T+4 ºC) depletion curves of the snow coverage in all elevation zones including the glacier zones C and D of the Illecillewaet basin.
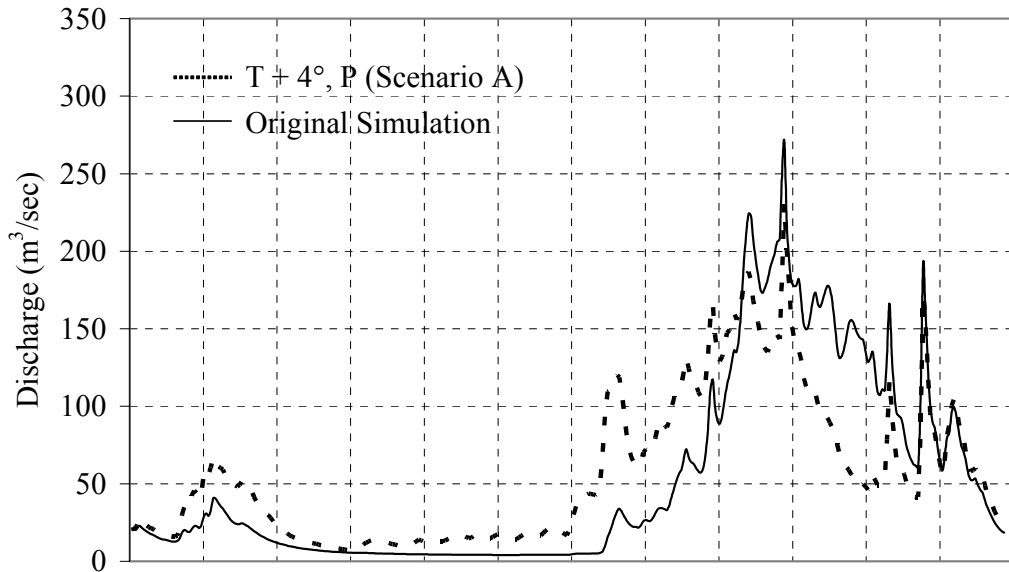
Fig. 44 Computed runoff in the Illecillewaet basin in the year 1984 and climate-affected runoff increased by glacier melt.

Rearranging Equation (28) and recalling that $M_G = 0$, it follows:

$$M_{G\,CLIM} \cdot c = R_{CLIM} - R + (S_{CLIM} - ST) \cdot c - (\Delta CO_{CLIM} - \Delta CO) \cdot c =$$

$$= 12.30 \text{ cm} - 1.15 \text{ cm} + 0.47 \text{ cm} = \underline{\textbf{11.62 cm}}$$

By adding up daily melt depths (starting date indicated by CDC_{CLIM} in Figure 43) a comparable amount is obtained:

Zone C :   26-31 July _____ 2.294 cm · 0.7 = 1.606 cm

August --------------------- 8.61 cm · 0.7 = 6.027 cm

September _____ 3.66 cm · 0.7 = 2.562 cm

Total: 10.195 cm

Zone D :   16-31 July_____ 37.719 cm · 0.7 = 26.403 cm

August --------------------- 52.84 cm · 0.7 = 36.988 cm

September ------------------ 12.62 cm · 0.7 = 8.834 cm

Total: 72.225 cm

Total basin:

$$M_{G\,CLIM} = 10.195 \text{ cm} \cdot \frac{468.9 \text{ km}^2}{1155.0 \text{ km}^2} + 72.225 \text{ cm} \cdot \frac{92.4 \text{ km}^2}{1155.0 \text{ km}^2} = \textbf{9.92 cm}$$

In terms of volume, the net glacier contribution to runoff is $134.2 \cdot 10^6$ m^3 according to the balance method, $114.6 \cdot 10^6$ m^3 from computed daily melt depths, and $142 \cdot 10^6$ m^3 according to the increase of the yearly runoff. This last amount is of course obtained only from an incomplete water balance. This hypothetical example assumes that the warm year occurs in present times. In reality, it can be expected that when such temperature increase is reached, the glacier areas will be in the meantime reduced. Modeling of a long term sequence of years would thus be needed, as outlined in the next section.

9.2 Long term behavior of glaciers in a warming climate

The WinSRM program enables climate runs to use as a "new climate", a set of normalized daily temperatures and precipitation to derive a normalized year (Section 8.5), as well as a data set (T,P) of a historical year, if available, and a data set of a future year, if the data can be generated.

So far, hydrological models took climate scenarios into account in one step. For example, the present climatic conditions were replaced by conditions predicted for the year 2050. This procedure is inadequate for glaciers because temperature will not continuously increase by a fraction of a degree each year. On the contrary, as in the past, temperature will fluctuate from year to year with an underlying increasing trend.

A stochastic series of temperature and precipitation data can be generated (Gyalistras *et al*, 1994) which can reach the values given by a climate scenario in the year in question.

In the starting year, the depletion curves of the snow coverage and the glacier area must be known apart from temperature and precipitation data. The glacier melt volume and the carry-over of the unmelted snow (if any) to the next year are computed. From the glacier melt volume, the reduced glacier area for the next year is estimated by statistically derived relations between the volume and area of glaciers (Bahr *et al*, 1997). With this new area together with temperature and precipitation data, we can evaluate next year's CDC's, the glacier melt volume and carry-over of unmelted snow to the next year. These computations are repeated year by year until the year for which the climate scenario is predicted. In a cold year, the carry-over of unmelted snow will increase and the CDC's will probably not decline to the glacier area, signaling no glacier melt.

Should the stochastic series indicate a sequence of cold years, the amount of unmelted snow by the end of each hydrological year will be built up. It cannot be determined which part of this snow will become part of a glacier. However, sooner or later this snow will be melted, the CDC's will decrease to the last derived glacier area and the glacier melt will start again. Each year the glacier melt volume will result in a reduced glacier area for the next year, until the ultimate disappearance of glaciers. Whether this will happen before or after the target year depends on the intervening weather conditions.

In spite of inherent approximations, this method may prove to be more realistic than mere speculations about the fate of glaciers. As a practical exploit for the management of water resources, in particular hydropower generation, the increase of runoff from glacierized basins in the coming decades can be evaluated.

10 SRM FOR WINDOWS (WINSRM) COMPUTER PROGRAM

10.1 Program overview

WinSRM provides the user with a complete modeling environment in which snowmelt runoff is simulated for mountain basins where snowmelt provides a major contribution to that runoff. The model manages a database of physical data for a given basin, and any number of individual simulation data sets, stored as unique tables in the database. Each simulation is an independent entity operating on a 2-366 day subset of the database's physical database. Simulation results are available to the user via a series of tabular reports and an extensive library of graphical plots. The model environment includes a unique ability to design complex 'scenarios' that describe a future changed climate in a basin, and then simulate the effect of such a scenario on runoff for that basin.

10.1.1 Historical background

The Martinec/Rango Snowmelt Runoff Model (SRM) was originally a FORTRAN model designed to operate on an IBM 370-series mainframe computer. The first computerized version of the model was developed by Martinec *et al.* (1983). In 1986 the model's FORTRAN code was downloaded to an IBM PC and modified to operate in the PC environment. That same year a decision was made to develop a unique PC-oriented version of the model, taking full advantage of the PC's inherent capabilities. The result of that decision was Micro-SRM, Version 1.0.

Additional refinements were incorporated in several subsequent Micro-SRM Versions up to and including 4.0. However, SRM itself remained unchanged and relatively simple, so that the computations by Equation (1) could still be performed by any pocket calculator which has a function x^y. The DOS PC program automatically handles the multiple input of temperature and precipitation for up to 8 elevations zones of a basin, any desired lag time, and complicated snow/rain situations. A model simulation for up to 365 days is finished within several seconds, the computed hydrograph is immediately displayed in comparison with the measured discharge and, if desired, quickly printed. Also, the achieved accuracy is automatically computed and displayed. A summary of parameter values can be displayed after each run so that adjustments can be made and their effect assessed.

SRM does not require numerous runs because calibration is not necessary. The ease with which the results are obtained should not lead to a replacement of the deterministic approach of SRM by a "try and see" philosophy. SRM is designed to operate with physically based estimates of parameters that should not require much change after the initial selection. Seemingly unsatisfactory results have been frequently improved not by adjusting the parameters but by correcting errors in data sets and in the input of variables.

A prime consideration in the design of Micro-SRM was to develop a snowmelt modeling "environment" such that the model user was provided not just model algorithms, but a complete set of tools for managing the associated model processes: data entry, storage and retrieval, display of data, and results. Traditionally, the most time consuming and error prone activity involved in using any physically based model has been the accumulation of large amounts of input data in the form and format needed to drive the simulation, with actual execution of the model a trivial task by comparison. Recognizing this, we chose to pattern the design of Micro-SRM after that originally developed during the automation of the Soil Conservation Service's (SCS) Technical Release Number 55 (TR-55), Urban Hydrology for Small Watersheds (Soil Conservation Service, 1986). This joint ARS/SCS effort provided valuable experience in developing highly interactive "front-ends" for interfacing complex models with model users.

The approach used by the ARS/SCS programming team that automated TR-55 was to develop an efficient, easy to use, highly interactive data entry/manipulation environment, and include model algorithms as just one of many functions that support and use that environment (Cronshey *et al.,* 1985). Micro-SRM consists of an integration of the mainframe SRM FORTRAN algorithms converted to Basic and a variation of TR-55's data entry/data management algorithms.

10.1.2 Program description

The Snowmelt-Runoff Model for Windows (WinSRM) is the first version of SRM that has been adapted for use with the Microsoft Windows operating system (Win 95/98/2000/XP). Limitations imposed on existing and future research by the physical constraints of DOS operating system, as well as its relative obsolescence, were the primary reasons for the transition to Windows.

This new version of the program is compatible with pre-existing DOS .SRM data files. The basic SRM model algorithm remains unchanged, producing identical simulation results to those obtained by the DOS version of the model. The graphical user interface (GUI) and data storage philosophy have undergone a complete redesign to take advantage of the enhanced capabilities available on the modern "windows" platform. All of the original DOS output products (graphs and reports) remain available, with enhancements provided that improve on-line analysis and usability, and off-line quality.

Basins may now consist of up to 16 elevation zones. Modern database technology is utilized to manage the data storage requirements of the model. Storage is organized using the concept of a 'basin' database. Within a basin database resides a single copy of the physical variables for the basin's 'period of record'. All the simulations developed for the basin are likewise located in the same database along with supporting information used by the modeler, such as climate change scenario definitions.

The most significant improvement in the model's capability is in the area of climate change simulation. The limitations imposed on climate change processing by DOS have been removed, allowing a much more detailed and robust definition of change to be studied.

Finally, the path of future research using the model has been laid by moving to an operating system and a model design that minimizes or removes the restraints to development inherent in the earlier design and operating system environment.

The current version of the model, WinSRM, Version 1.11, was developed using Microsoft Visual Basic 6.0 and contains one custom control, Spread 2.5, from Farpoint Technologies[1].

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[1] Trademarks used in this document (e.g., IBM PC, IBM CORP., Visual BASIC, Microsoft Corp.; Spread grid OCX, Farpoint Technologies) are used solely for the purpose of providing specific information. Mention of a trade name does not constitute a guarantee or warranty for the product by the U.S. Department of Agriculture or an endorsement by the Department over other products not mentioned.

10.1.3 Capabilities and limitations

The Snowmelt Runoff Model for Windows (WinSRM) has the capacity to analyze watersheds that meet these criteria:

Table 9. WinSRM capabilities and limitations

Variable	Limits
Maximum basin area	No limit (917,444 km^2 max to date)
Number of elevation zones	1-16
Maximum simulation time period	366 days

10.2 WinSRM user interface

10.2.1 Entry window features

Figures 45 and 46 show some of the commonly used Graphical User Interface (GUI) objects WinSRM uses, with the features labeled.
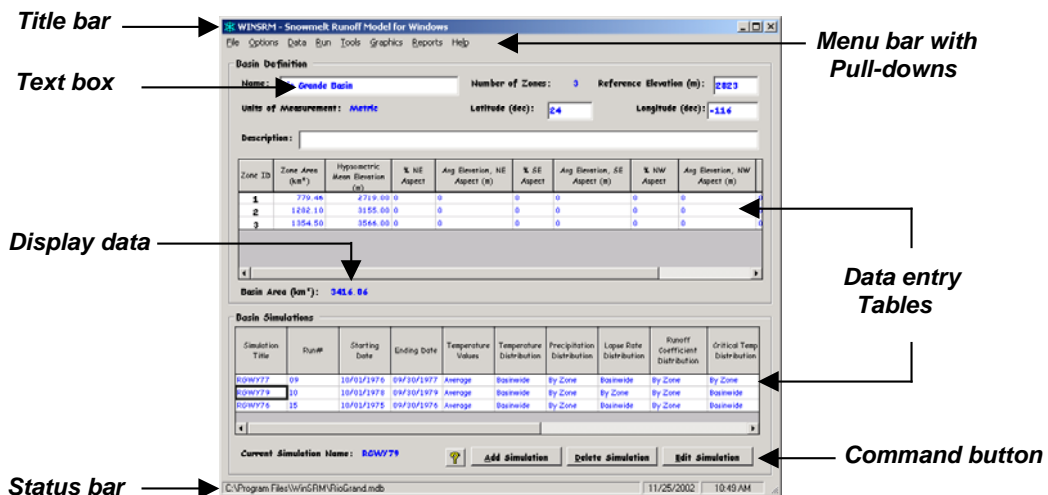
Fig. 45 Objects of the Graphical User Interface (GUI) window

Feature	Function
Window Title bar	Displays title of the window
Menu Bar with Pull-downs	Select menu options with further sub-options. In this text, references to menu choices will be appear in bold italics (*File / Save*)
Text box	Enter a single value into one field
Data entry tables	Enter related data into cells of a row
Display Data	Display only, cannot enter data into a display area

Command button	Click to access the functionality. In this text, references to command buttons will appear in a shaded, bounded box (**Help**).
Status Bar	Displays program status information
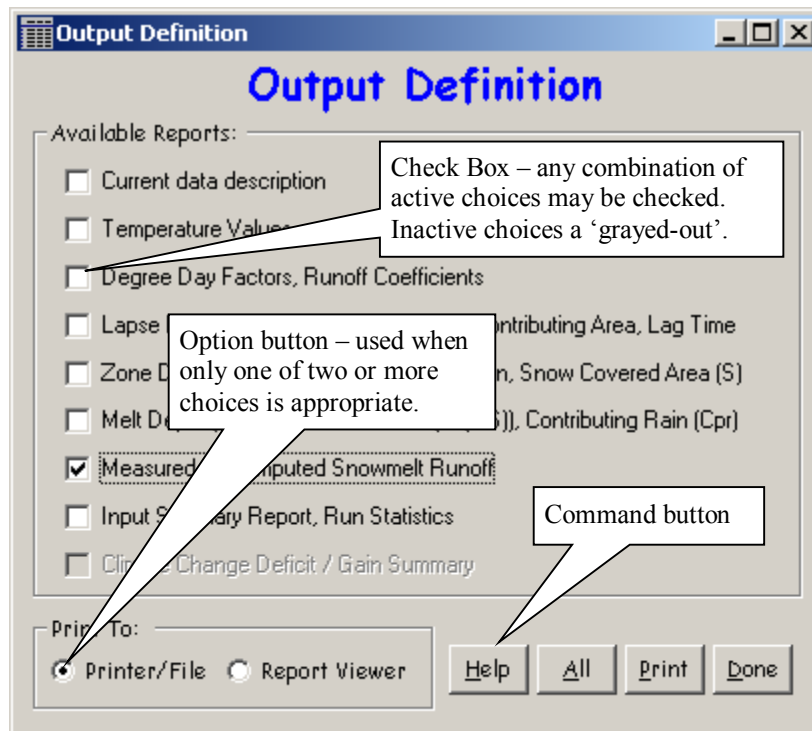
Fig. 46 Additional GUI objects used by the WinSRM interface

Feature	Function
Check box	Used to display multiple choices from which the user can select one or more.
Option button	Used to display multiple choices from which only one choice may be selected.
Command button	Begin, interrupt, or end a process. When chosen, a command button appears 'pressed-in'. Access the button functions using the keyboard by pressing the 'Alt' key, then the corresponding hot (underlined) key.

10.3 WinSRM Window descriptions

As mentioned previously, the WinSRM computer program interacts with the user through a collection of specialized 'windows' and window objects. Each window used by the model provides specific functionality designed to address the tasks inherent in computer modeling. The window descriptions that follow are presented in more-or-less the order that a user might see them upon initial inspection of the program.

10.3.1 Welcome to WinSRM Window

10.3.1.1 Purpose

This windows displays introductory information to the user. To skip this introduction in the future, click in the entry box in the lower left corner. The user may read additional help information or go directly to WinSRM. The window can be subsequently displayed from the *main* program window by clicking the **Help / Show WinSRM Welcome** menu item.

Window 1 - Welcome to WinSRM Window

10.3.1.2 Buttons

   Click to begin using the WinSRM software.
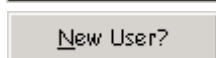
   Click New User to display introductory help text.
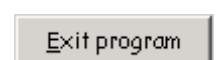
   Click to exit WinSRM. This button is only visible at program startup.

10.3.2 WinSRM main window

10.3.2.1 Purpose

The WinSRM *Main* Window controls the processes and functions that make up the snowmelt runoff modeling environment. The window allows the manual input of the basic information required by the model to define a 'basin' for which modeling will be performed. The window also displays all simulations that have been defined for this basin. Control 'objects', a window 'menu', and command buttons, are provided on this window to provide links to the functionality supported by WinSRM. A description of these control objects follows.
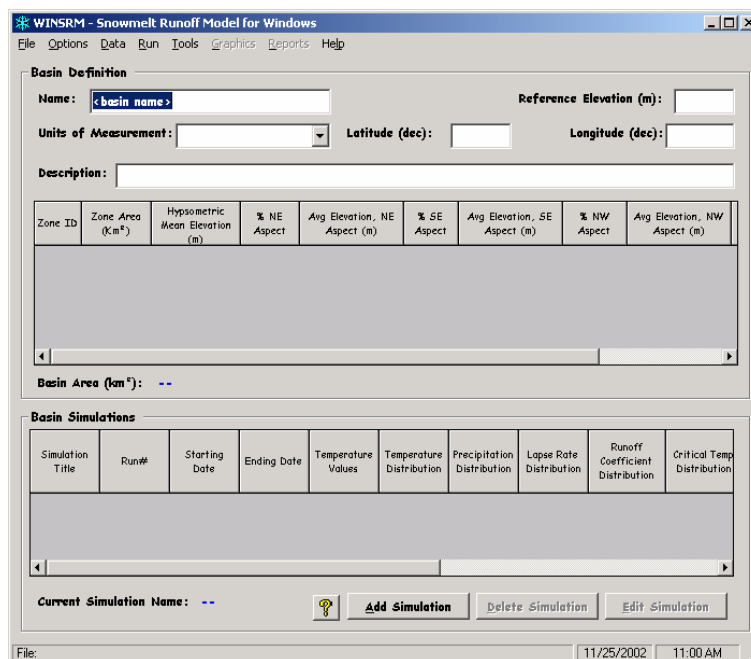
Window 2 - WinSRM Main Window

10.3.2.2 Menu

The WinSRM program menu is positioned at the top of the *main* window (Window 2). The menu consists of eight menu headings, under which all related program functions are grouped. When a main menu heading is 'clicked' or accessed via the keyboard using the menu shortcut key (pressing Alt and the appropriate underlined character) a 'drop-down' sub-menu appears (see Window 3 for an example of a 'drop-down'), providing access to logically-related program functionality.

File

The file menu pull-down (Window 3) groups together all of the functionality for moving information to and from WinSRM memory.
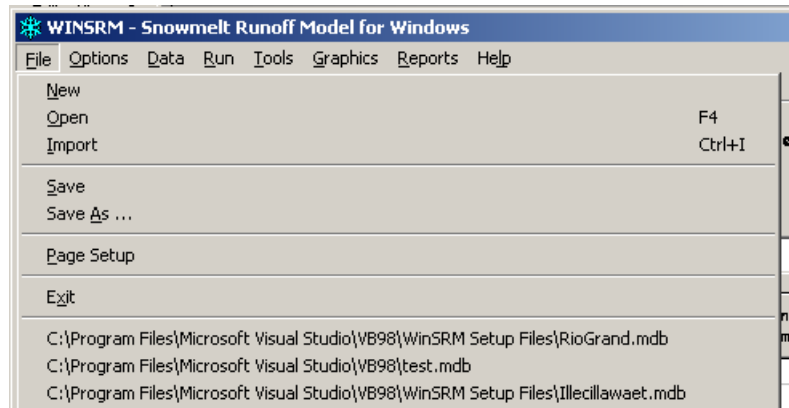
Window 3 - WinSRM Main Window (File Menu)

Menu Item	Drop-down Choice	Explanation
File	New	Create a new basin database
	Open	Open an existing WinSRM database
	Import	Import a DOS .srm data file into a new/existing database
	Save	Save current input database using current file name
	Save As	Save current input database with different filename
	Page Setup	Setup printer for page output
	Exit	Exit software
	List of Recent Files	Click to open one of the four most recently accessed WinSRM databases

Options

The Options menu item provides access to functionality related to the operation and display of the WinSRM software.

Window 4 - WinSRM Main Window (Options Menu)

Menu Item	Pull-down Choice	Explanation
Options	Run year-round simulations in 'No Snow' mode (this option is a research tool. Later versions of WinSRM may not support 'no snow'.)	When checked, the model runs only year-round simulations and forecasts. Snow is disregarded, with all melt coming from precipitation stored during the winter months for later melting as degree-days become available. In normal mode, this 'stored-snow' is set to zero when snow-covered area reaches 100% or on the first day of the melt season, whichever occurs first.
	Clear Recent Files	Clear the list of recently opened files at the bottom of the File menu

Data

The Data menu pull-down provides access to functionality for creating, editing, and displaying simulation parameter data, basin variable data, and climate change scenarios, tables of rules for altering the variables from a current climate to approximate some proposed future climate
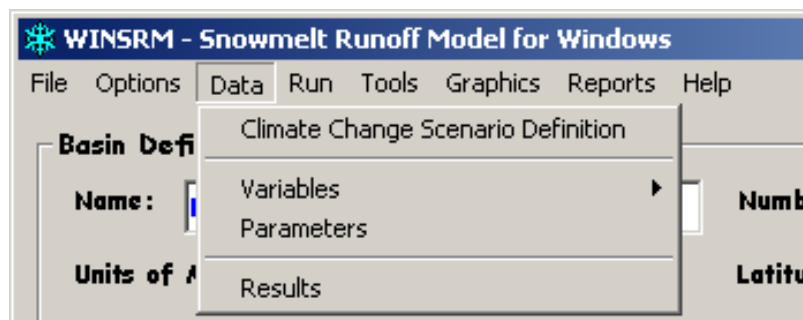
Window 5 - WinSRM Main Window (Data Menu)

Menu Item	Pull-down Choice	Explanation
Data	Climate Change Scenario Definition	Open window that manages climate change scenarios.
	Variables	Open submenu used to specify what physical data to load into the data entry/display window
	Parameters	Open the data entry / display window, loaded with the parameter data for the 'current' simulation.
	Results	Open the data entry / display window, loaded with the results table for the 'current' simulation

Run

The Run menu pull-down (Window 6) directs the user to the appropriate processing path for the task desired. Choosing ***Simulation/Melt season*** or ***Simulation/Year round*** will initiate a traditional SRM simulation. The two are essentially identical. The only distinction between the two is in the graphics plots available after completion of the simulation. Choosing *Melt season* will enable plots 13 through 16

(Appendix B) which only have relevance during the melting season. Two similar forecast processing modes are available under the ***Forecast*** menu. In Forecast mode, the model simulation is updated using measured runoff every 'n[th]' day (n is a user-defined value between 1 and 9). Selecting 'Climate Change' displays another window, the *Run a Climate Change* window ([Window 20](#)), that directs the multiple user interactions required to perform a climate change simulation.
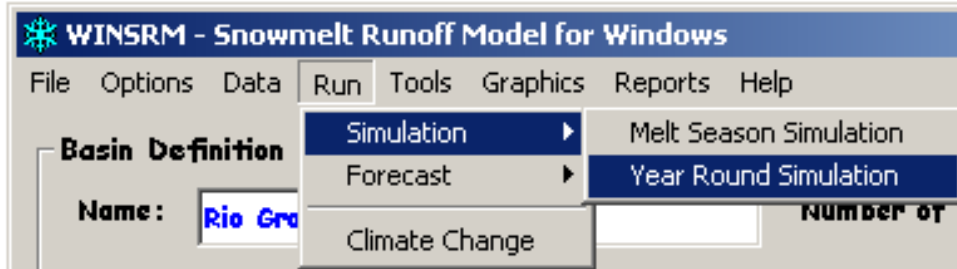
Window 6 - WinSRM Main Window (Run)

Menu Item	Pull-down Choice	Explanation
Run	Simulation (Melt Season)	Run a SRM simulation using the current simulation definition. A 'melt season' simulation activates several graphic plots that are not meaningful for 'year round' simulations.
	Simulation (Year Round)	Runs an SRM simulation for an entire year, using the current simulation definition. Plots not applicable for a year-round simulation are temporarily disabled.
	Forecast (Melt Season)	Run a SRM simulation in forecast mode using the current simulation definition. A separate dialog is presented that allows the user to specify forecast update frequency (see [Appendix F, Message 5](#)). Plot choices are identical to a melt-season simulation.
	Forecast (Year Round)	Runs an SRM forecast for an entire year, using the current simulation definition. Plot choices are identical to a year-round simulation.
	Climate Change	Open the '*Run a Climate Change*' Window, which manages a subsequent climate change model simulation.

Tools

The Tools menu pull-down organizes the additional support processing options available to the model user. When the 'Calculate …' option is selected, the *Long Term Monthly Averages* window (Window 22) is displayed, allowing the user to calculate and display the long term monthly averages for temperature and precipitation for the current basin. The 'Convert from …' choice is currently in development.
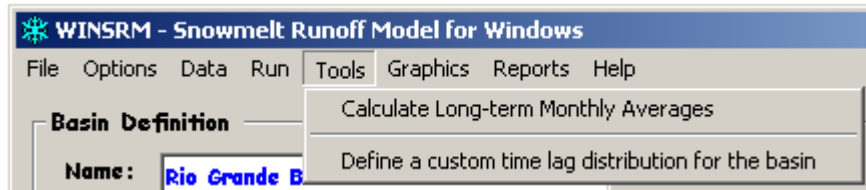
Window 7 - WinSRM Main Window (Tools Menu)

Item	Pull-down Choice	Explanation
Tools	Calculate Long-term Monthly Averages	Displays the 'Long-term Monthly Averages' window (Window 23), which calculates and displays LTMA for several types of physical data for the current basin database.
	Define a custom lag time distribution	Displays the 'Define a Custom Lag Distribution' window, in which a non-standard lag time distribution may be defined. A custom lag-time supersedes all simulation lag time definitions for the life of the model or until the window is reopened and unpopulated (Window 25).

Graphics

The Graphics menu choice transfers control to the *Graphics* window (Window 27) where all the available graphical outputs are selected and produced. Because there is only one option for this menu choice, there is no 'drop-down' menu.
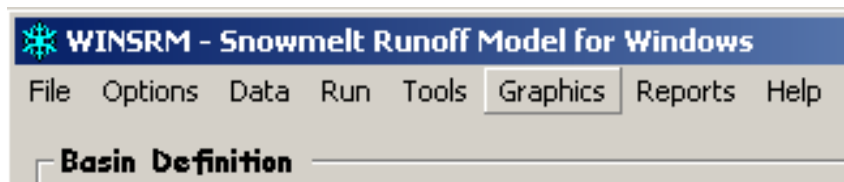
Window 8 - WinSRM Main Window (Graphics)

Menu Item	Explanation
Graphics	Displays the WinSRM *Graphics* window, the window that controls the selection and display of the available graphical outputs.

Reports

The Reports menu choice transfers control to the *Output Definition* window (Window 29), where all the available WinSRM reports are selected and produced. Reports has no 'drop-down' menu.

Window 9 - WinSRM Main Window (Reports)

Menu Item	Explanation
Reports	Displays the WinSRM Reports selection window, the window that controls production of the available tabular reports.

Help

The Help menu pull-down organizes the on-line help choices available for the *main* WinSRM window.
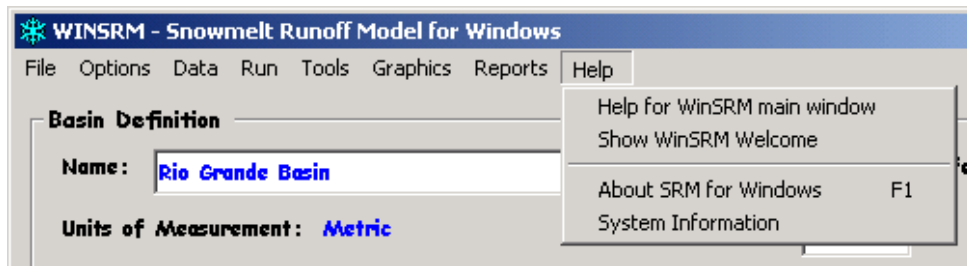
Window 10 - WinSRM Main Window (Help menu)

Menu Item	Pull-down Choice	Explanation
Help	Help for WinSRM *Main* Window F1	Displays help for the *main* window.
	Show WinSRM Welcome	Displays WinSRM Welcome Window
	About SRM for Windows	Displays description of the program, disclaimer, program version number and date
	System Information	Displays information about the your computer

10.3.2.3 Buttons

Add Simulation Click this button to create a new simulation for the current database. The *Edit Simulation Control Information* window is displayed, allowing the user to create the 'shell' parameter data table using default parameter values specified on the window.

Delete Simulation Click this button to delete the current simulation, as denoted on the *main* window. The simulation is highlighted and an 'are you sure?' prompt is issued before the desired action is completed.

Edit Simulation Click this button to display and edit the current simulation in the *Edit Simulation Control Information* window. Be forewarned that editing parameter value(s) for an existing simulation here will over-write ALL values for ALL zones with the default value specified.

[?]   When the QuickHelp for *Main* Window button is clicked, context-sensitive help is displayed for the screen elements and data entry structures within the *main* window that are subsequently clicked.   The help data is displayed near the bottom of the window.   While in help mode, a question mark (?) is displayed next to the cursor. No data can be entered and menu item and button functionality is suspended. Clicking the quickhelp button a second time will disable quickhelp, return to the standard cursor, and enable data entry and other functionality.

10.3.2.4 Basin definition frame

The basin definition frame (Window 2) is a container for the physical characteristics that name, describe, and geo-locate the basin.   This information is simulation neutral, that is, it applies for any simulation defined for the database.

Two values **NEVER** change after their initial definition. Those values are 'Units of Measurement' and 'Number of Zones'.   All other descriptive variables in the frame may be changed at will.   Generally, however, these variables will also be set only once.

The zone definition grid table (Window 31) is the tool for entering and displaying the zonal characteristics of the current basin.   Zone area and hypsometric mean elevation are the only values currently in use by the model.   The remaining (aspect related) table cells are intended for possible future use as variations of the basic model algorithm are developed.

The basin drainage area is automatically calculated using the areas entered in the zone definition grid table, and displayed (in **bold blue)** immediately underneath the table.

10.3.2.5 Basin simulation frame

The basin simulation frame (Window 2, Window 34) is a container used to display the individual simulation definition(s) that have been created for the current basin.   Each line in the frame's data grid (Window 34) represents a unique simulation present in the database.   Clicking on a grid line identifies that simulation as the 'current' simulation.

 The 'current' simulation is an important property the software uses whenever any simulation-related program functionality is accessed.   For instance, if you click the window's **Edit Simulation** button, the parameters for the current simulation are loaded into the *Edit Simulation Control Information* window.

Each grid line constitutes a simulation, containing a variety of control information the model needs to initialize the physical and parameter data sets prior to simulation or climate-change processing.   See Appendix D, SimulationIndex Table, for a description of these control columns. The 'current' simulation name is displayed below the basin simulations grid table in **bold blue.**

10.3.2.6 Status bar

The path and filename of the current basin database is displayed on the left side of the status bar at the bottom of the window (Window 2). If no database is open, the text ' File:' appears in this location.   The remainder of the status bar contains fields for the current date and time.   The same status bar appears on several other larger-size data entry windows.

10.3.3 Edit simulation control information window

Window 11 - Edit Simulation Control Information Dialog

10.3.3.1 Method of access

The *Edit Simulation Control Information* window for a new simulation is accessed from the *main* window by clicking the ⬚ **Add Simulation** ⬚ button, or alternatively, when a DOS .SRM data file is imported using the menu bar *File / Import* function. When dealing with a new or imported simulation, a 'naming' dialog window is displayed:

Window 12 - Naming dialog for a new simulation
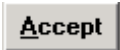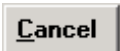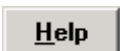
After a name has been assigned, the window is then displayed. To display the window loaded with an existing database simulation, first identify the simulation by clicking on the appropriate grid line, then click the ⬚ **Edit Simulation** ⬚ button. A modified version of the window will display, allowing changes to the simulation control information values only.

The *Initial Parameter Values* frame displays the parameter values for day #1, zone #1 as found in the simulation's parameter table.

10.3.3.2 Purpose

The *Edit Simulation Control Information* window is used to define the initial parameter values and the control information for a new simulation. When a new simulation is created, a parameter table, named after the simulation, is added to the database. The default parameters provided from this window are used to populate the new table by assigning the parameter default value to all corresponding daily values for each zone for the entire simulation period. Once created, the simulation parameter table can be edited in more detail using the Edit Simulation Parameters window, by clicking the *Data/Parameters* on the *main* WinSRM window menu.

10.3.3.3 Buttons

Accept	Accept and apply the changes to the simulation and return to the *Main* Window.
Cancel	Ignore any changes. Return control to the *Main* Window.
Help	Display help window describing the window and its functions.
?	Toggle quickhelp comments related to the window elements/fields.

10.3.4 Edit {type of data} window

10.3.4.1 Method of access

After a current simulation has been identified, by clicking on a row in the Basin Simulations data grid, the variables and parameters used for the simulation may be displayed and edited using the Edit … Window. The appropriate window is accessed through the *Main* Window menu bar.
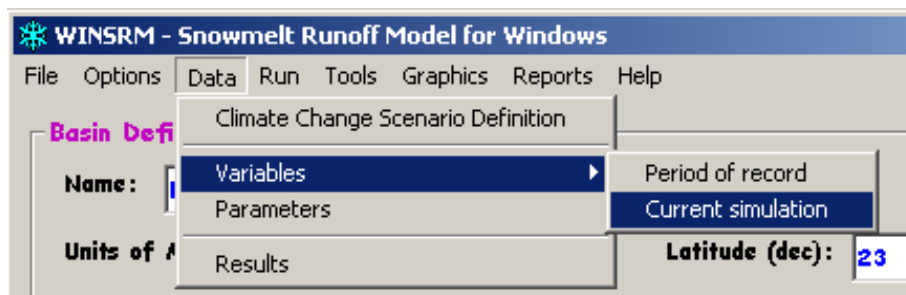
Window 13 - Display the Edit Basin Variables Dialog

10.3.4.2 Purpose

The *Edit Basin Variables Window* (Window 14) is used for detailed editing of basin variables. The same window, with appropriate changes to its title and data grid contents, is used for displaying/editing simulation parameters and simulation results.
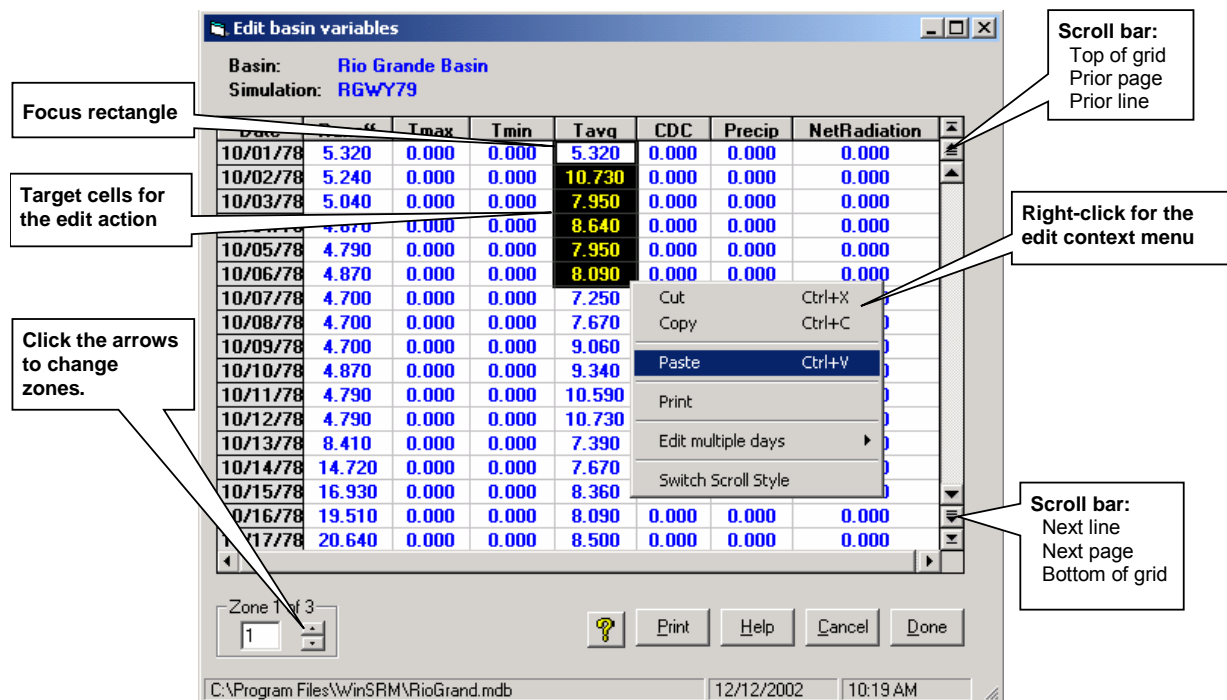
Window 14 - Edit Basin Variables Dialog

The basic structure of the window is the data grid, which displays information related to a given elevation zone. Each line of the grid represents a single day for that elevation zone, with each cell in the line containing the variable or parameter value for that particular day and zone.

10.3.4.3 Data selection / data entry

Click on the up-down arrows at the bottom of the window to switch between elevation zones. To view and edit days/columns that are 'hidden', use the grid scroll bars to reposition the grid's contents to the desired location different day and/or column. The keyboard's cursor (arrow) keys can also be used to reposition the grid display.

To change a cell's value using the keyboard, first identify the cell by moving the focus rectangle to the desired cell using the mouse or keyboard cursors. To 'typeover' (replace) the existing value simply begin typing the new value into the cell. Press the Backspace key to edit modify the existing cell value. The change is completed when focus is move to another cell.

The width of each grid column imposes a limit on the number of characters comprising the data entry value when that data value is manually entered using the keyboard. This is overcome by using the mouse to resize the column. To resize any grid column, simply point at a column title line boundary until the mouse pointer changes to double lines. Then, press and hold the left mouse button while dragging the column boundary to its new location.

Data can be copied to or from the data entry grid on this window using one of several common-editing techniques for grid (spreadsheet) data, as follows:

- Identify a complete column to edit by clicking the column header. The object of the subsequent edit (in this case the column) is highlighted. Then press the right mouse button to expose the 'edit function' context pop-up menu, and click on the desired function to apply to the selected cells.

- Identify multiple complete columns by clicking the first column header, pressing the 'Shift' key, and clicking the last column. The target column(s) are highlighted. Proceed with the edit as described above.

- Identify a cell or range of cells by clicking on the first cell, then, while pressing the 'Shift' key, clicking on the last cell in the range. Proceed with the edit as described above.

- Equivalent keyboard edit commands are supported within the data edit grid. Identify the cell by setting the focus rectangle using the cursor keys. Identify a block of cells by identifying a corner cell of the desired block of cells using the cursor keys, then, while pressing the 'Shift' key, using the cursor keys to move to the opposite corner of the block. Once the block is highlighted, the edit function can be selected from the right-mouse-click edit context menu, or by pressing the Ctrl key then pressing X (cut), C (copy), or V (paste).

10.3.4.4 Buttons
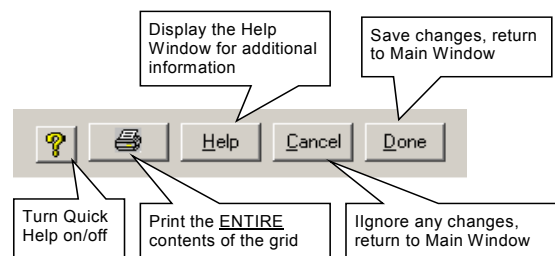
10.3.5 Climate change scenario definition window

10.3.5.1 Method of access

After a current simulation has been identified, by clicking on a row in the Basin Simulations data grid, the climate change scenarios for the simulation may be displayed and edited using the *Climate Change Scenario Definition* window. Display this window by clicking on the *Main* Window menu bar, **Data / Climate Change Scenario Definition** (Window 15).
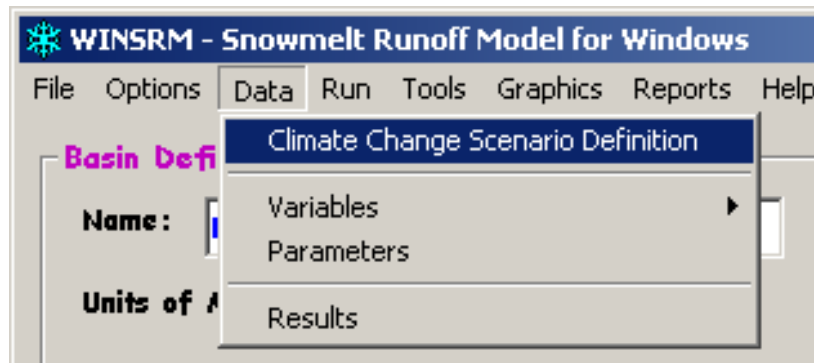
Window 15 - Display the Climate Change Scenario Definition Window

10.3.5.2 Purpose

The *Climate Change Scenario Definition* Window (Window 16) is a specialized editor used to create and manage the various climate change scenarios (CCS) for a given simulation. A CCS is a set of user-provided rules that WinSRM uses to create a modified version of the physical and/or parameter data that will be used to approximate a 'changed' climate for the given simulation period.
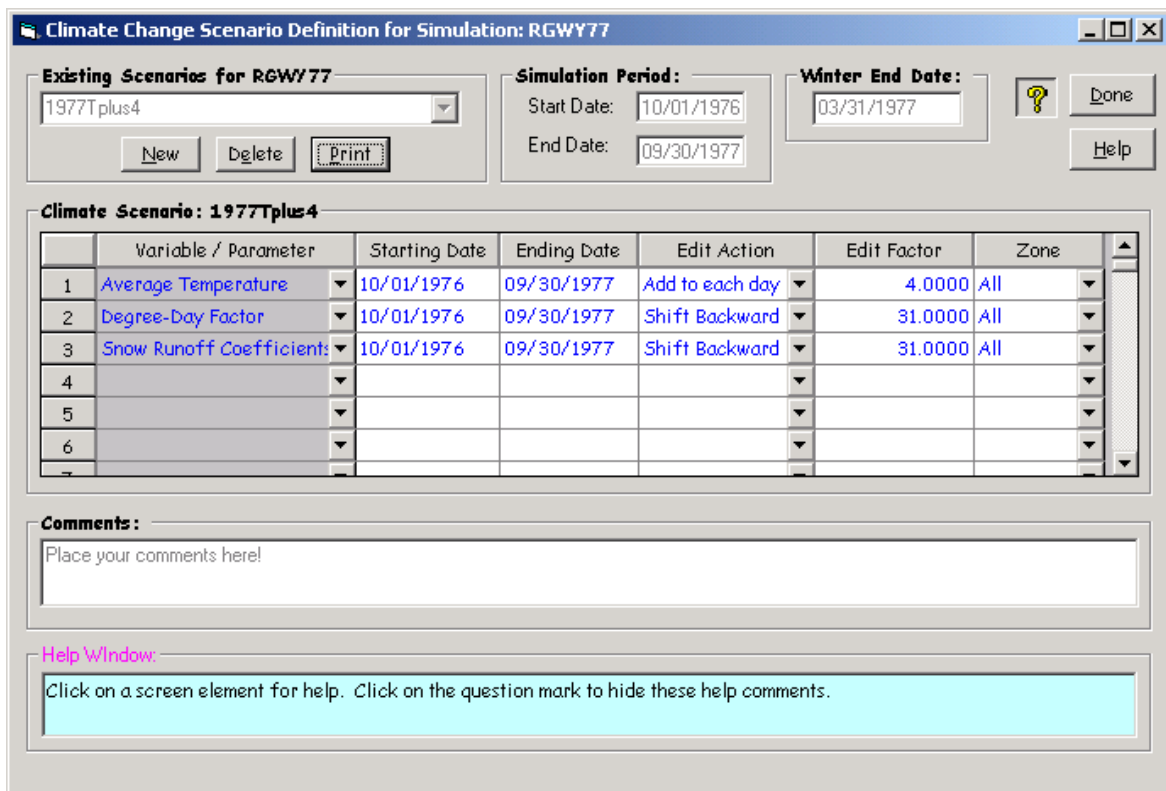
Window 16 - Climate Change Scenario Definition Window

A simple example is to add 4 º to each daily temperature value, in a rough attempt to examine the effect of global warming. Each scenario is stored in the database as a separate, uniquely-named table.

10.3.5.3 Data entry and selection

Select a scenario from the 'Existing Scenarios for …' combo box in the upper-left corner of the window. The scenario rule information is load into the window. To create a new scenario, click the **New** button. A 'naming' dialog will display. Provide a unique scenario name in response.

Enter a 'Winter End Date' if the default provided by WinSRM is unsatisfactory. The default winter end date is the date halfway between the simulation starting and ending dates. A maximum of 500 rules per scenario may be defined, one per line in the Climate Definition grid. Each rule consists of the following component parts:

- Variable / Parameter - Each grid cell is a combo box containing the variables and parameters for which WinSRM will accept climate changes

- Date – the rule must specify the time period for which this change applies

- Edit Action – a combo box of the v
    - Add to each day
    - Multiply each day
    - Shift backward/forward
    - Normalize (temperature and precipitation only)

- Edit Factor – the value applied to the specified data using the specified edit action

- Zone – the zonal scope of the change (all zones, or one specific zone)

A 'comments' text box near the bottom of the window provides a location where the user can self-document the scenario.

10.3.5.4 Buttons
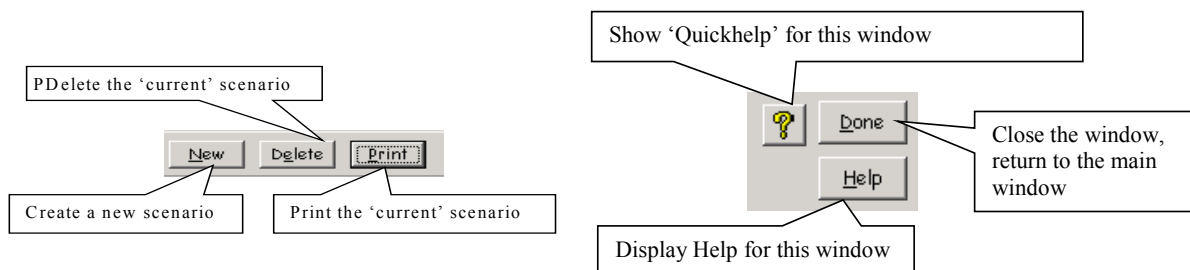
Access the button functions via a left mouse-click or, using the keyboard, by pressing the 'Alt' key, then the corresponding hot (underlined) key.

10.3.6 Simulation statistics window

10.3.6.1 Method of access

After a current simulation has been identified, by clicking on a row in the Basin Simulations data grid, a simulation is initiated by clicking the *Main* Window menu bar, **Run/Simulation/Melt Season Simulation, Run/Simulation/Year Round Simulation, Run/Forecast/Melt Season Forecast, or Run/Forecast/Year Round Forecast** as in Window 17.
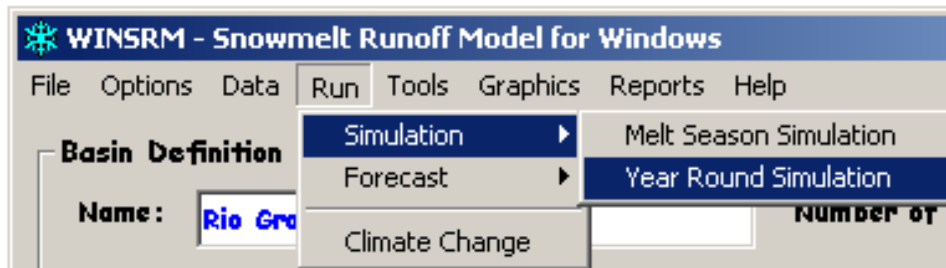
Window 17 - Run a simulation

10.3.6.2 Purpose

The *Simulation Statistics window* (Window 18) appears upon successful completion of the current model simulation. The window displays several important statistics that quantify the accuracy of the calculations. Also displayed for reference purposes are the current date, the source of the simulation data (the database name, and the simulation table name), and the user-provided comments that describe and document the simulation. The window (and any other) can be captured to the Windows Clipboard by clicking on the window title bar to give it 'focus', then pressing Alt_PrintScrn keyboard keys. The window's title bar caption will identify the processing choice selected from the Run menu (see above).
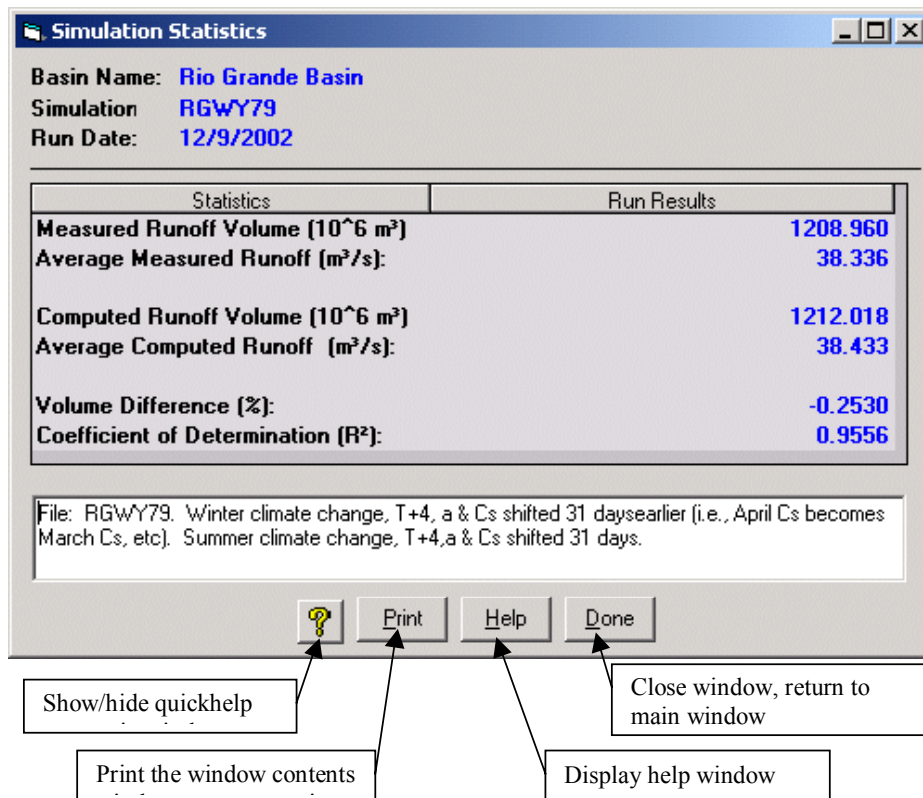
Window 18 - Simulation Statistics Window

Once in the clipboard, the window's image can be pasted into another application that can access the Windows clipboard (via a paste command). The information shown on the window is available as part of the WinSRM 'Measured vs. Computed Snowmelt Runoff' report (see section on reports).

<u>10.3.6.3 Buttons</u>

See Window 18 above. Access the button functions using the keyboard by pressing the 'Alt' key, then the corresponding hot (underlined) key.

10.3.7 Run a climate change window

<u>10.3.7.1 Method of access</u>

After a current simulation has been identified, by clicking on a row in the Basin Simulations data grid, climate change processing is initiated by clicking the *Main* Window menu bar, ***Run / Climate Change*** (Window 19).

Window 19 - Initiate Climate Change Processing

<u>10.3.7.2 Purpose</u>

The *Run a Climate Change* window (Window 20) guides the user through the complex process of simulating climate change in a mountain basin for an entire hydrologic year. The functionality supported by this window can be subdivided into three areas: selection, control, and reporting.
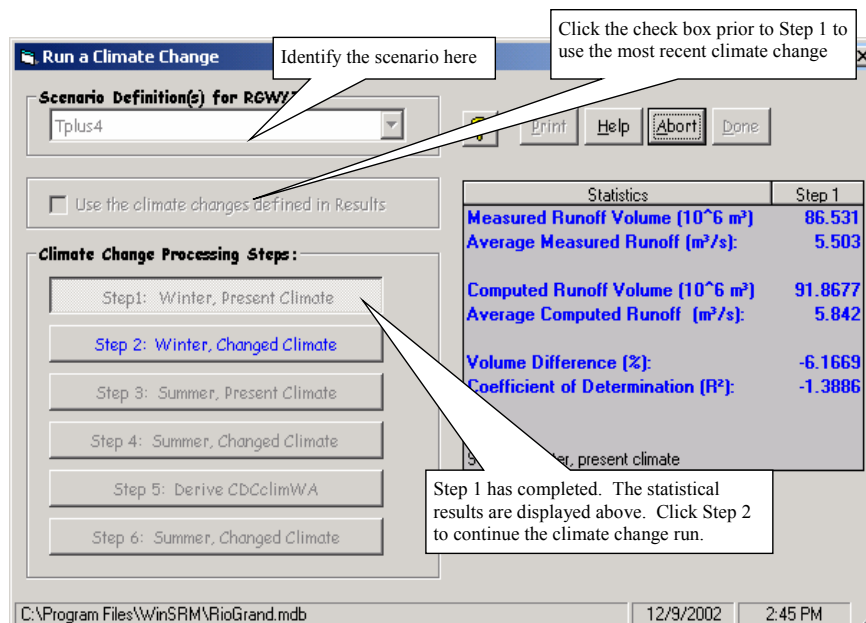
Window 20 - Run a Climate Change

Selection – The first step in modeling climate change is to identify the climate change scenario that will control the process. A climate change scenario (See Climate Change Scenario Definition Window, Appendix D, ClimateScenario table) is a database table containing a set of rules for altering the original variables and/or parameters used with a simulation to approximate a 'changed-climate'. Included in the scenario is a 'WinterEndDate', which separates the simulation period into winter and a summer half-years. The scenario is identified by selecting an entry from the Existing Scenario Definition(s) dropdown combo box, located in the upper left corner of the window. This combo box contains a list of all the climate change scenarios that have been defined for use with the 'current' simulation. An alternative (to be discussed later in this document) is to re-use the climate changes from an earlier climate change run. This is accomplished by clicking the 'Use the Climate Changes Defined in Results' check-box. (Note that you must still select a scenario from the combo box, as that is where WinSRM obtains the 'Winter End Date' value needed during processing.)

Control – After the scenario has been determined, the model is ready to begin processing. A 'climate-change' run is, in reality, four complete iterations through the model algorithms (Steps 1,2,3,6), one partial model execution (Step 4), and a 'data generation step' (Step 5), wherein climate-changed snow cover data is modeled. Each step is executed in sequence by clicking the 'active' button on the Climate Change Processing Steps frame.

Reporting – as each processing step is completed, the *Statistics* data grid is updated to display the statistics resulting from the completion of the step (Steps 1,2,3,6 only). In addition to this reporting of simulation statistics, the user can access the *main* window's plotting and reporting capabilities by clicking on the *main* window menu-bar (*Graphics* or *Reports*)

10.3.7.3 Buttons
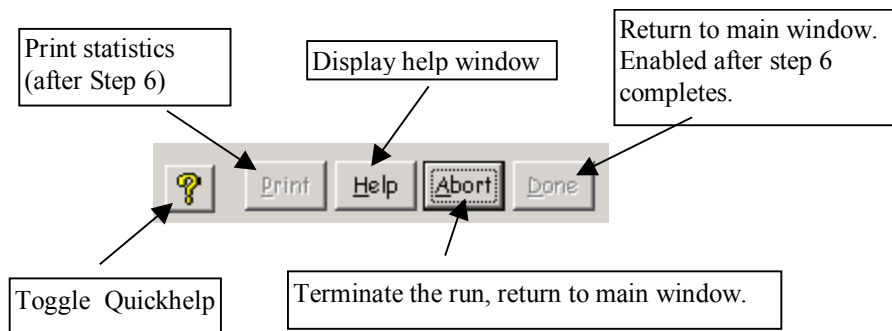
10.3.7.4 Processing steps controlled by the step buttons

Step 1: Winter, Present Climate
Prior to a WinSRM simulation (with on exception), a copy of the pertinent physical data is queried from the database and combined with the current simulation's parameter data table to form a temporary table named 'Results'. There is one Results table per WinSRM database. Each simulation overwrites the existing table. After the Results table is created, companion columns to the variables and parameters that affect climate change are initialized using the associated 'present climate' values, and then modified under control of the rules found in the selected climate change scenario. These companion columns, identified with the 'CC' postfix in the column heading, represent the variables and parameters that define the proposed changed-climate.

The exception noted above occurs when the 'Use the Climate Changes Defined in Results' check box is checked. When checked, the process of building the Results table is bypassed. The Results table built

during the most recent simulation is re-used.   See Appendix A, Example 1 for a discussion of re-using a Results table.

After the Results table has been established, a simulation for the winter half-year is run to determine total zonal melt and total precipitation occurring during winter, under present climate conditions.

Step 2: Winter, Changed Climate

A simulation for the winter half-year is run for the changed-climate.   Changes in total zonal melt and total precipitation are calculated

Step 3: Summer, Present Climate

Run a summer simulation for the present climate. Save the data needed to recreate modified depletion curves, MDC_{EXCL}, accumulated zonal melt curves, AZM_{EXCL} and the simulated runoff hydrograph Q_{SIM}.

Step 4: Summer, Changed Climate

Run a summer simulation for the changed climate. Save $\sum(aT)_{CLIM}$, $\sum(newmelt)_{CLIM}$.

Step 5: Derive CDCCLIM WA using MDCCLIM (adjusted for Winter Change).

(5a) Compute ΔH_W (Winter Change), (Σwinter_zonal_melt$_{NORMAL}$ - Σwinter_zonal_melt$_{CLIM}$, from Steps 1, 2 above).

Reduce/enhance effect of temperature-induced deficit by adding any net change to seasonal precipitation resulting from the climate change scenario. In the case of Illecillewaet, 1984, zones C and D, the scenario T + 4°C, P·1.2, results in a positive Winter Change (increases in P overwhelm the winter deficit in melt). In that case, MDC_{EXCL} is "stretched" rather than "cut-off", as explained in Step (5c).

The Winter Change for Zone … dialog (Window 21) allows a user to over-ride a calculated zonal Winter Change value at this point in the processing sequence. See previous sections for a description of when such intervention might be advisable.
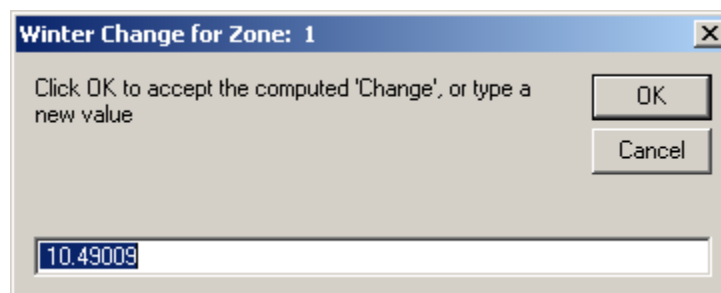
Window 21 - Winter Change for Zone … Dialog

(5b) For each zone, develop zonal melt curve, AZM_{EXCL} ($\Sigma(a \cdot T \cdot S)$ vs Time) for the normal climate. Find the date along AZM_{EXCL} where zonal Winter Change is equaled or exceeded.

At this point, the Climate Change Statistics Report is produced. This printout (disk file if no printer is available) details the calculated values used by SRM to compute zonal Winter Change and the "cutoff" points or "gain factors" used in Step (5c) to derive $MDC_{EXCL\ WA}$

(5c) Create data for a new curve, $MDC_{EXCL\ WA}$.

To understand the methodology for modeling CDC_{CLIM}, it is important to understand the MDC_{EXCL} curve. Each point along the curve is a daily intersection of snow water equivalent independent of melt season snowfalls (Σ ($a \cdot T$-newmelt)), and daily % snow covered area (% S), on the x-axis and y-axis respectively. The data are saved internally by SRM in ascending order, by date. SRM uses two different methodologies for creating $MDC_{EXCL\ WA}$.

- Methodology for winter deficits: Beginning on the date following that identified by Step (5b) above (i.e., the "cutoff" date), all remaining daily values for MDC_{EXCL} {% S and Σ ($a\cdot$T-newmelt)} are shifted backwards in time to the beginning of the melt season. Additionally, as the curve′s x values are shifted, each daily value is reduced by a constant equal to the 1st x value following the "cutoff" date, reestablishing an x origin of 0.0. For example, if a "cutoff" date of 15 April is identified (15 days into the melt season), then all succeeding days for the data constituting the curve are shifted to the corresponding day 15 days earlier, with each daily $\Sigma(a\cdot$T-newmelt) being reduced by $\Sigma(a\cdot$T-newmelt)$_{day\ 16}$

- Methodology for winter surpluses (increased P overwhelms temperature increase for the zone, stretch the MDC). Compute the proportional increase in winter-ending snow water equivalent using values obtained in Steps (1-2) above:

$$\frac{\Sigma\,P_{CLIM}\ -\ \Sigma\,Zonal\_\,Melt_{CLIM}}{\Sigma\,P-\Sigma\,Zonal\_\,Melt} \tag{29}$$

Multiply each x value of MDC_{EXCL} by this factor to "stretch" MDC_{EXCL} creating $MDC_{EXCL\ WA}$.

(5d) Derive a new curve, $MDC_{CLIM\ WA}$, by adding to $MDC_{EXCL\ WA}$ the corresponding daily melt depths of new snow "surviving" in the warmer climate $\Sigma(newmelt)_{CLIM}$ from Step (4).

(5e) For each daily value, n, in $MDC_{EXCL\ WA}$ find the first day on $\Sigma(a\cdot$T)$_{CLIM}$ from Step (4) when the value is equaled or exceeded. Move the corresponding day's snow cover % to day n of the $CDC_{CLIM\ WA}$ array. On days when multiple % S values for the same day in CDC_{CLIM} result, the first (highest) value is used, the remaining values are ignored.

(5f) After all derived values have been calculated for $CDC_{CLIM\ WA}$ SRM completes the new curve, $CDC_{CLIM\ WA\ MA}$ by supplying all missing daily snow cover values using the following logic:

- Missing days that lie between two days with derived values will inherit the earlier day′s derived % S value.

- All missing days following the last derived daily value will inherit a 'residual value' that is determined in two different ways depending upon the difference between the last derived daily value and the corresponding value in CDC_{NORMAL} The normal difference will be negative ($CDC_{CLIM}< CDC_{NORMAL}$). In this situation, the residual value is set equal to the last % S value in the CDC_{NORMAL}. This value will typically be zero, except in cases where the zone includes a glacier or permanent snow cover. In the infrequent cases where the difference is positive ($CDC_{CLIM}> CDC_{NORMAL}$) each missing daily value after the last derived day will take on the corresponding day′s % S value from CDC_{NORMAL} plus the difference.

(5g) Plot MDC_{EXCL} and $MDC_{EXCL\ WA}$

(5h) Plot AZM_{INCL}, AZM_{EXCL}, $AZM_{EXCL\ WA}$.

(5i) Optionally plot $MDC_{EXCL\ WA}$, $MDC_{CLIM\ WA}$.

(5j) Plot CDC, $CDC_{CLIM\ WA}$.

(5k Replace CDC with $CDC_{CLIM\ WA,\ MA}$.

Step 6: Summer, Changed Climate

Run a final summer simulation for the changed climate. This run uses the existing climate-change scenario with the derived $CDC_{CLIM\ WA,\ MA}$ curves to produce runoff after the climate change, Q_{SIM}. After completion of step 6, the model 'changes state'. Several new plots (Appendix B) and a new tabular report are enabled to augment the model's output options.

10.3.8 Long term monthly averages window

10.3.8.1 Method of access

The *Long Term Monthly Averages* Window is displayed by clicking the *Main* Window menu bar, **Tools /**
Calculate Long-term Monthly Averages (Window 22).
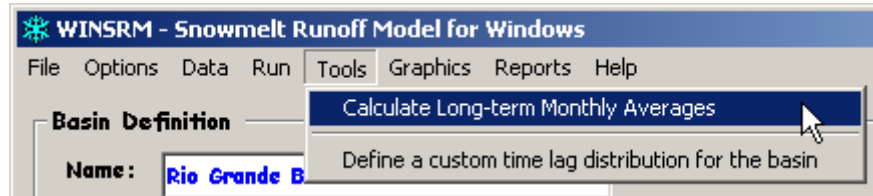
Window 22 - Access the Long-term Monthly Averages window

10.3.8.2 Purpose

The *Long-term Monthly Averages* Window (Window 23) calculates and displays monthly averages for
daily maximum temperature, daily minimum temperature, daily average temperature, and daily
precipitation for the period of record reflected in the current basin database. The averages are stored in
the 'Basin Averages' database table.

Window 23 - Long-term Monthly Averages Window

These monthly averages are used during climate change processing when the climate change scenario
includes the 'normalize' edit action for temperature and/or precipitation.

To normalize daily temperature values, the program calculates the difference between the monthly
average temperature (simulation) and monthly average temperature (period of record), and applies that
difference, or normalization factor, to each daily temperature value in the respective month. The resulting
set of normalized temperature values are then used to define the 'changed-climate'.

 Normalizing precipitation involves multiplying each daily precipitation value for the zone by the ratio of the long-term monthly average precipitation over the current monthly average precipitation.

10.3.9 Custom lag time distribution window

<u>10.3.9.1 Method of access</u>

The *Custom Lag Time Distribution* Window is displayed by clicking the *Main* Window menu bar, ***Tools / Define a custom time lag distribution for the basin*** (Window 24).
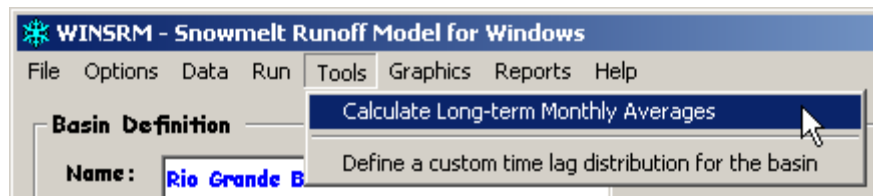
Window 24 - Access the Long-term Monthly Averages window

<u>10.3.9.2 Purpose</u>

The *Custom Lag Time Distribution* window (Window 25) provides an alternative method for establishing a time distribution for allocating snowmelt over multiple days. When used, this 'custom' allocation overrides the time-lag values present in the simulation tables found in the basin database. See Section 5.3.7 for more information on the time lag parameter
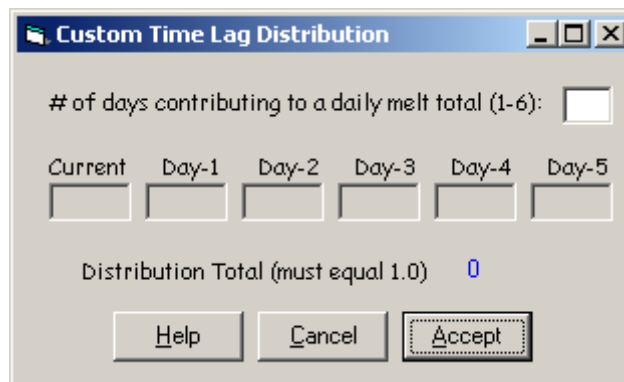
Window 25 - Custom Time Lag Distribution Window

10.3.10 Graphics window

<u>10.3.10.1 Method of access</u>

The *Graphics* window is viewed by clicking ***Graphics*** on the Window menu bar (Window 26).
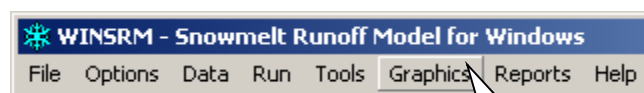
Window 26 - View Graphics Window

10.3.10.2 Purpose

The *Graphics* Window (Window 27) is the tool provided by WinSRM to manage the presentation and manipulation of simulation parameter data, basin variable data, and simulation results in a graphical format.
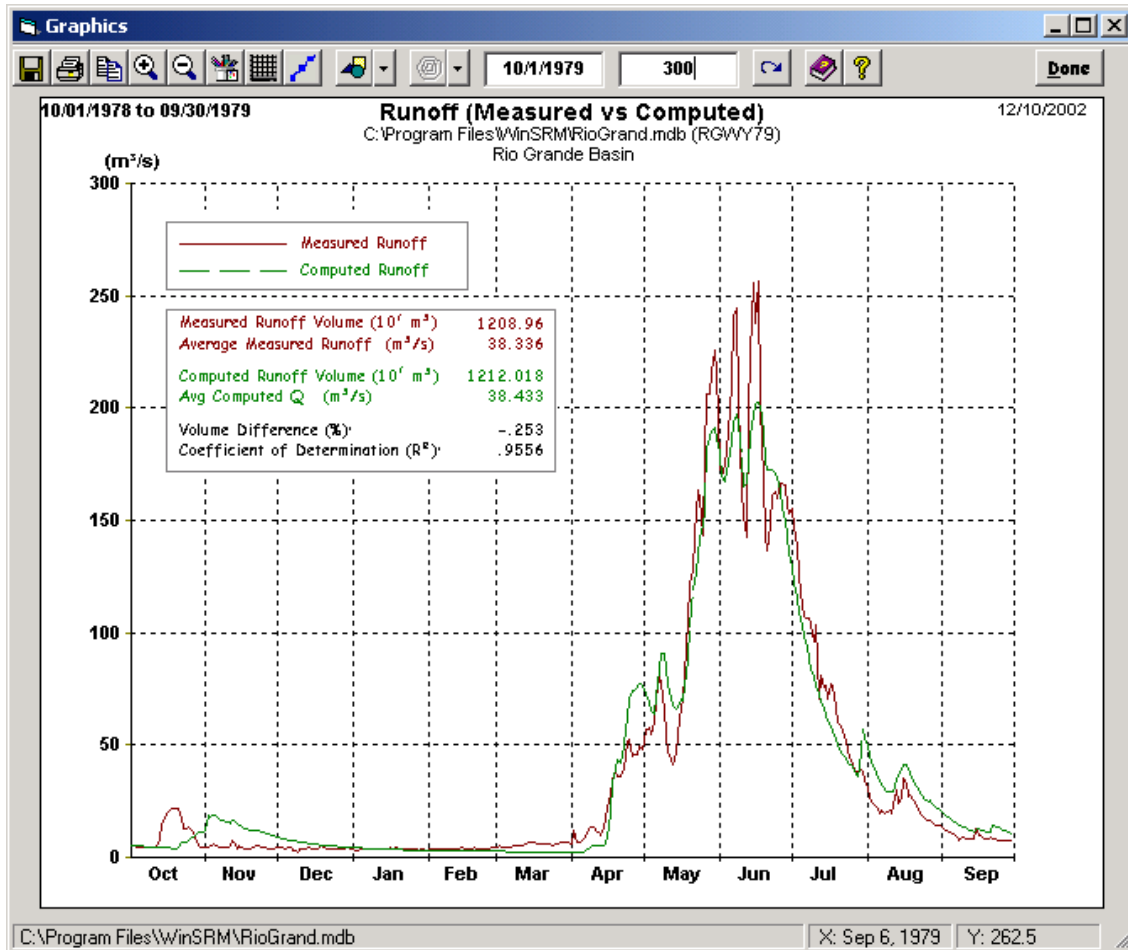
Window 27 - Graphics Window

10.3.10.3 Button-bar menu

The button bar menu at the top of the *Graphics* window (see above and Appendix B) provides easy access to all the underlying functionality supported by the window. The following buttons are found on the button-bar:

🖫	Save the image as a bitmap(.bmp) file or a text (.txt) file. Beginning with version 1.00.10, a third output format (.flx) is supported. This option saves the flow data in a form compatible with the SLURP model. Flow values saved in the Slurp format are always metric (cubic meters per second). The model automatically converts English format flow values to metric.
🖨	Print the screen to a printer
🖹	Copy the image to the Windows clipboard
🔍	Make a vertical subset of the image to magnify
🔍	Redisplay the image at its original resolution
🔧	Display a window (Window 26) to edit the current graphical attributes
▦	Change the grid style (none, vertical, horizontal, both)
📈	Add/remove markers for the points on the plot line(s)
📊▾	Drop-down menu of the available plot choices (Appendix B)
◎▾	Drop-down menu of available zone choices (if applicable)
📖	Displays the *Help* Window with additional information about the window
❓	Shows/hides 'Quickhelp', short descriptions of the window elements
↻	Redraw at revised scale (only displays when scale factor changes, see below)
Done	Close the window and return to the *Main* window

Plots are drawn using default scaling derived from the data been depicted. To alter the scale, for instance, to enhance comparison of similar plots, there are two text boxes located on the button bar, one for maximum x value, one for a maximum y value. When a value in either box is changed, the 'Redraw' button is added to the button bar (see example below). When it is 'clicked', the current plot is redrawn using the modified scaling factors.

Button bar, default scale	Button bar, modified scale
10/1/1979 256.21	10/1/1979 300

Each plot includes a legend box that displays an identified sample of each line shown on the plot. Hydrograph plots also include an additional legend box displaying the statistics resulting from the simulation that generated the hydrograph. Both legend boxes can be repositioned on the plot by dragging them to another, unused, position.

The mouse cursor changes from its normal (arrowhead) shape to a move (cross with four arrowheads) shape when moved over a legend box. To move a legend, move the cursor over a blank area of the legend, press and hold the left mouse button, and drag the legend to the desired location, then release the mouse button. The legend's upper-left corner will assume the position at the cursor when the mouse button is released. For this reason, we recommend that, when moving a legend, you position the mouse cursor over the existing upper-left corner of the legend box before initiating the drag-drop. Also, the program will not allow one legend to be 'dropped' over itself or another legend.

10.3.11 Line attributes window

10.3.11.1 Method of access

The *Line Attributes* window is viewed by clicking [icon] on the *Graphics* window button-bar.
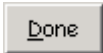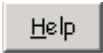
10.3.11.2 Purpose

The *Line Attributes* window (Window 28) is the tool provided by WinSRM to customize and enhance the plots presented in the *Graphics* window through use of color, line thickness and line style.
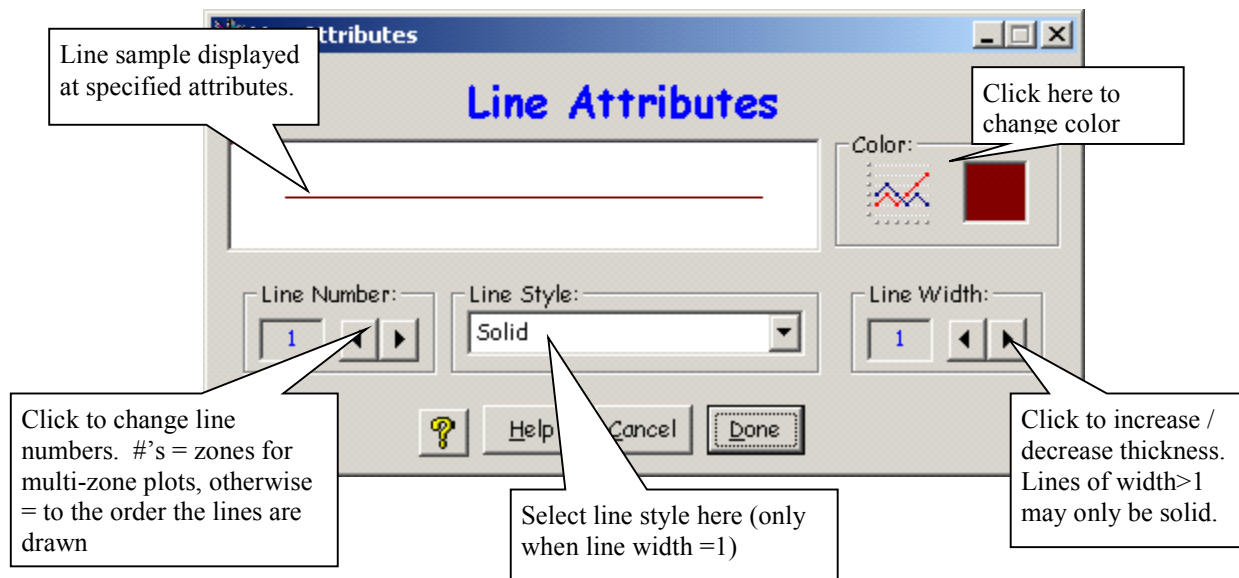
Window 28 - Line Attributes Window

10.3.11.3 Buttons

Done	Close the *Line Attributes* window. Redraw plot in *Graphics* window using the new attribute set.
Cancel	Close the window, return to the *Graphics* window. Ignore any changes.
Help	Close the window, return to the *Graphics* window. Ignore any changes
?	Toggle quickhelp comments related to the window elements/fields

10.3.12 Output definition window

10.3.12.1 Method of access

The *Output Definition* window is viewed by clicking Reports on the Window menu bar (Window 9).

10.3.12.2 Purpose

The *Output Definition* Window (Window 29 is the tool provided by WinSRM to manage the presentation of simulation parameter data, basin variable data, and simulation results in tabular formats. The report choices on the window are dependent upon the current state of model operation. For example, reports that include calculated results are not available until a successful simulation has completed. Reports are unavailable when they appear in the window as 'disabled' choices, light gray in color and unresponsive to mouse clicks.
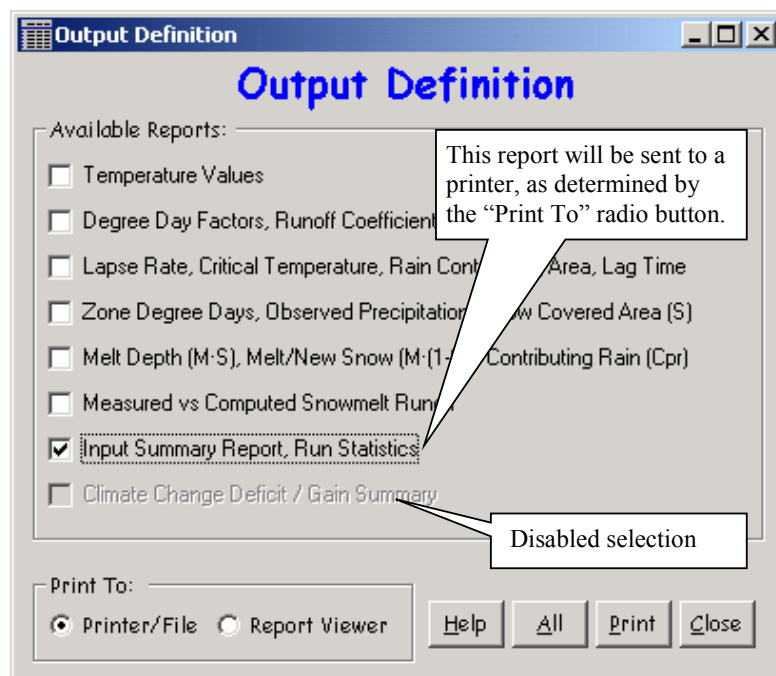
Window 29 - Output Definition Window

10.3.12.3 Buttons

| Close | Click "Close" to close the *Output* Definition window and return to the WinSRM *Main* window. |

| Print | This button caption toggles between View and Print, depending on which option button is selected, either Printer/File or Report Viewer. |

| All | If there are reports not checked, the button caption is "All". Click "All" to check all the reports. When all the reports are checked, the caption toggles to "Reset", which will clear all the check boxes. |

| Help | Click "Help" to display the help text for the *Output Definition* Window |

10.3.12.4 Available reports

Available reports shown in the *Output Definition* window are shown in the following summary

Report Name	Description
Current data description	Lists the current user-input data.
Temperature values	A listing of the observed temperature data used with the current simulation. The type of temperature information (average, max/min) is determined by the simulation's temperature-type control value.
Degree-day factors Runoff coefficients	Parameters for the current simulation. This report is for one zone, or all zones, depending on the parameters' distribution modifiers.
Lapse Rate Critical Temperature Lag Time	Parameters for the current simulation. This report is for one zone, or all zones, depending on the parameters' distribution modifiers.
Zone Degree Days (DD) Observed Precipitation Snow Covered Area (S)	A table of the physical data for degree-day temperature, precipitation, and snow cover for each elevation zone. DD values are calculated during a simulation. If changes are made to the input data afterwards, the table will display '**' for each DD value, and add a footnote to the table requesting a new simulation run.
Melt Depth (M·S) Melt/New Snow(M·(1-S)) Contributing Rain (Cpr)	A table displaying three important zonal values derived by the model during the simulation.
Measured vs. Computed Snowmelt Runoff	A table comparing daily basin runoff derived by the model with observed daily basin runoff, if available. Run statistics are included in this report.
Input Summary Report Run Statistics	A summary of bimonthly values (1st, 16th) for 7 model parameters is printed for each zone in the basin. Run statistics are for the most current model simulation.
Climate Change Deficit / Gain Summary	The Climate Change Deficit/Gain Summary presents the computed values used to derive climate-affected snow cover.

10.3.13 File display window

10.3.13.1 Method of access

The *File Display* window, also referred to as the Report Viewer, is displayed from the *Output Definition* window (Window 29) by selecting a report or reports, clicking the *Print to Report Viewer* radio button, then clicking the [View] button.

10.3.13.2 Purpose

The *File Display* window (Window 30) is a tool provided by WinSRM to preview one or more 'printed' tabular reports available for use at any given point in the modeling process. Reports that include calculated values may be viewed only when a model simulation has been successfully executed.
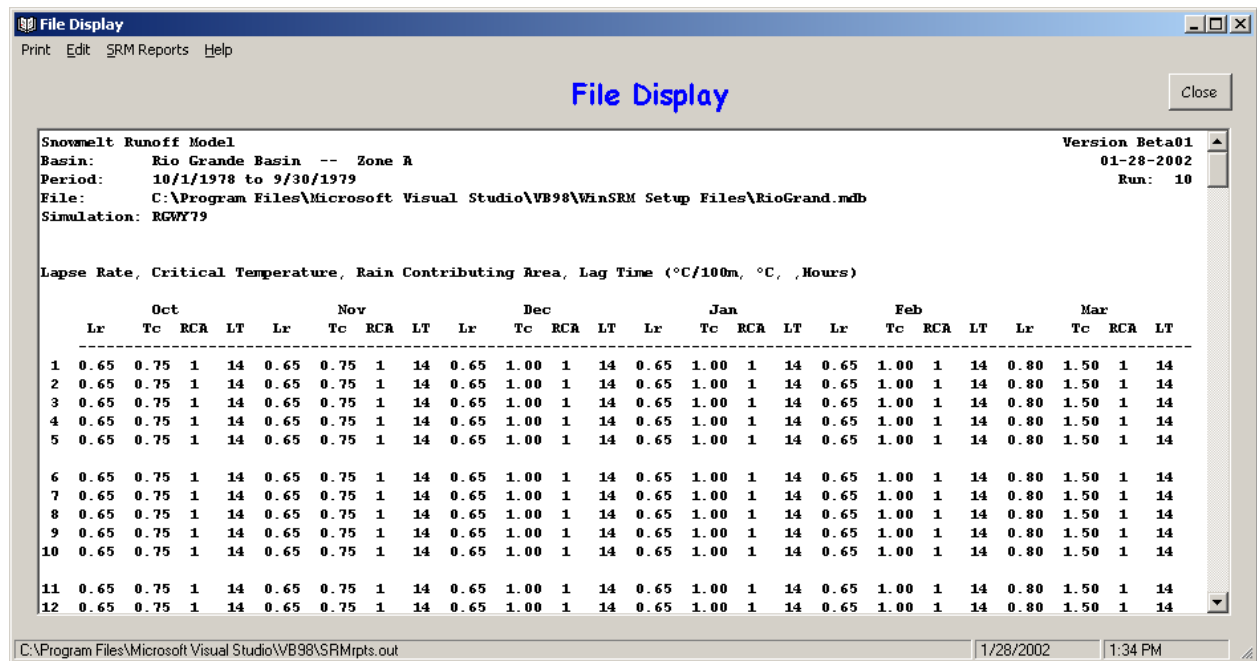
Window 30 - File Display Window

10.3.13.3 Menu

The *File Display* window menu provides tools to transfer the window's contents to a printer or the Windows clipboard, and allows access to other reports and Help.

Print
The print menu pull-down provides the choice of printing a multi-page report with or without page-breaks. Suppressing page-breaks will minimize paper usage with a cost of reduced readability. Also included on the print pull-down is the *PageSetup* choice, where the user can customize printer parameters such as margins and page orientation.

Edit
Click to copy the entire contents of the window to the Windows clipboard. Refer to the following section for instructions on copying portions of the window to the clipboard.

SRM Reports
Displays a drop-down menu of the reports that may be viewed, given the current point of model operation. Selecting a report from this menu replaces the window's text contents with the selected report.

Help
Displays a separate *Help* window that documents the *File Display* window and its use.

10.3.13.4 Window control

The model attempts to display the lines of each report as separate lines in the window. If the physical width of the window is too narrow to adequately display a line, it will be continued (wrapped) to the next line in the window, making the report difficult to read. To alleviate such situations, the window may be 'resized' by moving the mouse cursor over a window border until the cursor changes to a double-headed arrow, then dragging the window into a larger state. Alternatively, the window can be 'maximized' by clicking the 'maximize' icon on the window's title bar. Portions of report text may be copied to the Windows clipboard by clicking some starting point in the window, then while pressing the left mouse button, dragging the mouse to an ending point. The highlighted text is copied by right-clicking then clicking *Copy to Clipboard*.

10.4 WinSRM operation

Prior to the running the snowmelt runoff model processing algorithms, there are number of supporting tasks that must first be addressed. The task list will vary depending upon the state of the currently loaded database and the processing algorithm (simulation or climate-change) desired. The following sections briefly describe these tasks.

10.4.1 Building a WinSRM basin database
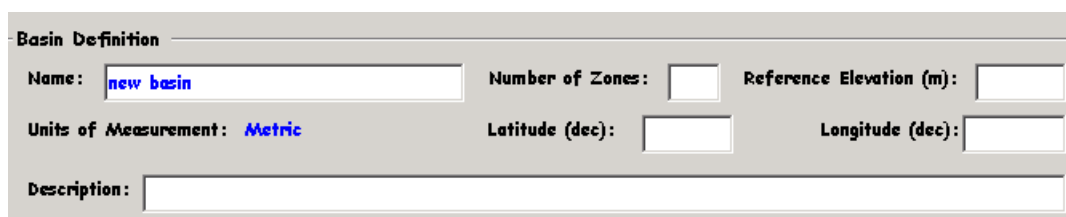
There are two procedures for creating a new WinSRM basin database. Each procedure begins with the program in a 'new' data state, either at program startup, or by clicking the **File / New** menu option on the *main* window menu bar.

10.4.1.1 Manually populate your WinSRM database

The procedure that will be used by most new users of WinSRM will involve manual population of a new database. This sounds worse than it should prove to be, in that the model supports cut-and-paste of data from within WinSRM as well as from other sources, typically spreadsheet programs. Several types of data are required before a simulation can be attempted. These data are stored in database 'tables' within the new database. The tables are described in the order in that they are created during development of the new database.

BasinDescription table
When a new basin database is created, the first step in the definition process is entering several values that are unique and will typically not change. This is accomplished by typing the values in text boxes in the Basin Definition portion of the *main* window (see below).

Window 31 - Create the basin description table

In the example above, the basin name (new basin) and the units have already been entered. Notice the units are set to metric and may not be changed. Mixed units are not allowed in a WinSRM database. As with 'Units…', the 'Number of Zones' text box, once populated with a value, will also become fixed for the life of the database. All the other basin definition variables may be changed as necessary. These unique basin descriptors are stored in the BasinDescription table in the new database.

PhysicalData table
The PhysicalData table contains all the physical data observations (temperature, precipitation, snow-covered areas) required by WinSRM to drive its simulations. Once the number of elevation zones in the basin is defined (Window 31), the user is provided with an opportunity to 'populate' (initialize) the PhysicalData table, using a dialog window shown below (Window 32).
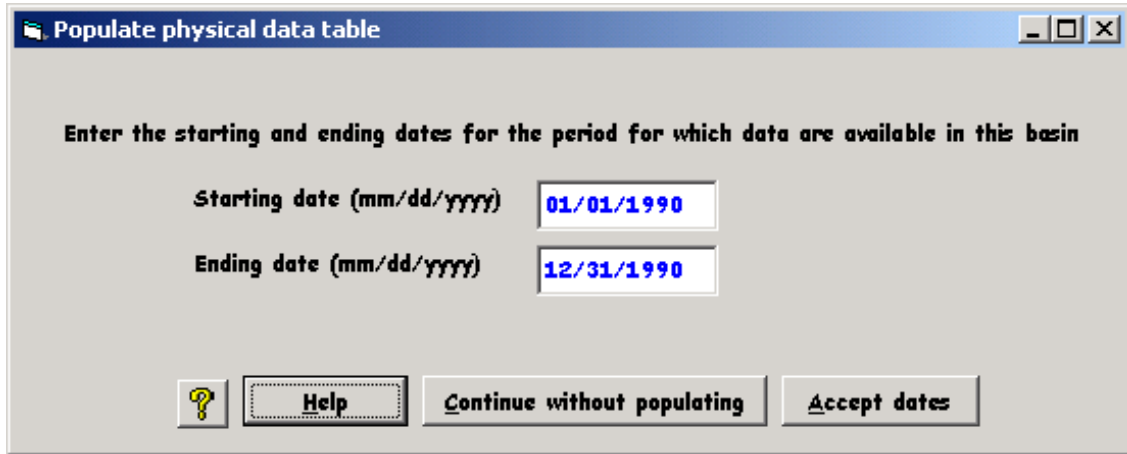
Window 32 - Populate physical data table prompt

Using the period-of-record provided in this dialog, WinSRM will populate the PhysicalData table with the necessary 'records', one for each zone/day. If this step is bypassed, the records will be created as required for each new simulation definition. Values for the entire period-of-record for the basin are stored in this table and are shared by each of the basin's simulations. Providing values for these 'new' records is described below, in another section.

ZoneDescription table
After the 'Populate…' dialog is released, by clicking **Continue without populating** or **Accept dates**, control returns to the *main* window. At this point, the user provides the critical values required to describe the zones that will subdivide this basin. Each line in the grid shown below (Window 33) represents a single elevation zone in the new basin. Currently, the model requires values for zone elevation and zone area only. The remaining columns in the grid may be provided for descriptive purposes but are not used by the model's processing algorithms. The information contained in this grid is stored in the ZoneDescription table.

Zone ID	Zone Area (km²)	Hypsometric Mean Elevation (m)	% NE Aspect	Avg Elevation, NE Aspect (m)	% SE Aspect	Avg Elevation, SE Aspect (m)	% NW Aspect	Avg Elevation, NW Aspect (m)
1	100.00	0.00						
2								
3								

Window 33 - Zone Definition grid

SimulationIndex table
As its name indicates, this table is the index of all the simulations that exist in the basin database. Each record in the table represents a unique basin simulation, and stores the control information (name, run #, starting and ending date, etc.) required by the model when the simulation is 'run'. This information is displayed in the Basin Simulations grid on the WinSRM *main* window (Window 34). Each simulation name must be unique in the database, as that value is used to create and access the simulation's simulation parameter table, described below.

Window 34 - Basin Simulations grid

Simulation Parameter Table
Each line in the Basin Simulations grid represents a unique simulation parameter table stored in the current database, named using the value in the line's Simulation Title grid cell (RGWY79 in the example depicted in Window 34). The simulation table is the repository for the model parameters used by WinSRM for that simulation. Each record in the table represents a parameter set for a given zone/day. Each new simulation is created by clicking the ⬚ **Add Simulation** ⬚ button on the *main* window. Once a name for the new simulation is provided (Window 12), control passes to the *Edit Simulation Control Information* dialog, where an initial set of simulation parameters is described.

Once a simulation parameter table has been defined, and indexed in the SimulationIndex table, the new database can be 'Saved', by clicking ***File/Save As***.

10.4.1.2 Import an existing DOS .SRM data file

The simplest way to populate a WinSRM basin database is to import an existing .SRM data file created by an earlier DOS version of the SRM model software. When an existing .SRM file is imported into a new (empty) database, the basin, zone, and physical variable database tables described in the next section are initialized using imported values, and a simulation parameter table for the simulation is created using the imported simulation parameters. After the import finishes, the database is adequately populated to support model processing of that simulation.

Importing a DOS .SRM file into an existing WinSRM database is identical to that for a new database with the follow exceptions:

- The program checks for inconsistencies between the basin database and the basin defined in the .SRM file. Units of measurement and the number of zones must be identical.
- Since the Basin and Zone data tables in the existing database are populated, the program asks the user whether to overwrite that information, using similar values present in each .SRM file. (Appendix F, Message 3).
- Since WinSRM maintains a single set of physical variable data, imported simulation files may duplicate one or more days already present in the database. When this occurs, the user is asked to decide which set of duplicate value(s) to use. (Appendix F, Message 4).

10.4.2 Data base data entry

At this point in the database creation process, the data storage structures (tables) required by the model have been created and initialized.

However, before any meaningful modeling can be performed, 'real' data and parameters must be provided, replacing the default values assigned during the table creation steps just described. Data entry is performed using the Edit{Variable/Parameters} dialog (Window 14).

Though the values required may be entered using the computer keyboard, the recommended method for moving data into the WinSRM database is through use of cut/copy/paste functionality found in WinSRM and in most Windows software. The initial step in this process would be to import the digital data into a spreadsheet program (Microsoft Excel, Corel Quattro Pro, etc). Once the data are in such a form it becomes a simple task to copy columns of values to corresponding positions in the WinSRM edit dialog.
Be aware that the scope of any data entry/editing varies depending upon whether the data are basin variables (in the PhysicalData table) or simulation parameters in a simulation table. Basin variables 'belong' to the basin, not the individual simulation. Changes to basin variables are 'global' in scope. They will affect ALL basin simulations that utilize the edited data. Changes to parameter values are 'local'. Each simulation has its own set of parameter values so changes to these data only affect that simulation.

10.4.3 Running WinSRM

After a current simulation has been identified, by clicking on a row in the Basin Simulations data grid, a simulation is initiated by clicking the *main* Window menu bar, ***Run / Simulation / Melt Season*** or ***Run / Simulation / Year round*** (Window 6). As mentioned earlier in the section describing the WinSRM main menu the distinction between these two alternatives lies in the package of output graphics available upon completion of the simulation. See Appendix B for more information about the graphics alternatives.

10.4.3.1 WinSRM processing steps

WinSRM assembles the basin variables for the required simulation period with the simulation parameter data into a temporary database table, named SimResults. The model uses the data in SimResults to drive the simulation and stores many of its temporary and final calculations in the same table. All model tabular and graphic output is generated using the information found in SimResults (see Appendix D).
The model:

- Develops temperature profile at zone hypsometric mean elevation(s)
- Determines the effect of daily precipitation upon basin runoff
- Determines basin runoff derived from melt of the existing snow pack
- Derives total basin runoff by combining snowmelt runoff with net-daily-precipitation contributing to runoff
- Displays basic statistics compiled from the computed results of the simulation (see Window 18)

11. REFERENCES

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Appendix A – Examples

Example 1 –Create a new basin database by importing a DOS .SRM data file.

1. Start new session of WinSRM, or click *File / New* in an existing session.

2. Click File / Import. In the Import a DOS SRM data file dialog window, click on SAMPLE1.SRM, then click **Open** .

3. Provide a simulation name that will uniquely identify this simulation in the dialog depicted below. Click **Ok** .
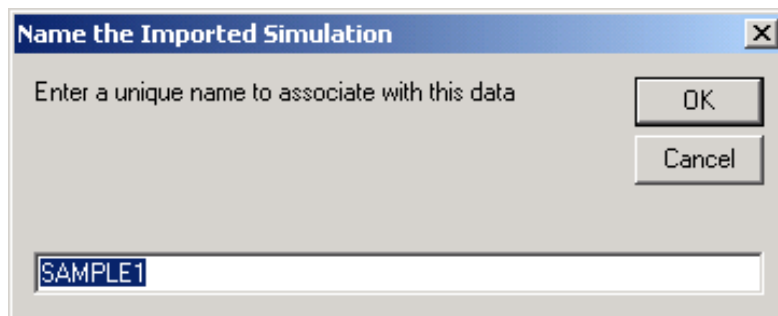
4. The Edit Simulation Control dialog appears. Click **Accept** to accept the parameters exactly as defined in the DOS data set. Be aware that if you attempt to edit any of the values in this dialog, each zone in the simulation's parameter table will be initialized using the values shown.

5. At this point the *main* window regains control. The DOS file has been 'imported' into a new database. Before continuing, you should save the new database using *File / SaveAs*.

6. Run the imported simulation, click *Run / Simulation / Melt Season.*   A warning message dialog appears as shown below. This occurs since there is no initial runoff value present in the physical data table for the date March 31, 1975. The model will use the value contained in the DOS simulation (12.0) for that missing value. Click **Ok** to proceed with the simulation.
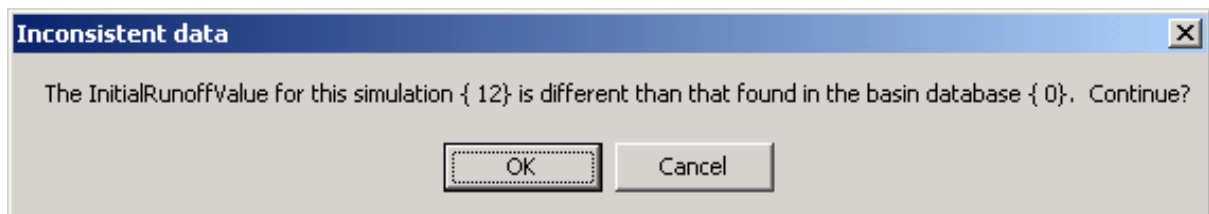
7. Because no latitude/longitude is available from the DOS SRM file, another warning dialog appears, as shown below. Click **Yes** to continue.
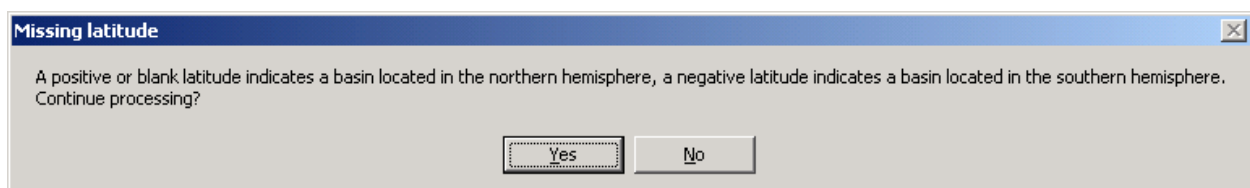
8. Upon completion of the simulation, the Results dialog appears, as shown below. After examining the statistics, click **Done** to return to the *main* window.
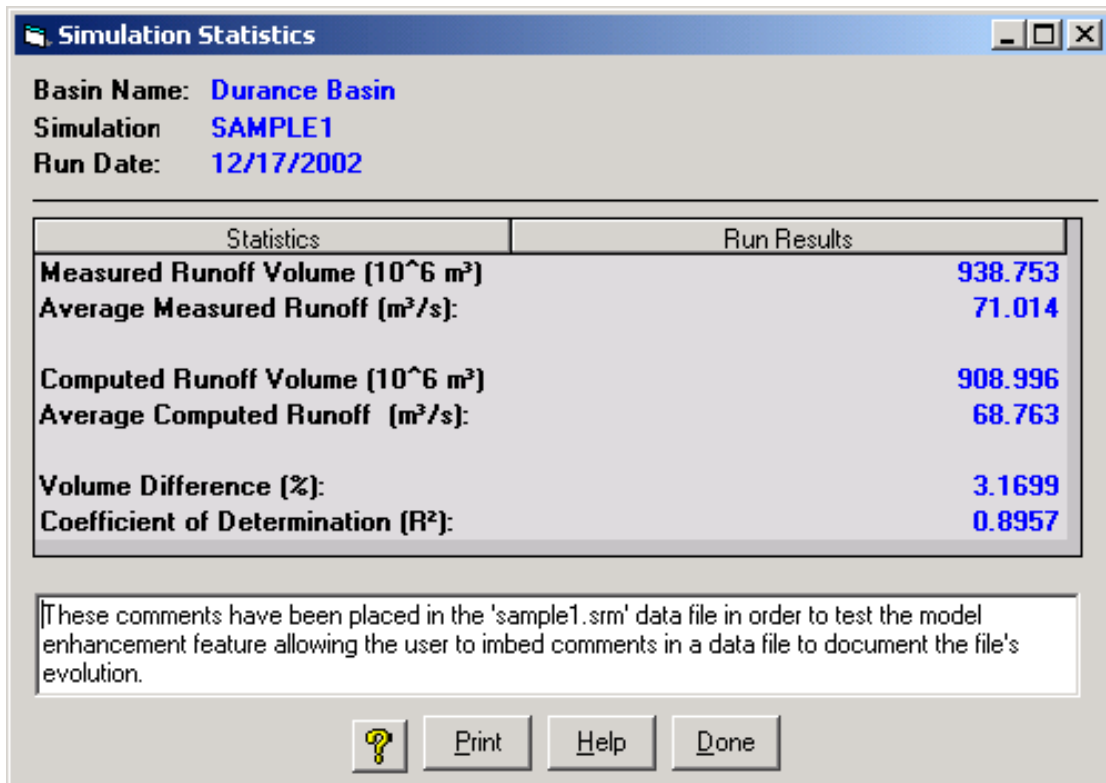
9. After the successful simulation, you can familiarize yourself with the graphical and tabular output products available to the modeler by clicking ***Graphics*** or ***Reports*** on the main menu.

Example 2 - Adding physical data to a database from another (digital) source

1. Load the database created in Example 1, or any of the other sample WinSRM databases.

2. Click **Add Simulation**, enter a new simulation in the *Name the New Simulation* dialog, then click **Ok**. The Edit Simulation Control Information window appears.

3. For purposes of this example, the default information in this dialog will be used as presented. Click **Accept** to add the new simulation to the database. Two dialogs appear as shown below:

Click **Ok** .

WinSRM ☒

Daily physical data records for the period '10/1/1980 to 9/30/1981' will be added to this basin's physical data table. Ok?

[<u>Y</u>es]   [<u>N</u>o]
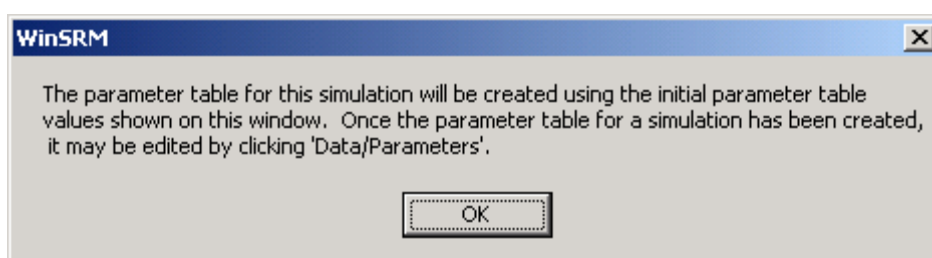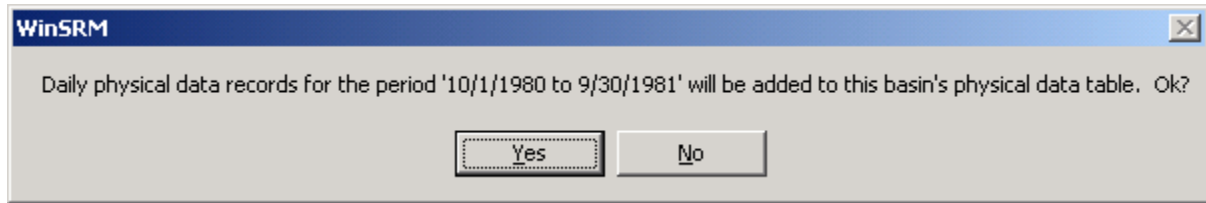
Click **Yes** to add new records for the specified date period to your PhysicalData table.

4. Click on **Data / Variables / Period of record** to display the *Edit basin variables* window (see Window 14). Experiment adding data to the data base by first typing values into the cells for several days. Then sample the "Copy/Paste" functionality with the following steps:

   a)   Click on the data cell for runoff, April 1, 1975. Holding the left mouse button down, drag the mouse down to April 15.   An alternative to 'dragging' is to click on April 1, press the keyboard Shift key, then click on April 15. The block selected is highlighted after this process.

   b)   Right-click on the block selected. A popup menu appears. Click the **Copy** menu choice. The keyboard alternative is to press and hold the Ctrl key, then press 'C'. (Ctrl+C). This copies the highlighted data to the Windows clipboard.

   c)   Click on the data cell for runoff, April 1, 1981. Press the right mouse button, then click the popup menu item **Paste** to copy the data from the clipboard to the grid.   The keyboard equivalent is Ctrl+V.

5. This technique described in step 4 (cut and paste) is very common in the Windows environment. Typically, a user will import digital information into a spreadsheet program, then use cut-and-paste to move the information into corresponding WinSRM locations.

Example 3 – Developing a climate change scenario

This exercise results in a climate change scenario that the model developers have created during climate change research activities. The success of the exercise can be verified by running the pre-existing scenario that is already resident it the WinSRM database that you will be using.

1. Start the WinSRM program. Load the Rio Grande database that is included with the software by clicking **File / Open**. In the *Open an SRM database dialog,* double-click the entry 'RioGrand.mdb'. Control will return to the *main* window, populated with the new database information.

2. In the Basin Simulation grid, click on the second simulation title, 'RGWY79', making it the 'current' simulation.

3. Click on ***Data / Climate Change Scenario Definition.*** The Climate *Change Scenario Definition for Simulation: RGWY79* window appears (See Window 16). Click [**New**] . The *Create a new climate change scenario* dialog appears. Enter the name Ex3 for your new climate change scenario.

4. The definition dialog is initialized to an empty, new state. Notice the simulation period cannot be changed, and that it is one year in length. WinSRM performs climate change over a one-year period only. Notice also that the Winter End Date defaults to the halfway point in the year. This value may be modified by the user.

5. Begin creating your set of 'rules' that will define your changed climate. You estimate that temperature will be warmer by 4°C throughout the entire year in your changed climate.

    a)   In Row 1, click the Variable/Parameter drop-down list and select *Average Temperature.*

    b)   Double-click the starting date cell to set the starting date for this change to the simulation starting date. Double-click the ending date cell to set the change's ending date to the simulation ending date.

    c)   Click on the Edit Action drop-down list and select *Add to each day*. Type 4 into the Edit Factor cell.

    d)   Select *All* from the Zone drop-down list, meaning this rule will apply to temperatures in every zone.

    e)   In Row 2, select *Degree-Day Factor* from the Variable/Parameter drop-down.

    f)   Set the date period in row 2 by repeating step (b).

    g)   Select *Shift Backward* from the Edit Action drop-down. (the increased temperature of the changed-climate necessitates utilization of the warmer month's DD factors earlier in the season than would occur in the present climate).

    h)   Enter 31 as the edit factor for this rule line. When used with 'shifts', the edit factor is the number of days to shift the parameter (e.g., a shift backward of 15 days moves 4/16 to 4/1, 4/17 to 4/2, etc.).

    i)   For Row 3, select *Snow Runoff Coefficients* from the Variable/Parameter drop-down. Complete the line by repeating steps (f), (g), and (h).

6. Click Done to close the *Climate Change Scenario Definition* dialog and return control to the *main* window. To preserve the newly created scenario, click ***File / Save***.

Example 4 – Simulating climate change using a climate change scenario

This exercise uses the climate change scenario, Ex3, developed in the previous example. If Example 3 was skipped, the climate change scenario Tplus4 can be substituted for Ex3. Skip steps 1 and 2 if you have proceeded to this example directly from completion of Example 3.

1. Start the WinSRM program. Load the Rio Grande database that is included with the software by clicking ***File / Open***. In the *Open an SRM database dialog,* double-click the entry 'RioGrand.mdb'. Control will return to the *main* window, populated with the new database information.
2. Click on 'RGWY79' in the Basin Simulations grid, making it the current simulation.
3. Click ***Run / Climate Change*** to begin the climate change simulation process. The *Run a Climate Change* window appears.
4. Select *Ex3* from the Scenario Definition(s) for RGWY79 drop-down list. This list contains all the scenarios in the database that have been created to use with simulation RGWY79.
5. Click [**Step1: Winter, Present Climate**] to begin the climate change simulation. As with any normal simulation, the model first initializes the SimResults table with a copy of variables and parameters taken from the database that are required to drive the simulation. Next, using the rules contained in

the Ex3 scenario, the model creates a set of changed-climate data, modifying variables and/or parameters as directed by the rules contained in the climate change scenario, Ex3. Finally, the model runs a simulation for winter, present climate.

6. After the step completes, results of the simulation are displayed in the Statistics grid on the right side of the window. At this point, the user can click on the *main* window, then view the simulation's results using ***Graphics*** and/or ***Reports***. The user can also examine the date in SimResults by clicking ***Data / Results***. (data editing is disabled during this process). Notice that several of the menu choices on the *main* window are 'disabled' (not available for use) while the climate-change process is active.

7. Click the remaining Step buttons as they become active. After steps 2,3 and 6 you may repeat the post-completion directions detailed above in paragraph 6.

8. When ⌐ **Step5: Derive CDCclimWS** ⌐ is clicked, the *Winter Change for Zone:* dialog appears, one for each zone. The value shown in the dialog is the calculated melt gain/loss realized during the winter half-year resulting from the climate change. Click **Ok** to accept these values.
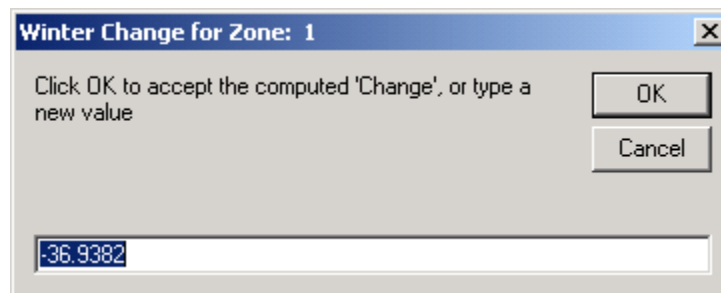
9. The climate change simulation is completed once the six step buttons have been clicked. Click the **Print** button to print the statistics displayed in the dialog to the system printer.

10. Click ***Graphics*** or ***Reports*** to examine the plots and reports, respectively, available after a successful climate change simulation.

Example 5 – Developing a custom climate change scenario

This example demonstrates a method for modeling an extremely complex or unusual climate change, one that the *Climate Change Scenario Definition* window is unable to create. This example substitutes the 'climate' of one year, 1977, as the 'changed-climate' for a climate change simulation for year 1979.

1. Start the WinSRM program. Load the Rio Grande database that is included with the software by clicking ***File / Open***. In the *Open an SRM database dialog,* double-click the entry 'RioGrand.mdb'. Control will return to the *main* window, populated with the new database information.

2. Click on RGWY79 in the Basin Simulations grid, making it the 'current' simulation.

3. Click on ***Data / Climate Change Scenario Definition***. When this window appears, click on the Existing Scenarios drop-down list and select *Manual1*. This scenario will be used to recreate the SimResults table. It changes temperature in the new climate by adding 0 to each temperature value, shifts a parameter (c_S) 31 days, but does nothing else to the 'new' climate. Click **Done** when you have examined the scenario to return to the *main window*.

4.	Click on ***Run / Climate Change***. The *Run a Climate Change* window appears. Select Manual1 from the Scenario Definition(s) … drop-down list. Click on Step1: Winter, Present Climate . As explained above (Example 4, Step 5) the model recreates the SimResults table using the selected scenario to generate the 'changed' climate variables and/or parameters. In the example, the only effective change is the 31-day shift of snow runoff coefficients (c_S). Simulation.

5.	After Step1 completes, click on Abort to terminate the simulation. Control returns to the *main window*.

Now we will begin to 'customize' the SimResults table with a changed-climate that would be impossible to accomplish with a climate change scenario, by cutting-and-pasting the climate variables (temperature and precipitation) from 1977 to 1979's new climate.

6.	Click on RGWY77 in the Basin Simulations grid. Click on ***Data / Variables / Current Simulation***. The *Edit basin variables* dialog appears. Click on the column header *Tavg*. The entire column should be 'highlighted'. Right-click on this column, then select Copy (or press Ctrl+C) to copy the year of temperature data for zone A to the Windows clipboard. Click Cancel to close the dialog and return to the *main window*.

7.	Click on RGWY79 in the Basin Simulations grid. Click on ***Data / Results***. The *Simulation results* editing dialog appears. Notice that a number of the column headers end with 'CC'. These columns contain the post-climate-change values for that variable/parameter. If a column header is only partially visible you can resize the column by placing the mouse on a column border in the header. When the mouse changes state, press the left mouse button and drag to complete the resize.

8.	Click on the column header TavgCC to select the entire column. The column will be highlighted. Right-click the column and select Paste from the popup menu (or press Ctrl+V). The data copied to the clipboard in Step 6 will replace the data in the column. Since the temperature distribution for RGWY79 is 'Basinwide' (see the *main* window), no further temperature modification is necessary. (Basinwide variables are always stored in Zone 1 in WinSRM tables). Click Done to close the dialog and return to the *main* window.

9.	Click on RGWY77 in the Basin Simulations grid. Click on ***Data / Variables / Current Simulation***. The *Edit basin variables* dialog appears. Click on the column header *Precip*. The entire column should be 'highlighted'. Right-click on this column, then select Copy (or press Ctrl+C) to copy the precipitation data for zone A to the clipboard. Click Cancel to close the dialog and return to the *main* window.

10.	Click on RGWY79 in the Basin Simulations grid. Click on ***Data / Results***. The *Simulation results* editing dialog appears. Click on the column header *PrecipCC*. The entire column should be 'highlighted'. Right-click the column and select Paste from the popup menu (or press Ctrl+V). The 1977 precipitation data copied to the clipboard in Step 9 will replace the data in the column. Click Done to close the dialog and return to the *main* window.

11.	Copy the 1977 precipitation for zones B and C to SimResults zones B and C by repeating steps 9&10 for each zone.

12.	At this point your customized climate change definition is complete. Before running the climate change simulation you may want to save the database to preserve the SimResults table in its customized form (there is only one SimResults table per database. The table is recreated each time a simulation is performed).

13. Click ***Run / Climate Change.*** The *Run a Climate Change* window appears. Select Manual1 from the Scenario Definitions(s)… drop-down list. (the model uses the winter-end-date found in this scenario).

14. Click the *Use the climate changes defined in Results* checkbox .

15. Click on ⬚ **Step1: Winter, Present Climate** . Because the checkbox (Step 14) is 'checked', the model skips the preliminary step that recreates the SimResults table. Instead, the table used is the one we created and edited in steps 4-10.

16. Complete the climate change simulation by following Example 4, Steps 6-10.

Example 6 – Developing a normalized year

This example illustrates the steps required to create a normalized year of temperature, precipitation and snow-depletion data, using as a source a year-round simulation selected from a WinSRM basin database. See Section 8.5 to learn more about normalized data and how it is used in simulating climate-change. See Section 10.3.8 to learn how WinSRM derives long-term monthly averages for temperature and precipitation, and how it uses these long-term averages to adjust corresponding observed daily values (during climate-change processing), resulting in a set of 'normalized' temperature and precipitation for the given year, and the resulting snow-depletion curve(s) derived using the 'normalized' climate. The example assumes that multiple years of physical data are present in the current basin database. An alternative, manual method for normalizing your data, replacing Step 4, is described at the end of this example. The alternative method demonstrates how long-term averages derived externally from other sources, are applied to the selected simulation year.

1. Load an existing WinSRM database.
   Click ***File / Open*** (or File followed by selecting a WinSRM database from the 'Recent Files' list)

2. Save the WinSRM database to a new (mirrored) database file.
   File/Save As
   After this step, the database displayed by the model screens is the new, mirror database.

3. Select a simulation from the 'Basin Simulations' grid. The selected simulation must be a year-round simulation for the year you want to normalize.

4. Create a climate change scenario with temperature and/or precipitation modified using the 'Normalize' climate change function.

   Click ***Data/Climate Change Scenario Definition***.
   Click ***New***. Type in a new scenario name. Click Ok.
   Define a modifying rule for temperature:
       A. Select temperature from variable/parameter dropdown menu
       B. Identify the starting and ending dates (winter starting date through summer ending date)
       C. Select 'Normalize' from the edit action dropdown menu
       D. Type '0' (zero) in the edit factor cell
       E. Select 'All' from the zone dropdown if temperature selected in sub-step A is 'Average'
          Select the 'A' zone if temperature option selected is Max/Min
   Repeat modifying rule steps above for precipitation.
   Change the 'Winter End Date' if necessary.
   Enter comments in the 'Comments' box if desired.
   Click **Done** to return to the main WinSRM window.

5. Run a climate change simulation using the scenario created in Step 4.

    Click ***Run/Climate Change***.
    Select the scenario created in Step 4 from the 'Scenario Definitions' drop-down menu.
    Proceed with the simulation by clicking the six 'Climate Change Processing Steps' buttons.
    Click **Done** after completion of the climate change simulation.

The 'Results' database table now contains a normalized set of temperature and precipitation data, a set of 'normalized' snow-depletion curves derived using said data, and a year of 'normalized' runoff values. To preserve this 'normalized' year' for use in subsequent climate modeling activities, these data need to be saved to the 'mirrored' database created in step 2 (overwriting the corresponding actual observed data). The following steps accomplish this task.

6. Copy the 'normalized' temperature values generated by the climate change run (Step 5) to the corresponding physical variables in the current (mirror) database. For purposes of this example, we will assume that 'basin-wide' average temperatures were used in the original simulation (Step 3).

    Click ***Data / Results*** to display the results generated for the climate change run (from Step 5).

    a) Click the header of the column of the average temperatures that were modified (normalized) by the above scenario. The column title is 'TavgCC' (you may need to resize the column to see the complete column name). The column should be 'highlighted' after the column title is clicked (see below).

Window A1 - Copying normalized temperature data to the Windows clipboard

    b) Copy the 'selected' data to the Windows clipboard. Right-click the column, then click Copy.
    c) Click **Done** to return to main window.

Assuming the current basin simulation is unchanged from Steps 3-5, open the 'Edit Basin Variables' window by clicking ***Data/Variables / Current Simulation*** (see below).

Select the target column for the copy (the column corresponding to that chosen in 6a) by clicking its column heading. In this example, the column name is 'Tavg'.

After the column is selected (highlighted), right-click on the column, then click ***Paste*** to copy the data from the Windows clipboard to the data grid.
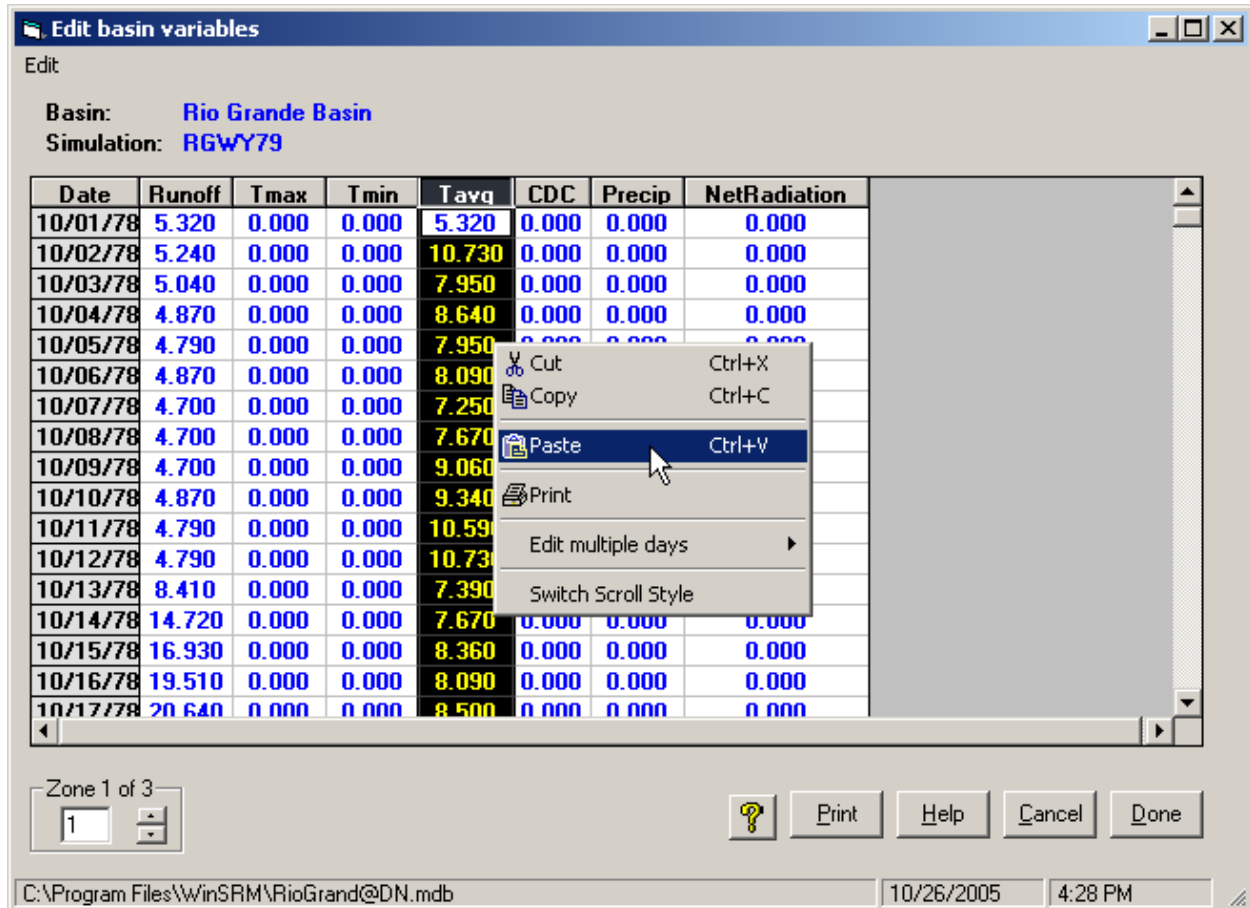
Window A2 - Replacing basin temperature data with normalized data

Click **Done** to save the changes made in this window to the database and return to main window.

6.   Repeat Step 6 for each zone of precipitation data by copying column {PrecipCC} from the 'Results' table to column {Precip} in the 'Edit Basin Variables' table for the current simulation.
7.   Repeat Step 6 for each zone of snow-depletion data by copying column {CDCclimWAMA} from the 'Results' table to column {CDC} in the 'Edit Basin Variables' table for the current simulation.
8.   Repeat Step 6 for normalized daily runoff by copying column {DailyQ} from the 'Results' table (column #46) to column {Runoff} in the 'Edit Basin Variables' table for the current simulation.
9.   The physical basin variables (temperature, precipitation, and snow-covered area) for the time period denoted in the current simulation have now been normalized. Save the (mirror) database at this point to preserve the changes made above.
     File/Save

The 'normalized' year thus created can now be utilized as a non-biased source year for other climate change studies.

Manual alternative for normalizing temperature and precipitation for a basin

The climate change scenario describe in step 4 above, takes advantage of a 'built-in' WinSRM function that automatically generates monthly temperature and precipitation 'adjustment factors' which serve as the climate change scenario. These factors are the differences between the long-term monthly averages for T & P for the basin, and monthly averages for the current simulation year. Daily temperatures (T) for each month are adjusted (+ or -) by the difference between the current year's monthly average T and the long-term monthly average T for the corresponding month. Daily precipitation (P) amounts for each month are adjusted by multiplying each daily value by a proportional factor (LT monthly average P / monthly average P).

An example of Step 4, performed manually can be found in one of the sample databases (RioGrand@DN.mdb) included in the standard installation package. Load this database into the program and select the simulation 'RGWY79' by left-clicking the name in the Basin Simulations data grid. Then click **Data / Climate Change Scenario Definition.** Click on the *Existing Scenarios for RGWY79* combo box and click *Normalized5794*. The dialog window (shown below) will display the manual normalization that model developer's performed on a simulation year for the Del Norte Rio Grande basin using a 38 year period-of-record. These monthly edit factors were developed externally and provided using the *Climate Change Scenario Definition* window.

Window A3 - Normalizing temperature using externally generated 'adjustment factors'

Appendix B – Graphical Plots

The interface for graphical plots consist of a *Graphics* window with drop-down plot menus as portrayed in the following picture. See previous sections for a description of the buttons on the *Graphics* window "button bar" shown below.

Appendix C – Program Windows

Appendix D – WinSRM Database Schema

WinSRM utilizes a Microsoft Access database as it's primary storage medium. The tables described below hold the variable and parameter information for a single mountain basin.

BasinDescription Table

The basin description table occurs once in each database. A single record in this table holds the physical description of the basin that the database represents. Two fields in this record, zones and units, are permanently fixed at file creation.

Field Name	Data Type	Description
BasinName $_1$	Text	Name of the basin (1-50 characters)
BasinDescription	Text	Brief basin description (1-50 characters)
Latitude	Float	Decimal latitude
Longitude	Float	Decimal longitude
RefElev $_1$	Float	Elevation of met station (feet/meters)
Zones $_1$	Integer	Number of elevation zones (1-16)
Units $_1$	Integer	English = 0, Metric = 1

1 = required

ZoneDescription Table

The zone description table occurs once per database. The table contains one record for each elevation zone into which the basin has been subdivided (the number of zones is defined at database creation). Each zone record contains three required values, the zone id, and the area and hypsometric mean elevation of the zone. Aspect-related fields are currently unused.

Field Name	Data Type	Description
ZoneId $_1$	Integer	Zone identifier (1-10)
ZoneArea $_1$	Single	Total area of the zone (mi^2 / $km^{2)}$)
HypsometricElevation $_1$	Single	Hypsometric mean elevation of the zone (ft/m)
AspectNE	Single	% with northeast aspect (unused)
AspectNE_Elev	Single	hypsometric mean elevation of the zone's NE aspect
Ditto SE, SW, NW		

1 = required

SimulationIndex Table

The simulationindex table occurs once per database. The table contains one record for each simulation that has been developed and saved in the database. Each record contains a unique value in the field SimName that ties the simulation to a separate <u>simulation parameter table</u> (see below). The remainder of the record contains specific control information the model uses to control processing.

Field Name	Data Type	Description
SimName$_1$	Text	Name assigned to the simulation (used to index the simulation's parameter table) (1-50 characters)
SimRunNumber	Text	Unused (artifact from DOS)
SimStartDate$_1$	Date	Month/Day/Year of start of simulation (mm/dd/yyyy)
SimEndDate$_1$	Date	Month/Day/Year of end of simulation (mm/dd/yyyy)
SimUnits	Integer	Unused (units are specified in <u>BasinDefiniton</u> table)
SimTempType $_1$	Integer	0 = daily average temperature, 1 = daily max/min
SimTemp_Distribution $_1$	Integer	0 = basinwide (lapsing required), 1 = separately by zone
SimP_Distribution $_1$	Integer	0 = basinwide (zone#1 P for all) , 1 = P for each zone
SimLR_Distribution $_1$	Integer	0 = basinwide (zone#1 LR for all) , 1 = LR for each zone
SimCoeff_Distribution $_1$	Integer	0 = basinwide (zone#1 Cs/Cr for all) , 1 = Cs/Cr for each
SimTcrit_Distribution $_1$	Integer	0 = basinwide (use zone#1 Tc for all) , 1 = Tc for each zone
SimXY_Distribution $_1$	Integer	0 = basinwide (zone#1 X/Y for all) , 1 = X/Y for each zone
SimInitialRunoff	Double	Runoff from day preceding day1 of the simulation (f^3/s, m^3/s)
SimPrecipThreshold	Single	Precipitation value indicative of a significant event, requiring special processing. (in/cm)
SimX	Single	Unused
SimY	Single	Unused
SimComments	Text	1-255 character description of the simulation

1 = required

PhysicalData Table

This table occurs once per database. It is the repository for the physical variables representing the basin's period of record (POR). The POR consists of all the unique time-periods referenced by the simulations stored in the database. Once entered, records representing physical time-periods are never removed, even if the simulation that originally stipulated the time period is deleted. Physical data are *unique*. Many simulations in the database may utilize the same set of daily values. If modeling requires differing sets of these physical data, the solution is to create another copy of the database (see Window 3) with the alternative set of physical data.

Field Name	Data Type	Description
Zone	Integer	Zone identifier (1-10)
Date	Date	Month/Day/Year these data were measured. (mm/dd/yyyy)
Runoff	Single	These values represent the total runoff flowing from the basin. They are NOT zone specific. Runoff is always stored in zone #1. (f^3/s, m^3/s)
Tmax $_2$	Single	Daily maximum temperature at the hypsometric mean elevation (HME) of the zone. If 'basinwide' is indicated (see SimulationIndex table), the temperatures are assumed to have been measured at the reference elevation (see BasinDescription table), and will be lapsed to the HME. Basinwide variables are always stored in the first zone. (F/C)
Tmin $_2$	Single	Daily minimum temperature. Same conditions as Tmax. (F/C)
Tavg $_2$	Single	Daily average temperature. Same conditions as Tmax.. The model uses max/min or average temperatures as specified in a given simulation's temperature-type flag (see SimulationIndex table). (F/C)
Precip $_1$	Single	Precipitation measured either at the HME of the zone or at the reference elevation. As with the other variables, if precipitation is flagged as basinwide (see SimulationIndex), it is stored in the first zone.
SCA $_1$	Single	Snow Covered Area. This is the percentage (0 to 1.0) of the zone that is snow-covered. These values MUST be provided for each zone.
NetRadiation	Single	unused

1 = required   2 = either Tmax/Tmin or Tavg are required

Simulation Parameter Table

Unlike the tables previously defined, the following table is replicated for each simulation in the database (see the SimulationIndex table) and the table's name is identical to the simulation's name.

Field Name	Data Type	Description
Zone	Integer	Zone identifier (1-10)
Date	Date	Month/Day/Year these parameters represent. (mm/dd/yyyy)
Tcrit	Single	Critical temperature (See Section 5.3.4) determines whether precipitation is treated as rain or snow by the model.. Tcrit can be provided for each zone, or as a basinwide parameter (See SimulationIndex table). (°C/°F)
LagTime	Single	Lag time (see Section 5.3.2) is the time difference between the start of increasing temperatures and the corresponding increase in runoff from the basin. This is always a basinwide parameter, and is entered in zone#1.
LapseRate	Single	If a single set of temperature data are provided at the reference elevation, the model uses lapse rates (see Section 5.3.3) to adjust the values for the effects of elevation, to each zone's hypsometric mean elevation. (°C/100m or °F/1000 ft). Also see SimulationIndex table description.
An	Single	The degree-day factor (see Section 5.3.2) converts the number of degree-days in daily snowmelt depth. An must be provided for each day / zone. See Section 5.3.2
Cs	Single	The snow runoff coefficient (see Section 5.3.1) takes care of losses due to surface conditions within the zone. Cs can be provided for each zone, or as a basinwide parameter (See SimulationIndex table). (% water volume)
Cr	Single	The rain runoff coefficient (see Section 5.3.1) takes care of losses due to surface conditions within the zone. Cs can be provided for each zone, or as a basinwide parameter (See SimulationIndex table). (% water volume)
RCA	Single	Rainfall Contributing Area (see Section 5.3.5) is a switch that determines how the model responds to rain falling on a zone's snow pack. (0-dry snowpack, rain is retained by the snow, 1-ripe snowpack, rain from the entire zone area contributes to runoff.
Xcoeff	Single	X value for computing the recession coefficient (See Section 5.3.6).
Ycoeff	Single	Y value for computing the recession coefficient (See Section 5.3.6).

1 = required   2 = either Tmax/Tmin or Tavg are required

SimResults Table

The SimResults table occurs once per database. With one exception (see 9.3.7.4 and Appendix A, Example 5), this table is recreated each time a simulation is performed. The records in the table represent one day for each zone for the simulation time period. The table is initialized using corresponding information from the PhysicalData table and the simulation's simulation parameter table. For climate change simulations, values representing the 'changed' climate are also included in separate fields within each record (postfix 'CC'). The SimResults table is the 'working copy' that the simulation uses as its input source and output destination. All reports and graphical plots that display calculated values obtain their information from this table

#	Field Name	Data Type	Description
1	Zone	Integer	Zone identifier (1-10)
2	Date	Date	Month/Day/Year (mm/dd/yyyy)
3	ActualQ	Single	Measured runoff (if available)
4	Tmax	Single	Maximum temperature
5	TmaxCC	Single	Maximum temperature, changed-climate
6	Tmin	Single	Minimum temperature
7	TminCC	Single	Minimum temperature, changed-climate
8	Tavg	Single	Average temperature
9	TavgCC	Single	Average temperature, changed-climate
10	Precip	Single	Measured precipitation
11	PrecipCC	Single	Measured precipitation, changed-climate
12	SCA	Single	Snow-Covered Area
13	SCACC	Single	
14	SCAClim	Single	
15	SCAclimWA	Single	
16	SCAclimWAMA	Single	
17	ZoneDD	Single	Degree-days at zone hypsometric mean elevation
18	ZoneDDCC	Single	Degree-days at HME, changed-climate
19	LR	Single	Temperature lapse rate (see Section 5.3.3)
20	LRCC	Single	Temperature lapse rate, changed-climate
21	Tcrit	Single	Critical temperature (See Section 5.3.4)
22	TcritCC	Single	Critical temperature, changed-climate
23	An	Single	Degree-day factor (see Section 5.3.2)
24	AnCC	Single	Degree-day factor, changed-climate
25	Cs	Single	Snow runoff coefficient (see Section 5.3.1)
26	CsCC	Single	Snow runoff coefficient, changed-climate

27	Cr	Single	Rain runoff coefficient (see Section 5.3.1)
28	CrCC	Single	Rain runoff coefficient, changed-climate
29	LagTime	Single	Lag time (see Section 5.3.2)
30	LagTimeCC	Single	Lag time, changed-climate
31	RCA	Integer	Rainfall Contributing Area (see Section 5.3.5)
32	RCACC	Integer	Rainfall Contributing Area, changed-climate
33	NetRad	Single	unused
34	NetRadDD	Single	unused
35	Xcoeff	Double	X value for computing the recession coefficient (5.3.6).
36	XcoeffCC	Double	X value, recession coefficient, changed-climate
37	Ycoeff	Double	Y value for computing the recession coefficient (5.3.6).
38	YcoeffCC	Double	Y value, recession coefficient , changed-climate
39	Cpr	Single	If a single set of temperature data are provided at the reference elevation, the model uses lapse rates (see Section 5.3.3) to adjust the values for the effects of elevation, to each zone's hypsometric mean elevation. (°C/100m or °F/1000 ft). Also see SimulationIndex table description.
40	SumAT	Single	
41	Newmelt	Single	
42	M1S	Single	
43	aT	Single	
44	SnowOnStore	Single	
45	ZonalMelt	Single	
46	TotalMelt	Single	
47	DailyQ	Double	
48	MDCincl	Single	
49	MDCexcl	Single	
50	MDCexclWA	Single	
51	MCDexclWAnew	Single	
52	MeltOffset	Single	
53	DailyQPresent	Double	
54	AZMincl	Single	
55	AZMexcl	Single	
56	AZNexclWA	Single	
57	AZMwork	Single	

ClimateScenarioIndex Table

The ClimateScenarioIndex table occurs once per database. The table contains one record for each climate scenario table present in the database. Each record in this index table also contains the name of the simulation for which the scenario table was prepared. Simulations may "own" multiple climate change scenarios.

#	Field Name	Data Type	Description
1	SimulationFile	Text	The name of the simulation that "owns' the scenario
2	ScenarioFile	Text	The name of the scenario table that contains the definition (rules) for the climate change scenario.
3	WinterEndDate	Date	The last day of the winter half-year.
4	CreationDate	Date	Date the scenario was last changed.
5	Comments	Memo	Description of the climate-change.

ClimateScenario Table

The ClimateScenario table is the structure that contains the climate-change scenario for a specific simulation in the database. It occurs 1-n times within a database. Each table contains 1-n records, Each record contains a 'rule' (9.3.5.3) for temporarily altering a variable/parameter to formulate the 'new' climate for the simulation. See Example 3 for more information on climate scenarios.

#	Field Name	Data Type	Description
1	VarParm	Integer	The number of the variable/parameter affected by the rule (see Table D-2)
2	StartDate	Date	The starting date of the period for which the rule applies.
3	EndDate	Date	The ending date of the period for which the rule applies.
4	EditAction	Integer	The edit action to be performed (see Table D-2)
5	EditFactor	Single	Value used for the edit action
5	Zones	Integer	The elevation zone(s) to be modified by the rule.

#	Variable/parameter
0	Max/min temperature
1	Average temperature
2	Precipitation
3	unused
4	Critical temperature
5	Lag time to gage
6	Temperature lapse rate
7	Degree-day factor
8	Snow runoff coefficients
9	Rain runoff coefficients
10	Rainfall contributing area
11	Radiation coefficients (unused)

Table D-1
Numeric equivalents to
variables and parameters

#	Edit action
0	Add edit factor to each day
1	Multiply daily value(s) by edit factor
2	Shift values forward {edit factor} number of days
3	Shift values backward {edit factor} number of days
4	Normalize values (temperature and precipitation only)

Table D-2
Numeric equivalents
for edit actions

Appendix E – Additional Windows
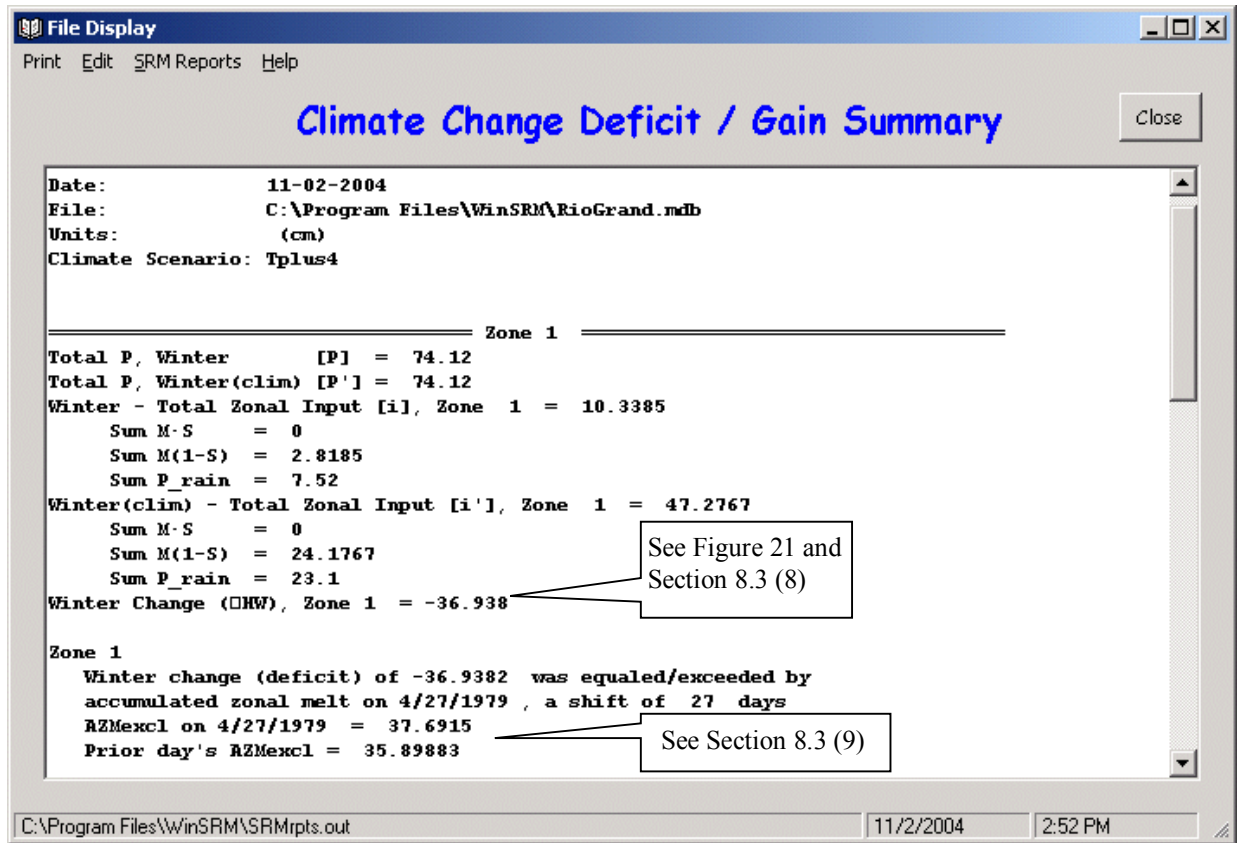
Window E1 - Climate Change Deficit / Gain Summary Report

Appendix F – Program Message Dialogs
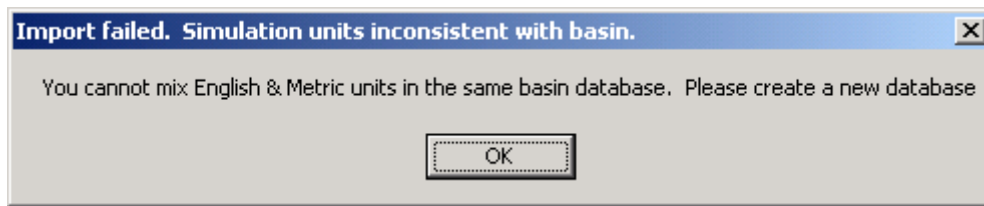
Message 1 - Inconsistent units between target database and 'import' file
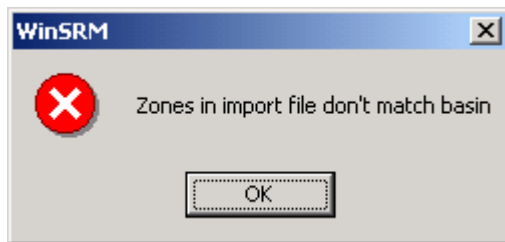
Message 2 - Inconsistent zones between target database and 'import' file
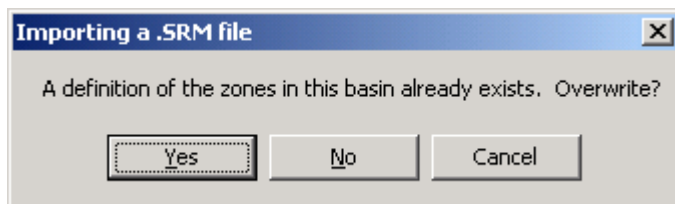
Message 3 - Use the basin definition from the 'import' file?
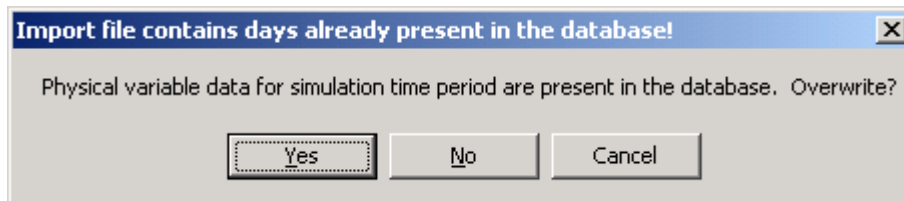
Message 4 - Physical data already present in database
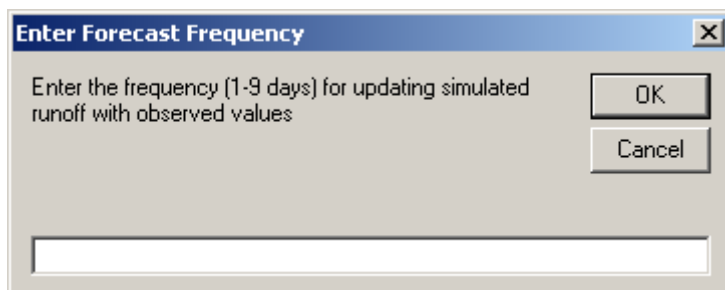
Message 5 - Physical data already present in database (see Page 86)

Appendix G – SRM Computer Program Version 4

G.1 Background

The current version of the model, Micro-SRM, Version 4.0, was developed using Microsoft QuickBASIC 4.5 and contains several subroutines from QuickPak Professional, a BASIC toolbox developed by Crescent Software, Inc.[1]

G.2 Getting started

G.2.1 System requirements

Micro-SRM requires the following personal computer resources:

- Any 100% IBM PC compatible machine

- 1 floppy disk drive. The model is distributed on a 3½" floppy disk. By special request, 5¼" media are available. The latest version release and documentation are also available via the Internet at:

     http://www.ars.usda.gov/Services/docs.htm?docid=8872

- A minimum of 600K available random access memory (RAM)

- A PC DOS operating system, Version 3.0 or later. SRM will run in a MS-DOS window under Microsoft Windows 3.1/95

- If graphics are desired, a graphics adapter is required. Micro-SRM supports the following graphics modes:

 - CGA - Color Graphics   - EGA - Enhanced Graphics
 - HGA - Hercules Graphics   - VGA - Virtual Graphics

- For printed output, a dot-matrix or other printer that supports a 132-character print line, either physically or using "compressed-mode" print characters

- A Microsoft-compatible mouse (optional).

G.2.2 Installing Micro-SRM

Micro-SRM is completely contained on one distribution diskette. It may be executed directly from that diskette. The following steps describe installation on a hard disk, and assume C: and A: are the hard disk and floppy disk drives, respectively:

(1) Put Micro-SRM diskette in your floppy drive.

(2) At the C> prompt, enter the following command lines, ending each line by pressing Enter ◁┘

---

[1] Trademarks used in this document (e.g., IBM PC, IBM CORP.; MS-DOS, QuickBASIC, Microsoft Corp.; QuickPak Professional, Crescent Software) are used solely for the purpose of providing specific information. Mention of a trade name does not constitute a guarantee or warranty for the product by the U.S. Department of Agriculture or an endorsement by the Department over other products not mentioned.

C> **cd **	: change to C: 's root directory
C> **md \\srm**	: create a model subdirectory
C> **copy a:*.* c:\\srm**	: copy all files from floppy A: to new subdirectory C:\\SRM

G.2.3 Configuring Micro-SRM

The model uses an external "configuration" file to define the variables that Micro-SRM uses to control the interface between model and user. The configuration file is specified on the command line invoking Micro-SRM. If no filename is specified, the model uses the configuration file residing on the default directory named "SRM.CFG".

The file initializes program variables that define available disk devices, printer control codes, screen display color characteristics, audio tone level, and video graphics mode. Included on the distribution disk are several sample ".CFG" files and a utility program, CONFIG.EXE, that gives a user the ability to customize the model's interface for his/her unique hardware configuration.

G.2.4 Operating instructions

The following command syntax runs Micro-SRM from the default directory. *Filenames* must be complete pathnames if the target file does not reside in the default directory.

SRM4 *configfile* {option(s)} Enter ◄┘

The following list describes valid Micro-SRM command line options. Values enclosed in brackets [] denote SRM default values.

<u>Argument</u>	<u>Description</u>
ConfigFile	See description above [SRM.CFG].
/TIN = *tracefile*	Control SRM via a trace file, not the keyboard. See previous section for a complete description of the trace feature.
/TOUT = *tracefile*	Save keypresses from current run in a tracefile.
/TDELAY = *seconds*	Use with /TIN to vary speed of trace operation [.5]. See previous section for more on the trace delay.
/P = *printfile*	Redirect LPT1: (printed output) to a disk file.

The following examples demonstrate several common command line option combinations for initiating Micro-SRM:

C > **SRM4**
    Run the model from the default (in this case the root) directory, using the default configuration file, C:SRM.CFG, stored in that directory.

C > **A:**

A > **SRM4 EGA.CFG /P=SRMPRINT.PRT**
>   Switch to the A: drive, then run the model from the A: default directory. Use the A:EGA.CFG
>   configuration file. Reroute any printed output to a disk file, A:SRMPRINT.PRT.

C > **SRM > SRM4 /TOUT=trace.fl**
>   From the SRM subdirectory, run SRM using the default config file, and capture all keypresses
>   during the run, storing then in a trace file named C:\SRM\TRACE.FL

C > **C:\SRM\SRM4 C:\SRM\SRM.CFG /TIN=C:\SRM\TRACE.FL /TDELAY=2**
>   Run SRM from the root directory, using full pathnames for all file references. Drive the model
>   with keypresses stored in C:\SRM\TRACE.FL, with a 2 second delay between commands.

C > **MSHERC**
>   **SRM4 HERC.CFG**
>   Load Microsoft's Hercules graphics driver and run SRM in the Hercules graphics mode.

HINT*:* Create a batch file to run Micro-SRM. Store the batch file on the root directory of your hard disk
and include the root directory in your PATH statement (refer to your DOS manual for a description of
PATH). To create a batch (.BAT) file, type the following commands, each terminated by Enter◄┘ :

**C> cd **	: Make root dir the current dir
C> copy con SRM.BAT	: Copy from keyboard to SRM.BAT
cd \srm	: Line #1, change to model dir
srm4	: Line #2, run model
**cd **	: Line #3, change to root dir
<F6>	: Press Function Key F6, then Enter◄┘ to terminate copy con;

To run Micro-SRM using a batch file, simply type the batch file name, followed by Enter ◄┘

G.3 Program features

G.3.1 Screen display types

The model user interacts with Micro-SRM through a combination of text, data and menu screens. Each
screen display can be broken into several component parts.

- The screen header, lines 1-3 of the display, identifies the screen and in some cases includes run-
  specific information.

- The prompt line, line 24, columns 1-71, provides a location where the program can display prompts
  and warning/error messages as required.

- The keyboard "state" indicators, line 24, columns 74-80, display the current state (on/off) of the
  CapsLock and NumLock keyboard keys.

- The function key line, line 25, describes important functions available while the screen is displayed.

- Screen "hot" areas, highlighted (**bold)** text or characters, may appear anywhere on the screen. They
  draw attention to the screen area, as with function keys, and they provide a region that may be
  "mouse-clicked", to provide a mouse equivalent to a keypress response.

- The remaining screen area, lines 4-23, will have a type-specific definition. Micro-SRM uses three
  types of screen display to communicate with the model user.

G.3.2 Text screens

The model introduction screen and fifteen "Help" screens provide the user with on-line documentation to assist in resolving questions concerning the use of the computer program and to provide limited information about the model and the variables and parameters required to use it. The introduction screen appears immediately after the program welcome screen. The help screen most appropriate to the user's current location in the data entry process is displayed upon user request (by pressing Function Key #1). Once in "help" mode, the user may "PgUp" to a prior help screen, "PgDn" to the next help screen, or "ESCape" to return to the screen from which help was initiated.

G.3.3 Menu screens

Micro-SRM uses the menu screen to provide a simple method for controlling processes that require a single selection from among an array of possible choices. The menu screen presents the user with a list of possible selections along with their associated letter code. The user indicates a menu selection by entering its appropriate letter code, "clicking" on the selection with left mouse button, or by moving the "light bar", the menu selection displayed in contrasting color or reverse video, up/down the menu list using the arrow up/down (↑↓) keys. The user activates the selection by pressing Enter◄┘ .

There are three full screen menus used within SRM. The "Plot" and "Print" Menus control selection of available plot and print products respectively. The "Basin Variable/Parameter" Menu controls which of the 13 daily basin variable or parameter data input screens is to be displayed for data entry. In addition to these three "full screen" menus, SRM uses several "pop-up" menus. A "pop-up" is a display that is temporarily superimposed over some existing screen. An example is the FileIO function's "pop-up" menu that controls selection of the model's input/output options .

```
◄┘ └►         Snowmelt Runoff Model Help Screen          Version 4.0
                    HELP - Program Options
Start/End      - 4 digits to define the processing period.  The period runs
  Date               from day DD of Start MM through day DD of End MM.


Model Mode     - 0=Simulation, n=Updating (where calculated Q is adjusted
                     every nth day using actual flow values).


Temperature    - 0=Daily mean temperature provided
Average (°F/C) - 1=Use daily max,min temperature to calculate daily means


Temperature    - 0=a single set of daily temperatures will be applied to each
  Input              hypsometric mean elevation using temperature lapse rates.
               - 1=Daily mean temperature to entered by user for each zone,
                     SRM will NOT lapse temperature.  Not used for Max,Min temp.


Lapse Rates    - 0=Enter variable/parameter values for zone A only, all
Precipitation      remaining zones will be assumed identical to A.
Runoff Coeffs  - 1=Enter zone specific variable/parameter values.
Critical Temp


Runoff Avail - required to run SRM in updating mode.


Esc-exit help      PgUp-go to prior help screen      PgDn-go to next help screen
```

Typical Help Screen.

```
 ◄┘              Snowmelt Runoff Model (SRM)            Version 4.0
            Basin Variable/Parameter Definition Menu

                    ↓↑ to select, Enter◄┘ to edit values


                    A - Actual Stream Runoff (ACTUAL)
                    B - Maximum Daily Temperature (TMAX)
          Basin     C - Minimum Daily Temperature (TMIN)
          Variables D - Average Daily Temperature (T)
                    E - Precipitation (P)
                    F - Snow-Covered Area in Zone (S)

                    G - Critical Temperature (Tc)
          Basin     H - La┌──────────┐age (L)
          Parameters I - Te│ Action?  │apse Rate (LR)
                    J - De├──────────┤ctors (AN)
                    K - Sn│ Load     │oefficients (CS)
                    L - Ra│ Save     │oefficients (CR)
                    M - Ra│ Delete   │ributing Area (RCA)
                          │ Import   │
                          └──────────┘
                    Variable  Code = A



    F1Help     F2Summary     F3FileIO     F5Plot     F6Print     F7Compute
```

Full Screen Menu and FileIO "Pop-Up" Menu.

G.3.4 Data entry screens

Micro-SRM's data input screens are simply electronic versions of standard printed forms (income tax forms being a good example), which consist of one or more pages of information requests with associated reply spaces or "fields" provided for entering data values. In Micro-SRM, the basic data entry screen display consists of background text that names and/or briefly describes each field, field "shadows", strings of a special character (·····) that visually define both the physical dimension and screen location of each data field, and a blinking data character or cursor (▒) that marks the model user's current position within a data screen

  The current value of the model variable represented by each field is superimposed over its corresponding field shadow. Field values are accentuated on the display by varying light intensity or color on monochrome and color monitors, respectively.
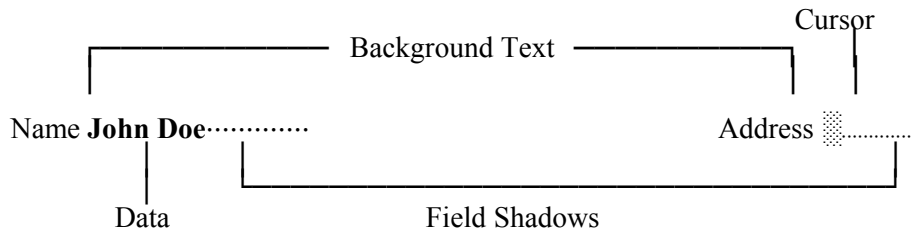
Data Entry Screen Components.

The model user types text or other data onto the data fields provided on the screen display, at the position marked by blinking cursor. Micro-SRM interactively controls and validates the characters entered using each data field's three associated data validation attributes: maximum length, context, and content range.

Maximum Length - each data entry field displayed on the screen has a predefined physical dimension that is displayed via the field's "shadow". Any attempt by the user to exceed a field's "shadow" is ignored and a warning message is displayed.

Field Context - each field has a predefined "context" that dictates the type of characters which it may receive. If the context rule for the field is violated, the illegal character is ignored and a warning message is displayed. There are 3 basic contexts:

Alphanumeric: the default context. Any character is valid.

Binary: a value of 0 or 1.

Numeric: valid numeric character (i.e., 0-9, ., -, +).

Field Content - Content validation differs from the first two validation forms in that it occurs after all the characters for a given field have been entered. The information may then be validated as a distinct entity. It is at this point that field values are checked for valid range, consistency with previously entered data, etc. Violation of a field's range or consistency checks causes a error message to be generated and locks the cursor on the invalid field until the condition is corrected. These techniques help insure that data entry errors are minimized and are caught "before the fact", that is, before the data are introduced to the actual model algorithms. There are three data entry screens used within Micro-SRM.

```
 ◄┘  └►                 Snowmelt Runoff Model  (SRM)              Version 4.0
                             Program Options


Model Run Number 17                          Start Date (MMDD) 0401


Units (0=Metric 1=English) 1                 End Date (MMDD)   0831


Model Mode 0                                 Temperature Average (°F/°C) 0
(0=Simulation 1-9=Updating)                  (0=Daily Mean   1=Max,Min)


Temperature Input 1                          Temperature Lapse Rates 0
(0=basin wide   1=by zone)                   (0=basin wide   1=by zone)


Precipitation Input 1                        Runoff Coefficients 1
(0=basin wide   1=by zone)                   (0=basin wide   1=by zone)


Critical Temperature 1                       Actual Runoff Available 1
(0=basin wide   1=by zone)                   (0=No  1=Yes)


Comments Beginning with Version 3.10, three comment lines are provided.........
that allow a user to describe the current data, making it easier...............
to keep track of individual data files.......................................


  EscQuit    F1Help    F2Summary    F3FileIO    F5Plot    F6Print    F7Compute
```

Program Options Data Entry Screen.

G.3.5 Program options

The "Program Options" data entry screen displays run-specific data values. These items are initialized by the model on program entry.

G.3.6 Basin definition

The "Basin Definition" data entry screen is used to enter basin-wide values (e.g., zone area and hypsometric mean elevation) which identify and physically define the subject basin.

G.3.7 Basin variables/parameters

The "Basin Variable/Parameter" data entry screen manages the process of providing daily values for each required variable and parameter for the entire snowmelt period and for each elevation zone within the basin. Micro-SRM paints a screen display format that represents two calendar months of a given parameter or variable for a given elevation zone. The initial two months of data displayed in the format are for the first two months of the specified snowmelt period and for the lowest (or only) elevation zone, zone A. The model then uses the PgUp/PgDn keys to superimpose the next/prior two months' values onto the screen. If the basin contains multiple zones, Function keys F5/F6 are used to superimpose the prior/next zone's values for the 2-month period shown. Any given display is self-explanatory, showing the variable/parameter name, elevation zone, month names, and "hot" key areas and definitions. See previuos section for more information on these "hot" keys.

```
 ◄┘  └►              Snowmelt Runoff Model (SRM)            Version 4.0
                          Basin Definition

Basin Name Durance Basin .....         Number of Zones (1-8) 5

Model Year 1975                        Initial Runoff 12 .......

Parameters for computing recession coefficients:

     X= 1.0849 .....                   X1=........
     Y= 0.0528 .....                   Y1=........
     Effective Date = 0401             Effective Date =...

Reference Elevation 0 .....            Rainfall Threshold 6 ......

        Zone       Hypsometric            Zone       Hypsometric
Zone    Area     Mean Elevation     Zone  Area     Mean Elevation
════════════════════════════════     ════════════════════════════════
  A     219 ...        1141 ..        B    495...        1680 ..
  C     783 ...        2154 ..        D    536...        2577 ..
  E     120 ...        3074 ..        F     .....         ....
  G      .....          ....          H     ....          ....


   EscQuit   F1Help   F2Summary   F3FileIO   F5Plot   F6Print   F7Compute
```

Basin Definition Data Entry Screen.

```
 1975            Snowmelt Runoff Model (SRM)              Version 4.0
 Durance Basin          Basin Variables                     Zone A

 ══════════════════════════════════ Precipitation (P) ══════════════
    Function Keys    Apr  Value   Apr  Value ║ May  Value   May  Value

                      1   ....     16  .01 .. ║  1   ...      16  .02 ..
 F5 - Prior zone      2   .....    17  .....  ║  3   .04      18  .....
 F6 - Next zone       4   .58 ..   19  .....  ║  4   .7.      19  .12 ..
                      5   2.74 .   20  .....  ║  5   .03      20  .06 ..
 F7 - Duplicate an    6   .65 ..   21  .....  ║  6   .24      21  .11 ..
      existing zone   7   .1 ...   22  .....  ║  7   .15      22  .53 ..
                      8   .37 ..   23  .....  ║  8   .31      23  .....
 F8 - Repeat prior    9   .45 ..   24  .....  ║  9   .04      24  .....
      value 1 time   10   .....    25  .....  ║ 10   1.36     25  1.07 .
                     11   .....    26  .....  ║ 11   1.58     26  .13 ..
 F9 - Repeat prior   12   .....    27  .....  ║ 12   ...      27  .....
      value n times  13   .....    28  .....  ║ 13   ...      28  .05 ..
                     14   .02 ..   29  .....  ║ 14   .06      29  .41 ..
 F10-Adjust day(s)   15   .58 ..   30  .....  ║ 15   .07      30  .....
                                                             31  2.41 .

    Esc-Exit process    F1-Help    PgUp-Prior 2 months    PgDn-Next 2 months
```

Variable "Precipitation" Data Entry Screen.

G.3.8 Climate change processing control screens

Beginning with Version 4.0, the Snowmelt Runoff Model supports an expanded climate change modeling component that supports year-round climate change modeling (see Section 8 for a complete description of SRM's climate change approach). Two additional screens have be added to the computer program to manage the additional complexity required to support this new capability.

G.3.8.1 Climate change control screen

The "Climate Change Control" data entry screen provides the user with a template for defining the winter and summer periods of a hydrologic year and the seasonal climate change scenario associated with each. During climate change processing steps, SRM modifies the affected variables/parameters as described by the scenarios detailed on this screen.

The two variables and five parameters listed on the screen can be modified for a new climate in two basic ways.

Shifting: The model user may want to shift parameters most affected by climate to an earlier time period in the hydrologic year to reflect the new climate. The shift "field" allows the user to enter the number of days of shift desired. Shifts are currently restricted to model parameters only. When shifting parameters, the model also modifies the shift in two critical ways in order to impose reality on a mechanistic approach (see Section 8.4).

(1)   To insure that parameters for a cooler autumn month/s are not shifted into the final month/s of the melt season (for example, October snow runoff coefficients shifting to September on a defined shift of 31 days), SRM shifts parameters only within a hydrologic year, repeating the final daily value for the year the required number of days to complete the shift. With this approach, a shift of 31 days for a summer half year (4/1 to 9/30) would have September values shifted to August and all September days would take on September 30's daily value.

```
          Snowmelt Runoff Model (SRM)              Version 4.0
          Climate Change Control Screen

                          Winter                  Summer
                       1001    0331            0401    0930
                      _____       _____
                       Shift   Amount    |    Shift   Amount
                      _____    |_____
Temperature (T)        N/A     4····     |   N/A     4·····
Precipitation (P)      N/A     120%·     |   N/A     120%
Degree Day Factors (a) 31··    ······    |   31··    ······
Lapse Rates (γ)        ····    ······    |   ····    ······
Snow Runoff Coefficients (C_S) 31··      |   31··    ······
Rain Runoff Coefficients (C_R) ····  ····· |   ····   ······
Critical Temperature (T_CRIT)  ····  ······|   ····   ······


              EscAbort     F1Help     F7Begin
```

Climate Change Control Data Entry Screen.

(2) Winter parameter shifts operate only on the last (coldest) half of the winter season. This precludes the possibility of having the desired warmer winter climate negated by moving parameters associated with colder winter months into autumn months.

Amount: Daily temperature and precipitation values are normally changed for climate by some constant amount or percentage. Values entered in the amount field for a variable are applied to each daily observed value in the period during climate change runs. Values in the amount fields are assumed to be numeric constants unless otherwise noted (by including a % character). Parameters may also be modified by amount, though model developers prefer to utilize shifting to adjust parameters for climate change.

G.3.8.2 Climate change progress screen

The "Climate Change Progress" Screen tracks the multi-step process that SRM follows when performing a climate change simulation (see previous sections for a detailed explanation of the steps involved). At the completion of Steps 1-4, the progress screen displays basic zonal melt totals the model will use in Step 5 to derive climate modified snow depletion curves. After each of these initial steps, the user can initiate step-specific interim plots and reports, using the function keys displayed near the bottom of the screen.

At the beginning of Step 5, SRM computes net zonal Winter Change, and prompts the user to verify the results. At this point computed zonal Winter Change may be overridden with some other value (see Section 8.3 for discussion of a situation where such replacement would be appropriate).

```
10-10-97                  Snowmelt Runoff Model (SRM)              Version 4.0
(IL840606.SRM)            Climate Change Progress Screen


√  Step 1:    Winter simulation, normal climate (determine total zonal melt)
   Step 2:    Winter simulation, changed climate (determine total zonal melt)
   Step 3:    Summer simulation, normal climate (save MDC, simulated runoff)
   Step 4:    Summer simulation, changed climate (save MDC_CLIM)
   Step 5:    Create CDC_CLIM WA using MDC_CLIM (adjusted for Winter Change)
   Step 6:    Summer simulation, changed climate, using CDC_CLIM WA


  _____ Step 1 _____
   Zone     ΣM·S   +  M(1-S) + ΣP_rain  =  Zonal Input    Winter Change
    1       2.404    7.029   23.267       32.6998          0.000
    2       0.000    4.349   13.040       17.3895          0.000
    3       0.000    0.000    0.000        0.0000          0.000
    4       0.000    0.000    0.000        0.0000          0.000

Simulated Q on 3/31 = ...


_____
 EscAbort      F1Help      F2Summary      F5Plot      F6Print     ↵ Next Step
```

Climate Change Progress Screen

Step 6 models $CDC_{CLIM\ WA,\ MA}$. During this step, several new output products are automatically generated by the model. A printed report, the Climate Change Statistics Report (or optionally a disk file, SRM.LOG, on systems without a printer) displays the computed values used to derive these "climate-modified" CDC's The following curves are displayed in four new plots, allowing the user to visualize the modeling process:

MDC_{EXCL}, $MDC_{EXCL\ WA}$

AZM_{INCL}, AZM_{EXCL}, $AZM_{EXCL\ WA}$

$MDC_{EXCL\ WA}$, $MDC_{CLIM\ WA}$

CDC_{CLIM}, $CDC_{CLIM\ WA}$

Date: 10-10-1997
File: IL840606.SRM
===
Total P, Winter   [P] = 82.57877
Total P, Winter(clim)   [P'] = 99.09452
Winter - Total Zonal Input [i], Zone 1 = 32.69977
    $\Sigma M \cdot S$ = 2.404175
    $\Sigma M(1-S)$ = 7.028653
    ΣP_rain = 23.26694
Winter(clim) - Total Zonal Input [i'], Zone 1 = 80.41334
    $\Sigma M \cdot S$ = 39.92039
    $\Sigma M(1-S)$ = 0
    ΣP_rain = 40.49295
Winter Change (ΔHW), Zone 1 = [i - i' + P'- P] = -31.198
Zone 1
    Winter Change (deficit) of -31.19781 was equaled/exceeded by accumulated zonal melt on 5/5, a shift of 35 days AZM_{EXCL} on 5/5 = 31.42749
    Prior day's AZM_{EXCL} = 30.5473

===
Total P, Winter   [P] = 101.8937
Total P, Winter(clim)   [P'] = 122.2724
Winter - Total Zonal Input [i], Zone 2 = 17.38953
    $\Sigma M \cdot S$ = 0
    $\Sigma M(1-S)$ = 4.349365
    ΣP_rain = 13.04016
Winter(clim) - Total Zonal Input [i'], Zone 2 = 52.66322
    $\Sigma M \cdot S$ = 7.564875
    $\Sigma M(1-S)$ = 6.676103
    ΣP_rain = 38.42224
Winter Change (ΔHW), Zone 2 = [i - i' + P'- P] = -14.895
Zone 2
    Winter Change (deficit) of -14.89496 was equaled/exceeded by accumulated zonal melt on 5/17, a shift of 47 days AZM_{EXCL} on 5/17 = 15.63624
    Prior day's AZM_{EXCL} = 14.55844

===
Total P, Winter   [P] = 122.8147
Total P, Winter(clim)   [P'] = 147.3776
Winter - Total Zonal Input [i], Zone 3 = 0
    $\Sigma M \cdot S$ = 0
    $\Sigma M(1-S)$ = 0
    ΣP_rain = 0
Winter(clim) - Total Zonal Input [i'], Zone 3 = 16.24898
    $\Sigma M \cdot S$ = .8295755
    $\Sigma M(1-S)$ = 2.494999
    ΣP_rain = 12.92441
Gain(g) = (P' - i') / (P - i)
    g   = (147.3776 - 16.24898)/(122.8147/0) = 1.067699
Winter Change (ΔHW), Zone 3 = [i - i' + P'- P] = 8.314
Zone 3
    Winter Change (surplus) 8.313959 was accounted for by stretching MDCs by a factor of 1.067695

===
Total P, Winter   [P] = 122.8147
Total P, Winter(clim)   [P'] = 147.3776
Winter - Total Zonal Input [i], Zone4 = 0
    $\Sigma M \cdot S$ = 0
    $\Sigma M(1-S)$ = 0
    ΣP_rain = 0
Winter(clim) Total Zonal Input [i'], Zone 4 = 0
    $\Sigma M \cdot S$ = 0
    $\Sigma M(1-S)$ = 0
    ΣP_rain = 0
Gain(g) = (P' - i') / (P - i)
    g   = (147.3776 - 0) / (122.8147 / 0) = 1.2
Winter Change (ΔHW), Zone = [i - i' + P'- P] = 24.563
Zone 4
    Winter Change (surplus) 24.56294 was accounted for by stretching MDCs by a factor of 1.2

The climate change scenario described produced this Climate Change Statistics
Report (T + 4°C, P 120 %, 31 day shift of *a* and C$_S$.

Note! Zones 3-4 exhibit a positive Winter Change due to the increase in P
(120%) overwhelming the temperature-induced (+ 4°C) deficit.

Climate Change Statistics Screen.

G.4 Keyboard definition

User interaction with the model is initiated via the standard PC keyboard or the optional mouse. During
data entry, the program recognizes and accepts all the standard ASCII characters present on the keyboard.
In addition, Micro-SRM provides both intuitive and non-intuitive functionality to many of the "special"
PC keyboard keys. At any given point in the Micro-SRM modeling process one or more of these keys
may be "hot", that is, set to initiate a specific program-defined activity when pressed. These "hot" key
definitions are task-specific, and will be redefined or undefined as the model user changes tasks. These
"special" keys can be grouped into several broad categories.

G.4.1 Global definitions

The following four keyboard keys initiate logical functions which are available for use at any point in the
modeling process.   Where defined, the corresponding "mouse click" equivalent is presented in
parentheses at the end of the definition.

ESCape - The use of the ESCape key in Micro-SRM is consistent with most typical PC applications.
Basically, the ESCape key suspends the current activity (inspecting help screens, performing
variable/parameter data entry, loading a data file, etc.) and returns control to the point in the program
where the suspended activity was originally invoked. It backs the user up one logical processing step.
From the Program Option, Basin Definition, or Variable/Parameter Menu screens, the ESCape will
terminate Micro-SRM and return control to DOS. ("LeftClick" on Esc, or "RightClick" to simulate
ESCape).

PgUp, PgDn - The PgUp and PgDn keyboard keys control which screen display is presented to the user
of Micro-SRM. They are functionally equivalent to turning forward or back one page in a multi-page
form.   The exception to this usage rule occurs while entering or editing data values on the
variable/parameter data entry screen display. During this type of data entry, the PgUp and PgDn keys are
used to superimpose the next two or prior two month's data values for the specific variable/ parameter
onto the data entry screen, enabling the user to logically step forward or backward in time through the
snowmelt period. ("LeftClick" on ◁⌐ ∟≫ PgUp PgDn).

***Enter*◀┘** - The Enter◀┘ key is used by Micro-SRM to terminate keyboard responses. Enter◀┘ implies that information has been provided to the model, and the model should now react to that information. Most commonly, it signals that data entry for the current input data field is complete. When pressed, the model optionally validates the current field's contents for consistency, range validity, etc. (see field content validation above). Micro-SRM "remembers" each input field's most recent value, and so only initiates validation when field contents change. If the field value is unchanged or the changed value validates successfully, the model accepts it into its internal schema and advances the screen cursor to the next logical field on the screen display. If validation fails, an appropriate error message is displayed and the cursor relocates to the first character of the offending field's value. When used with a menu screen display or pop-up window, the Enter◀┘ key directs the model to use the menu option marked by the light bar as your choice from that menu. Enter◀┘ is also used during the FileIO process to terminate a request for a filename by the model. ("LeftClick" another input field or Enter◀┘).

G.4.2 Cursor movement keys

The keys described here are all capable of moving the screen cursor from the current data entry field to some other field in the same screen display. When that occurs, their use initiates a data validation response identical to that of the Enter◀┘ key. Using these keys, the model user may move freely about the input data screen, entering new and editing existing field values. ("LeftClick" on any field to move the cursor to that field.)

Movement between input fields initiated by cursor movement key-presses is governed by a forward and a backward progression sequence. The forward progression (via the Enter◀┘ or Tab keys) on a screen beginning at the top leftmost field, is from left to right, top to bottom. Backward progression is the reverse. Movement vertically is generally from the current field up/down to the next closest field. Movement via the Enter◀┘ key during daily variable/parameter data entry is from current day to next calendar day.

Tab - The Tab key functions exactly the same as Enter◀┘

{Shift}Tab - If the cursor is not on a field's first character, it shifts to the first character. If on the field's first character, the cursor moves to a prior field, as dictated by the backward progression.

Home/End - These keys move the cursor to the first/last data field, respectively, on the screen display.
↑←↓→ - Within a field value the screen cursor may be moved left or right from character to character. If the cursor is at the leftmost character of the field, a "←" moves the cursor to the prior field as defined by the screen's backward progression. If the cursor is at the rightmost character of the field value, a "→" moves the cursor to the next field in the forward progression. An "↑" or "↓" moves the cursor to the next higher/lower field relative to the current field.

G.4.3 Field editing keys

Micro-SRM uses "type-over" as its standard data entry mode. This means that any valid data character typed through the keyboard will replace that marked by the blinking cursor, with the cursor advancing to the next character position in the field. The model supports "word-processor-like" editing via the following keys:

Insert - The Insert key toggles the data entry mode to "insert", with any typed characters being inserted at the point in the field marked by the reverse-video cursor, and all existing characters shifted rightward. Insert mode is canceled by pressing Insert again, or moving the cursor to another data field or screen.

Delete - The Delete key is logically the opposite of Insert. The character marked by the cursor is deleted, and all characters to the right of the cursor are shifted left one position.

Backspace - The Backspace key deletes the character immediately to the left of the cursor, with all characters at and right of the cursor shifted left one position.

CapsLock - When CapsLock is set (indicator on screen line 24 is visible), any alphabetic character entered will appear in upper case. Press CapsLock again to turn off.

NumLock - When NumLock is set (indicator is visible), characters entered through the keyboard's number pad are treated as numbers. WARNING!! If NumLock is on, the cursor movement key equivalents on the number pad are deactivated. Micro-SRM assumes you are entering numeric data, not trying to relocate the cursor or change the display page.

G.4.4 Function keys

Micro-SRM uses the microcomputer's dedicated keyboard function keys (F1-F10) to provide the user with the ability to interrupt the current model activity (typically data entry) with a single keypress/mouse click, and transfer control to a specific predefined function process. On function termination, control returns to the point of interruption. Each Micro-SRM screen display includes information on the function keys that are "hot" (i.e., active at that point in the program).
The functions described below are Micro-SRM "primary" function key definitions. These functions are "hot" while the "Program Options", "Basin Definition", and "Basin Variable/Parameter Menu" screens are displayed:

F1-Help - The Help function is invoked by pressing/clicking function key F1 at any point in the modeling process. When help is requested from a primary screen display (Program Option, Basin Definition, Variable/Parameter Menu, Variable/Parameter Data Entry), Micro-SRM replaces that screen display with the Help Screen most logically related to the user's position within the model. While help is active, the user may PgUp or PgDn to view all of Micro-SRM's available help screens. The function is terminated with an ESCape, and returns the model to the logical state existing prior to the help request. When help is requested from within another function (SUMMARY, FILEIO, PLOT, PRINT), it is presented slightly differently, through the use of a pop-up window, a transient area nondestructively superimposed over the current display image. These function pop-ups are only accessible after invoking the specific function.

F2-Summary - This function is invoked by pressing/clicking function key F2 from the Program Options, Basin Definition, or Variable/Parameter display screens. The Micro-SRM summary screen provides the user with a "snapshot" of basin definition variables and zone-specific parameter values as they are currently defined. Beginning and mid-month value (day 1 and day 16 if different) for each month in the snowmelt period are displayed for seven model parameters. Each zone in the basin is displayed separately, and is accessed via the PgUp and PgDn keys. A printed version of the summary may be selected through the Print Menu (see below). The following keys are "hot" within the summary function:

> *F1* - Help info on this function
>
> *PgUp/PgDn* - - Display the next/prior zone's configuration.
>
> *ESCape* - Exit function and return to point where invoke

F3-FileIO - The File Input/Output function is invoked by pressing/clicking function key F3 from Program Options, Basin Definition, or Variable/Parameter display screens. In response to the hot-key, a small "pop-up" menu is displayed. The user specifies one of four sub-options by moving the menu bar using the up arrow or down arrow, then pressing Enter◄◄, pressing the desired sub-option's highlighted letter, or left-clicking on the menu selection. FileIO provides the modeler with tools to load, save and delete model data files and to import digital input data from non-model sources.

Load - The Load option allows the user to identify and input a .SRM data file (see SAVE below) into the model. After a successful load, the model assumes a state identical to that existing when the referenced data file was created.

Save - The Save option allows a user to create and name a file containing the ASCII representation of the data currently resident in the model's data structures. The file qualifier ".SRM" completes each save file's name, making it easy to recognize and manage model data. A data compression algorithm shrinks the 100K+ internal data structures into a more manageable size (a complete five zone basin might require 10K) using shorthand notation identical to the FORTRAN repeat count concept (IBM VS FORTRAN, 1983).

Delete - This option provides the model user with the ability to delete any SRM data file (.SRM-qualified) currently residing on any of the PC's storage devices.

Import - The Import option provides a method for introducing digital input data from a non-SRM source to the model. Using a simple format (press F1 for a popup describing the import format), any of the 13 model variables/ parameters detailed on the Variable/Parameter Input Data Screen may be generated externally and directly loaded into SRM. To be accessible to SRM, all import data files must be qualified ".DAT".

Once a FileIO option is selected, Micro-SRM displays a file selection/definition screen made up of two display panels. The upper panel displays the individual system's available devices, and lists all subdirectories and filenames for the current default device/directory. The lower panel displays the current pathname (i.e., the device, directory, or filename) that will be used to attempt to fulfill the current FileIO operation.

The selection screen uses two simple approaches for identifying target file names. The first approach is "point and shoot". With the upper panel "active", an object from that panel may be selected by moving the light bar to the desired object using the cursor keys, then pressing Enter◄◄, or by clicking on the desired object with the left-mouse-button. Alternatively, the user can press the TAB → key to switch to the lower panel and use the keyboard to enter the desired filename, then press Enter◄◄, to select the file. If the object selected/entered is a valid pathname (i.e., a device {A:, B:}, directory name ending with "\", or <Parent> the default device\ directory will be changed, and all appropriate files on the new path will be displayed.

F5-Plot - The PLOT Function is invoked by pressing/clicking function key F5 from the Program Options, Basin Definition, or Variable/Parameter Menu display screens. Micro-SRM will refuse this function request and generate an appropriate error message if the PC has no graphics adapter present or a

simulation/forecast has not been run since last data entry. If the F5 key is "hot", the plot options menu is displayed. The five Micro-SRM plot products available during normal processing are:

- Measured vs Computed Streamflow

- Snow Depletion vs Time

- Snow Depletion vs Total Snowmelt Depth

- Accumulated Zone Melt Depth vs Time

- Build External Plot File

If Micro-SRM performs a climate-change run, the state of the plot menu changes, presenting the user with the following choices:

- Computed Flow Before/After Climate Change

- CDC/Clim (Model Adjusted) vs Time

- Build External Plot File

The following keys are "hot" while this menu is displayed:

F1	- Help for Plot Menu
Up/Down Arrow	- Move menu bar to next/prior choice
Enter◄┘	- Invoke selected plot option
ESCape	- Exit function

After a plot has been displayed, the user may request a hard-copy by pressing function key F10. Press Enter◄┘ to cycle through any additional zone(s) in the basin. Press ESCape to return to the Plot Menu.

The fifth option on the menu, Build Plot File, generates an ASCII file containing all the information necessary to recreate a user-selected combination of the Micro-SRM plot products using non-model hardware/software.

F6-Print - The PRINT menu is displayed by pressing/clicking function key F6 from the Program Options, Basin Definition, or Variable/Parameter display screens. The print products available in Micro-SRM are:

- Temperature Values

- Degree Day Factors, Runoff Coefficients

- Lapse Rate, Critical Temperature, Rain Contributing Area, Lag Time

- Zone Degree-Days, Observed Precipitation, Snow-Covered Area (S)

- Melt Depth (M · S), Melt/New Snow (M (1−S)), Contributing Rain (Cpr)

- Measured vs. Computed Snowmelt Runoff
- Input Summary Report, Run Statistics
- All the above

The validity of some of these reports is contingent upon successful completion of a simulation/forecast.

F7-Compute - This function is invoked from the Program Options and Basin Definition data entry screens, or the Variable/Parameter display screen by pressing/clicking function key F7. It initiates actual model processing using the current version of input data. Processing may be suspended due to missing or invalid input variables. If processing is successful, a "results panel" will be displayed, showing results of the computations.

<table>
<tr><td colspan="3" align="center">SIMULATION</td></tr>
</table>

Measured Volume (10^6 m^3)	:	938.75
Average Measured Q (m^3/s)	:	71.01
Computed Volume (10^6 m³)	:	910.10
Average Computed Q (m^3/s)	:	68.85
R² Goodness of Fit	:	0.8959
Volume Difference (%)	:	3.0526

Screen display after compute.

G.4.5 Alternate function keys

In addition to the functions described above, there are several alternate function key definitions that supersede the primary function key definitions during basin variable/parameter data entry/data display. These alternate functions provide some additional tools useful in manipulating the complex structures required to store multiple day, multiple zone data. These functions are:

F5-Prior Zone/F6 Next Zone - As explained before, these keys change the Variable/Parameter data entry screen display to the same two-month period for the next or prior elevation zone. These keys are "hot" only for multi-zone basins and only for zone-specific variables and parameters.

F7-Duplicate Existing Zone - When invoked, this function prompts the user for a source and destination zone, then copies all the daily values from the source zone to corresponding days in the destination zone. This is particularly useful for some of the model's daily parameters, which may change very little from zone to zone.

F8-Repeat Prior Value - Pressing F8 causes the value for the day preceding that marked by the cursor to be copied into the current day position. The cursor then advances to the next day. If the cursor is on the first day of the earlier of the two months displayed, the prior day value used is out-of-sight, that is, the last day of month preceding the month displayed.

F9-Repeat Prior Value N Times - After prompting the user for a repeat count, the model enters the value from the day preceding the cursor into the next N days, moving the cursor as it proceeds. The repeat count can vary from 1 to 365.

F10-Insert/Delete Day - This function lets the user modify an existing array of daily values without reentering the entire array. When invoked, the user may insert a blank day at the point marked by the cursor, shifting existing day values one day forward in time, or delete the day marked by the cursor, shifting existing daily values one day back in time.

G.5 Micro-SRM output products

Several different forms of output have been included in Micro-SRM, designed to support a user's specific requirements for information provided to, and generated by the model. Model output is user-selectable, and for several of the forms, interactively controlled. The available output products are described in the following paragraphs.

G.5.1 Simulation/forecast statistics

Each time an F7-Compute is successfully executed, the model suspends further processing while it displays several important statistics which quantify the accuracy of the calculations. Any keypress then returns the model to its precompute state.

G.5.2 Summary display

Function Key F2 invokes the model summary screen. See previous sections for a complete description of this function. It is designed to give the user a quick overview of the state of seven critical model parameters. Summary is useful when making iterative runs, each with slightly different parameter configurations. The basin name and model run number are included, identifying the specific iterative version of the data displayed.

G.5.3 .SRM data file

As described before, the FileIO menu option "Save" creates a disk file containing all the information necessary to recreate the model run at some future time, via the "Load" function.

G.5.4 Plot displays

Micro-SRM produces several different plots in one of several different screen modes. Once plotted, and assuming a compatible printer, a hardcopy of the plot image can be produced.

Measured vs Computed Streamflow - Runoff is plotted along the Y-axis (instantaneous flow), time along the X-axis. Run statistics are displayed in the upper right corner.

Snow Depletion vs Time - Snow depletion curves for each zone are produced. The initial image displays all the basin's snow depletion curves on a single image. Press a key to produce a separate plot of each specific zone, in ascending order. Press ESCape to terminate the plot.

Snow Depletion vs Total Snowmelt Depth - Daily snow covered area (%) is plotted on the Y-axis, corresponding accumulated snowmelt depth, and accumulated snowmelt reduced by the effect of new snow, are plotted on the X-axis. Each zone is plotted separately. Press Enter◄┘ to see the next zone, ESCape to terminate and return to the Plot Menu.

Accumulated Zone Melt Depth vs. Time - Accumulated zone melt depth (areal coverage) (y) is plotted against time (x). Press Enter◄┘ to change zones, ESCape to terminate the plot.

".PLT" Plot File - All the input and model-generated values used to create Micro-SRM's plots are saved to a user-named external disk(ette) file (.PLT-qualified). The .PLT file format is described in more detail in the sample .PLT file included on the Micro-SRM distribution diskette.

G.5.4.1 Plot displays (climate change)

SRM, Version 4.0 and later will automatically produce several additional plot displays during climate change simulation runs.

MDC_{EXCL} vs $MDC_{EXCL\ WA}$ - The first curve depicts the snow water equivalent of the existing snow pack, new snow excluded, under normal climate conditions (the amount of melt needed to decrease the snow covered area to a certain proportion of the total). The second curve is derived from MDC_{EXCL} by introducing the effect of a winter climate change upon areal snow water equivalent.

AZM_{INCL}, AZM_{EXCL}, $AZM_{EXCL\ WA}$ - Accumulated zonal melt curves for the melt season, with and without new snow falls, and "winter-adjusted" AZM. The first two curves depict areal water equivalent of the initial snow cover under normal climate conditions, the last, areal water equivalent in a changed climate.

$MDC_{EXCL\ WA}$ vs $MDC_{CLIM\ WA}$ - These curves depict areal snow water equivalent of the initial snow cover in a changed climate, with and without new snow added.

CDC vs $CDC_{CLIM\ WA}$ - These curves depict snow covered area for the normal and changed climate. The first curve is taken from input data provided by the user. The second curve is derived by the climate change algorithms of SRM.

G.5.5 Printed reports

Micro-SRM includes 7 different printed report formats, each display one or more model variable(s). The menu controlling selection of printed reports allows the user to select an individual report, or the entire report set (see previous sections for more information on the F6 print function). Printing can be canceled by pressing ESCape at any time during printing (if print buffering is in effect, there will be some delay before ESCape takes effect). Each selected report will print, even if there are no data present (i.e., neither input nor computed). The following reports are available:

Temperature Values ({form})
Prints temperature values entered by the user in the temperature form selected (max/min, mean) for each day in the snowmelt period, as specified on the Program Options Screen .

Degree-Day Factors, Runoff Coefficients
Daily degree-day factors (AN) and snow/rain runoff coefficients are printed for each day of the melt period.

Lapse Rate, Critical Temperature, Rainfall Contributing Area, Lag Time
Parameters displayed control how discrete temperature values are applied basin-wide (lapse rate), when to treat precip as snow (critical temp), how to calculate the effect of precipitation (RCA), and how to distribute resulting runoff over time (lag time).

Zone Degree-Days, Observed Precip, Snow-Covered Area
A zone-specific report that displays DD temperature (either computed from max/min, average daily temperature, or entered directly as DD's), observed precip (these values may be zone specific or apply across the entire basin), and snow-covered area (% of zone covered on a given day).

Melt Depth, (M · S), Melt/New Snow (M (1−S)), Precip Contributing to Runoff
Intermediate results of Micro-SRM computations. For each elevation zone, this report details daily total melt depth, zone contribution to runoff (M · S), and precip contributing to runoff, either as rain, or as melted new-snow.

Measured vs Computed Snowmelt Runoff
Simulated/forecast and measured streamflow (if provided) are plotted against time. Run statistics (R^2, % Volumetric Difference) are meaningful only if actual runoff values have been provided.

Input Summary Report, Run Statistics
A printout of the model summary display. Bi-monthly values (1st, 16th) for 7 model parameters are printed for each zone in the basin. Run statistics are for the most current model run.

All the Above
Generates a complete set of printed reports.

G.5.6 Printed reports (climate change)

Version 4.0 of SRM includes one additional printed report, the Climate Change Statistics Report that presents the computed values used to derive climate-affected snow cover.

G.6 Using Micro-SRM

Assuming the availability of the data necessary to run the model, there are only two requirements for using Micro-SRM. The target basin must contain 8 or fewer elevation zones and the physical dimensions of required input data variables may not exceed the size of the screen fields defined for their storage. This should only occur during variable/parameter data entry, where daily values may contain no more than 6 digits.

The following sequence of steps describes a typical Micro-SRM session:

(1) User types SRM4, then presses Enter◄┘ to invoke Micro-SRM.

(2) After viewing the Introduction screen, the user presses PgDn to view the "Program Options" data screen.

(3) The user makes any required changes to the program control information displayed on this screen, then presses PgDn to view the "Basin Definition" data screen.

(4) After filling the required data fields on this screen, the user begins the variable/parameter data entry process by pressing PgDn to view the Basin Variable/Parameter Definition Menu.

(5) The user selects a variable/parameter from this menu, then presses Enter◄┘ to display daily values for the first two months of the snowmelt period for the selected variable.

(6) The user fills the daily value fields with appropriate data, then presses PgUp or PgDn to view a different two-month slice of daily values for the same variable.

(7) After data entry for the selected variable/parameter is complete, the user presses ESCape to return to the Basin Variable/Parameter Definition Menu.

(8) The user repeats steps 5-7 for all required variables and parameters.

At any point during these steps the user may interrupt the data entry activity by pressing an active function key (to request help, save data, display the data summary screen, etc.). After data entry is complete, the simulation or forecast can be computed (press F7) and the results displayed (F5 for plots, F6 for print).

Prior to each *F7Compute*, SRM performs a simple, "non-elegant", test to determine if all appropriate variables and parameters have been supplied by the user. For each required variable or parameter type (determined by Program Option field values), SRM simply checks for the presence of a non-zero value anywhere in the period. If any required variable or parameter fails this test, a data validation error screen is displayed that identifies the variable(s) and zone(s) that have failed the test. To view this screen, simply run Micro-SRM, enter some values on the Basin Definition Screen, and press F7Compute. Because certain model variables and parameters may legitimately contain all zero values (i.e., precipitation), the model user is given the opportunity to continue the simulation or forecast, or abort processing so the "missing data" condition may be corrected.

G.7 Using Micro-SRM to simulate a year-round climate change

Beginning with Version 3.11, Micro-SRM allowed a user to define a climate change scenario, a seasonal change of temperature and precipitation, and simulate its effect during the melt season. This feature was an important step in implementing the ongoing "climate-change" research that SRM model developers had conducted over the prior several years. However, we have recognized the limitation of the original climate-change algorithm, the fact that the change was isolated only on the melting season. In other words, the snowpack used during any climate change scenario was the observed real seasonal snow cover.

Version 4.0 incorporates much of the model developers′ latest research on the effect of climate change on snowmelt runoff over an entire hydrological year (see Section 8). The original (SRM, 3.11) program′s climate-change algorithms/processing steps have been replaced with new algorithms that model future snow conditions as well as climate-affected runoff. The computer program has been enhanced to manage the steps involved in simulating climate change, by providing a new data entry screen, the Climate Change Control Screen. This screen allows the user to easily describe climate change conditions that span an entire hydrological year, specifying both a winter and a summer season climate change scenario. By simulating the effect of winter climate change on the existing snowpack, the program can model the summer season′s climate-affected snow conditions and use those curves ($CDC_{CLIM\ WA}$) during the melt season climate change simulation.

In Version 4.0, a "climate-change run" is in reality five complete iterations through the model, along with a series of additional steps required to model climate-changed snow cover data. The program′s progress through these steps is monitored using another new screen display, the Climate Change Progress Screen. The steps defined by that screen are:

Step 1: *Winter simulation, normal climate (determine total zonal melt)*

- Run winter simulation with the normal climate. Compute $\Sigma winter\_zonal\_melt_{NORMAL}$, where zonal melt (*i*) is:

    M·S (melt from snowpack) + M·(1-S) (melt from newsnow) + contributing P (Cpr)

    where: M = *a*·T
    Cpr = contributing precipitation, .i.e., that precipitation falling as rain that fell on the snowfree area, a ripe snowpack, or a combination.)

- Determine ΣPrecipitation (P).

Step 2: *Winter simulation, changed climate (determine total zonal melt)*
- Run winter half-year simulation with the changed climate. Compute $\Sigma winter\_zonal\_melt_{CLIM}$ (*i'*).

- Determine ΣPrecipitation$_{CLIM}$ (P').

Step 3: *Summer simulation, normal climate (save* MDC's*, simulated runoff)*

• Run summer simulation with the normal climate, save data needed to recreate modified depletion curves, MDC$_{EXCL}$, accumulated zonal melt curves, AZM$_{EXCL}$, and the simulated runoff hydrograph, Q$_{SIM}$.

        MDC$_{EXCL}$ [snow depletion vs. $\Sigma(a \cdot T-$ newmelt)]

        AZM$_{EXCL}$ [$\Sigma((a \cdot T-$ newmelt)$\cdot S$) vs time]

Step 4: *Summer simulation, changed climate (save* MDC$_{CLIM}$ *)*
• Run summer simulation with the changed climate. Save $\Sigma(a \cdot T)_{CLIM}$, $\Sigma(\text{newmelt})_{CLIM}$.

Step 5: *Derive* CDC$_{CLIM\ WA}$ *using* MDC$_{CLIM}$ *(adjusted for Winter Change)*

  (5a) Compute ΔH_W (Winter Change), (Σwinter_zonal_melt$_{NORMAL}$ - Σwinter_zonal_melt$_{CLIM}$, from Steps 1, 2 above).

  Reduce/enhance effect of temperature-induced deficit by adding any net change to seasonal precipitation resulting from the climate change scenario. In the case of Illecillewaet, 1984, zones C and D, the scenario T + 4°C, P·1.2, results in a positive Winter Change (increases in P overwhelm the winter deficit in melt). In that case, MDC$_{EXCL}$ is "stretched" rather than "cut-off", as explained in Step (5c).
The Climate Change Progress Screen allows a user to over-ride a calculated zonal Winter Change value at this point in the processing sequence. See Section 8.3 for a description of when such intervention might be advisable.

  (5b) For each zone, develop zonal melt curve, AZM$_{EXCL}$ ($\Sigma(a \cdot T \cdot S)$ vs Time) for the normal climate. Find the date along AZM$_{EXCL}$ where zonal Winter Change is equaled or exceeded.

  At this point, the Climate Change Statistics Report is produced. This printout (disk file if no printer is available) details the calculated values used by SRM to compute zonal Winter Change and the "cutoff" points or "gain factors" used in Step (5c) to derive MDC$_{EXCL\ WA}$.

  (5c) Create data for a new curve, MDC$_{EXCL\ WA}$.

  To understand the methodology for modeling CDC$_{CLIM}$, it is important to understand the MDC$_{EXCL}$ curve. Each point along the curve is a daily intersection of snow water equivalent independent of melt season snowfalls ($\Sigma (a \cdot T$-newmelt), and daily % snow covered area (% S), on the x-axis and y-axis respectively. The data are saved internally by SRM in ascending order, by date. SRM uses two different methodologies for creating MDC$_{EXCL\ WA}$.

    • Methodology for winter deficits: Beginning on the date following that identified by Step (5b) above (i.e., the "cutoff" date), all remaining daily values for MDC$_{EXCL}$ {% S and Σ ($a \cdot T$-newmelt)} are shifted backwards in time to the beginning of the melt season. Additionally, as the curve′s x values are shifted, each daily value is reduced by a constant equal to the 1st x value following the "cutoff" date, reestablishing an x origin of 0.0. For example, if a "cutoff" date of 15 April is identified (15 days into the melt season), then all succeeding days for the data constituting the curve are shifted to the corresponding day 15 days earlier, with each daily $\Sigma(a \cdot T$-newmelt) being reduced by $\Sigma(a \cdot T$-newmelt)$_{day\ 16}$.

- Methodology for winter surpluses (increased P overwhelms temperature increase for the zone, stretch the MDC). Compute the proportional increase in winter-ending snow water equivalent using values obtained in Steps (1-2) above:

$$\frac{\Sigma \, P_{CLIM} \; - \; \Sigma \, Zonal\_ \, Melt_{CLIM}}{\Sigma \, P - \Sigma \, Zonal\_ \, Melt}$$

Multiply each x value of MDC_{EXCL} by this factor to "stretch" MDC_{EXCL}, creating $MDC_{EXCL \, WA}$.

(5d) Derive a new curve, $MDC_{CLIM \, WA}$, by adding to $MDC_{EXCL \, WA}$ the corresponding daily melt depths of new snow "surviving" in the warmer climate $\Sigma(newmelt)_{CLIM}$ from Step (4).

(5e) For each daily value, n, in $MDC_{EXCL \, WA}$, find the first day on $\Sigma(a \cdot T)_{CLIM}$ from Step (4) when the value is equaled or exceeded. Move the corresponding day's snow cover % to day n of the $CDC_{CLIM \, WA}$ array. On days when multiple % S values for the same day in CDC_{CLIM} result, the first (highest) value is used, the remaining values are ignored.

(5f) After all derived values have been calculated for $CDC_{CLIM \, WA}$, SRM completes the new curve, $CDC_{CLIM \, WA, \, MA}$ by supplying all missing daily snow cover values using the following logic:

- Missing days that lie between two days with derived values will inherit the earlier day′s derived % S value.

- All missing days following the last derived daily value will inherit a 'residual value' that is determined in two different ways depending upon the difference between the last derived daily value and the corresponding value in CDC_{NORMAL}. The normal difference will be negative ($CDC_{CLIM} < CDC_{NORMAL}$). In this situation, the residual value is set equal to the last % S value in the CDC_{NORMAL}. This value will typically be zero, except in cases where the zone includes a glacier or permanent snow cover. In the infrequent cases where the difference is positive ($CDC_{CLIM} > CDC_{NORMAL}$) each missing daily value after the last derived day will take on the corresponding day′s % S value from CDC_{NORMAL} plus the difference.

(5g) Plot MDC_{EXCL}, $MDC_{EXCL \, WA}$.

(5h) Plot AZM_{INCL}, AZM_{EXCL}, $AZM_{EXCL \, WA}$.

(5i) Optionally plot $MDC_{EXCL \, WA}$, $MDC_{CLIM \, WA}$.

(5j) Plot CDC, $CDC_{CLIM \, WA}$.

(5k) Replace CDC with $CDC_{CLIM \, WA, \, MA}$.

Step 6: *Summer simulation, changed climate, using* $CDC_{CLIM \, WA, \, MA}$.

- Make one final summer "climate-change" simulation, using the existing climate-change scenario with the derived $CDC_{CLIM \, WA}$ curves to produce Q_{CLIM}.

After a successful climate change computation, Micro-SRM "changes state", with references to actual and simulated runoff replaced with simulated runoff before/after climate change. The "post change" data is treated as normal Micro-SRM data with the exception that it may not be used as the "base" for another climate change. If "climate-modified" data is SAVEd and reLOADed, it induces the above referenced "state change". LOADing a normal SRM file resets the model to its normal "state".

G.8 Using Micro-SRM trace file options

Several Micro-SRM command line trace options allow the advanced model user to create and use files containing the commands provided to the model via the keyboard or mouse during all or part of a program execution. This feature can prove very useful if a user is faced with the task of performing an elaborate sequence of otherwise identical processing steps on multiple years of data. By building a trace file and using a text editor to modify references to any .SRM filenames, the user insures identical processing for each year of data.

In order for trace file processing to proceed in an orderly fashion, Micro-SRM makes the following assumptions when running in "trace mode":

(1) Micro-SRM processing (/TIN) begins from the same DOS path as did execution when (/TOUT) created the trace file.

(2) All pathnames and filenames referenced in a trace file exist on the PC.

During trace file creation (/TOUT={file}), each keystroke and mouse click is saved in {file}. Trace file creation can be terminated at any point in the model session by pressing **ALT_@**.

When the model runs under control of a trace file (/TIN={file}), the program reads and processes one command from the trace file every ½ second unless the /TDELAY option is included to specify the time increment. This control sequence will continue until one of the following three trace ending events occurs:

End of Program - the trace file includes the keystrokes necessary to end execution of Micro-SRM.

End of Trace File - When the last command is removed from the trace file, a message is displayed and program control is returned to the keyboard and mouse.

Trace Suspended - the user may suspend trace file processing by pressing **Esc**. After suspension, the user may optionally continue trace file processing, with the same or a modified trace delay, or terminate trace file processing at the suspension point, with control returning to the keyboard and mouse.

G.9 Micro-SRM availability

The Hydrology Laboratory supports and distributes the Snowmelt Runoff Model free of charge to any interested party. The program and related files are available via the Internet by accessing the SRM home page at http://www.ars.usda.gov/Services/docs.htm?docid=8872. This site also includes an electronic version of the SRM User's Manual. A distribution diskette, available on either 5¼" or 3½" media, containing the executable code, supporting files, and example data files can be provided upon request.. To obtain the latest version of Micro-SRM, contact:

> USDA-ARS, Hydrology and Remote Sensing Laboratory
> Bldg. 007, Room 104, BARC-W
> 10300 Baltimore Avenue
> Beltsville, MD 20705-2350 USA
> (301) 504-7490

or via electronic mail to:

> ralph.roberts@ars.usda.gov
> alrango@nmsu.edu

Micro-SRM has been distributed to several hundred individuals and institutions worldwide since 1985. We appreciate the feedback we receive from users of Micro-SRM, both positive and negative, and view it as a valuable resource in the process of debugging and improving the software.