Appendix D

Water Supply Simulation

The principal components of a surface-water reservoir operation are common regardless of purpose. What differs with each purpose is the nature of the stream flow, operational criteria, and demand. For water supply, low-flow periods are of special concern because it is during these periods that the possibility of not meeting water supply needs is greatest.

Low flows normally have the characteristic that they are relatively constant over a week or month period. Therefore, monthly stream flows are commonly used in water supply simulations. Also, low flows are commonly within channel. Consequently, routing criteria and water surface elevations, which are significant in flood control simulation, are less important in water supply. Low flows can be significantly affected by local inflow, effluent discharge from waste-water treatment plants, seepage to or from a river, evaporation and other phenomena.

Operating criteria for water supply is principally concerned with meeting demands over prolonged low-flow periods (droughts). In HEC-5, water supply demands are primarily simulated with low-flow targets and diversion schedules defined at model control points. System simulations illustrate the ability of the reservoirs to meet target demands with available storage allocation and specified flows. Additionally, HEC-5 can perform sequential analysis to determine the storage required to meet a specified demand or the scale of demand (yield) that can be met with a specified storage.

This appendix illustrates HEC-5 program features that apply to water supply simulation. Many options exist; however, the examples used should be sufficient to illustrate the input and expected output. Three example models are presented: Example 4 is a single reservoir model demonstrating seasonally varying storage, reservoir diversions and evaporation, and operation for downstream locations that contain diversions and minimum flow requirements; Example 5 is a three-reservoir system with seasonal-pool level goals and parallel operation for a downstream location; and Example 6 demonstrates the application of a firm-yield determination.

D.1 Single Reservoir Model

The single reservoir model (Example 4) illustrates reservoir data usually associated with low-flow studies. The reservoir has seasonally varying storage, evaporation, and operates for downstream diversions and low-flow targets. Several options for specifying demands are demonstrated.

D.1.1 Reservoir Model Data

The reservoir model has five levels, with top of Buffer at level 2, top of Conservation at level 3, and top of Flood Control at level 4. All monthly data start with January. Figure D.1 shows a schematic diagram of a single reservoir system. The reservoir data are shown in Table D.1.

The reservoir storage for Level 2 and Level 3 is seasonally varying. To do this, there is a **RL** Record for each reservoir level. To indicate a constant level, -1 is entered in the third field. To indicate the nine seasons, a 9 is entered in the third field. The nine seasons are defined in days on the **CS** Record, with 1 equal to January 1. The seasons must be defined to the end of the year, with 365 equal to December 31.

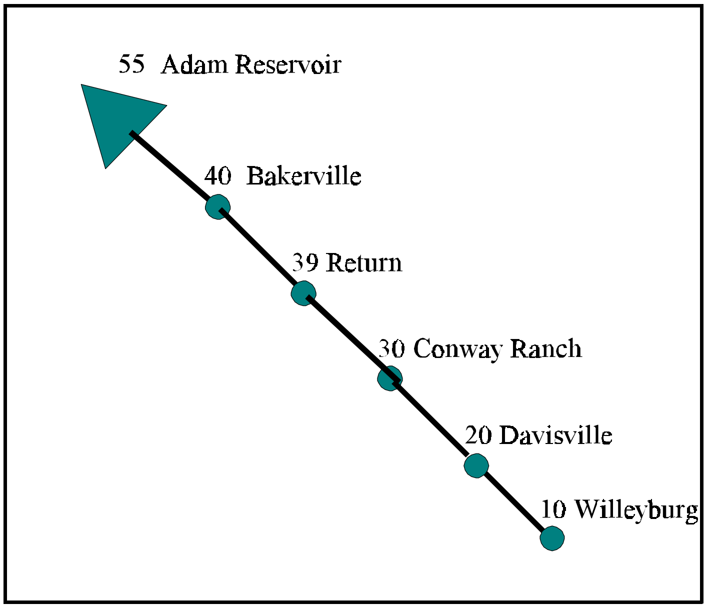

Figure D.1 Example 4 System Diagram

The reservoir operates for four downstream locations, as shown on the **RO** Record. Diversions and minimum flow requirements will be considered at those locations when making reservoir release determinations.

The storage in the reservoir is defined with 39 values from 0 to 3,070,000. The negative value (-39) in field 1 indicates that storage values are entered in 1000 acre-feet. Following the storage values are associated reservoir outflow capacity (**RQ**), reservoir area (**RA**), reservoir elevation (**RE**), and reservoir diversion (**RD**). The **DR** Record indicates the diversions from the reservoir leave the system (no divert to location). The diversion option (-2) indicates the diversion is a function of reservoir storage.

Reservoir net-evaporation is defined for the 12 months on **R3** Records. The first month for all monthly data is January. Minus evaporation values indicate a net gain for those months when precipitation is greater than evaporation. Evaporation data requires reservoir area data to compute the volume gained or loss during each simulation interval.

Control point data (**CP** Record), at the reservoir, indicates the minimum Desired flow is 450 and the Required flow is 230. The minimum reservoir release should be the Desired flow when the reservoir is above top-of-buffer level, and the Required flow when below top-of-buffer pool level. At level 1, inactive storage level, no releases are made and evaporation is the only loss from storage.

Table D.1. Example 4 Reservoir Data

```
RL    55 1957000
RL     1      55      -1          867600
RL     2      55       9         1369772 1400771 1400771 1400771 1400771 1400771
RL                               1400771 1400771 1369772
RL     3      55       9         1957000 1957000 1957000 1957000 1995200 1995200
RL                               1995200 1957000 1957000
RL     4      55      -1         2554000
RL     5      55      -1         3070000
RO     4      40      30      20      10
RS   -39       0     760     867     913     960    1009    1059    1085    1112
RS  1139    1166    1194    1222    1251    1280    1309    1339    1370    1401
RS  1432    1464    1496    1529    1561    1595    1629    1663    1698    1733
RS  1769    1805    1842    1879    1917    1957    1994    2034    2554    3070
RQ    39       0    1000    9750    9820    9870    9920    9970   10010   10050
RQ  9000    9000   10190   10230   10270   10300   10330   10370   10410   10450
RQ 10490   10530   10570   10610   10650   10690   10730   10770   10800   10830
RQ 10870   10910   10940   10980   11020   11060    9500    9500   11580   21850
RA    39       0   20508   22442   23217   24008   24833   25701   26159   26619
RA 27079   27535   27983   28432   28861   29291   29721   30153   30587   31023
RA 31461   31901   32343   32789   33238   33690   34147   34610   35079   35555
RA 36036   36522   37015   37515   38024   38542   39078   39638   47182   53300
RE    39    1420    1530    1535    1537    1539    1541    1543    1544    1545
RE  1546    1547    1548    1549    1550    1551    1552    1553    1554    1555
RE  1556    1557    1558    1559    1560    1561    1562    1563    1564    1565
RE  1566    1567    1568    1569    1570    1571    1572    1573    1585    1595
RD     0       0       0       0      10      10      10      10      10      10
RD    10      10      10      10      10      10      10      10      10      45
RD    45      45      45      45      67      67      67      67      67      67
RD    67      67      67      67      80      80      80      80      80      80
R3  -2.7    -2.0    -1.6     0.3     3.4     2.5     2.0     0.9     1.9     1.6
R3  -0.8    -1.6
CP    55   10000     450     230
IDADAM RESERVOIR
RT    55      40
DR    55                                          -2
CS     9       1      32      60      90     121     181     273     335     365
```

D.1.2 Control Point Data

There are five downstream control points and Table D.2 shows a listing of their data. The reservoir operates (**RO** Record) for all locations except for control point 39 (Return). Looking at the data for control points, shown in Table D-2, the first location is CP 40, Bakerville. The **CP** Record shows no minimum flow requirements. The **RT** Record shows the flow transfers to location 39 without routing. The diversion (**DR** Record) indicates a diversions from location 40 to location 39. Field 6 (0.70) shows 70% of the diversion returns to location 39, field 7 (0) indicates that the diversion will be constant, and field 8 (75) is the constant diversion rate.

Location 39 (Return) shows no minimum requirements or diversions. Seventy percent of the flow diverted from 40 will return here and be added to the local flow and routed upstream flow. Again, the reservoir does not operate for this location because there are no requirements because there are no requirements.

Table D.2. Example 4 Downstream Control Point Data

```
C **************** Green River at Bakerville ***********************************
CP    40   11000
IDBAKERVILLE
RT    40      39
DR    40      39                           0.70       0      75

C **************** Bakerville Return Flows *************************************
CP    39   11000
IDRETURN
RT    39      30

C **************** Conway Ranch ************************************************
CP    30  100000
IDCONWAY RANCH
RT    30      20
DR    30      20                           0.40       1
QD    12     5.3     5.1     5.8     7.3    40.3    89.5   122.0   135.2   118.0
QD  22.1     7.7     4.9

C **************** Green River at Davisville ***********************************
CP    20   17000     750     750
IDDAVISVILLE
C1    30    0.67
RT    20      10

C **************** Green River at Willeyburg ***********************************
CP    10  999999
IDWILLEYBURG
RT    10
QM   755     925     950    1030    1050    1100    1250    1150     755     755
QM   755     755

ED
```

Conway Ranch (CP 30) is the next location. There are no minimum flow requirments (**CP** Record) and the flow is transferred to location 20 (**RT** Record) with no routing. The Diversion data (**DR** Record) indicates a diversion from location 30 to location 20, with a monthly diversion schedule (field 7 = 1) and a 40% return flow (field 6 = 0.40). The monthly diversion schedule is provided on **QD** Records. The first field indicates that there are 12 values and the monthly schedule follows, with 5.3 ft^3/s specified for the month of January.

Davisville (CP 20) data indicates a minimum <u>desired</u> and <u>required</u> flow target of 750 ft^3/s (**CP** Record, fields 3 and 4). The **C1** Record (fields 1 and 2) indicates the local flow for this location will be set equal to 67% of the local flow at location 30. Flow transfers from this location to 10 without routing (**RT** Record).

The last control point (CP 10) is Willeyburg. The large channel capacity (999999) usually indicates there are no flood control limits here. The **RT** Record indicates this is the last location because the flow is not routed to another location. The monthly minimum desired-flow targets are defined on **QM** Records, starting with January.

The **ED** Record indicates the end of the system model.

D.1.3 Time-series Data

Time series data begins with the **BF** Record, as shown in Table D.3. The flow format, number of simulation periods, starting date and time and time interval are all defined. The tenth field (1900) provides for the century definition, because the date format only provides for two digits for the year. This example will simulate one year (365 periods) of daily (24 hour) data, starting at 0000 hour on 1 January 1986. The first output will be for 2400 hours on that date.

Table D.3. **Example 4 Time-series Input Data**

```
BF     2     365               086010100              24                    1900
ZR=IN55    A=EXAMPLE 4  B=ADAM RESERVOIR   C=LOCAL FLOW   F=ESTIMATED
ZR=IN40    A=EXAMPLE 4  B=BAKERVILLE       C=LOCAL FLOW   F=ESTIMATED
ZR=IN30    A=EXAMPLE 4  B=CONWAY RANCH     C=LOCAL FLOW   F=ESTIMATED
ZR=IN10    A=EXAMPLE 4  B=WILLEYBURG     C=FLOW-LOC-INC   F=ESTIMATED
ZW     A=EXAMPLE 4     F=BASIC WATER SUPPLY
EJ
ER
```

Because the flow data are read from a DSS file, the filename must be specified on the execution command line along with input and output filenames. The **ZR** Record format (**ZR=IN##**) associates the data in the DSS Record to **IN** Record input for model control point ##.

The **ZW** Record indicates writing results to the DSS file with pathname A-part as EXAMPLE 4, and pathname F-part as BASIC WATER SUPPLY. The Records to write are defined on the **JZ** Records, shown below. The negative values in the first field indicates that this data will not be printed. The default (without the minus sign) is to print the data table defined by the **JZ** Records in the same format as the **J8** Records (***USER** Tables).

Table D.4 Output Data to Write to DSS

```
JZ-55.22   55.10   40.03   30.03   20.04   10.04   10.05
```

D.1.4 Single Reservoir Simulation Output

The Example 4 output can be obtained by running the data set. Samples of the output are presented here to illustrate the program's operation with the specified demand data. Note, after the output listing of the input data including the flow data extracted from the DSS file, there are warning notes that there are negative flow values in the data set. HEC-5 can use negative values; however, in an actual study, the user would review the flow data to determine the cause for negative flow. The output then presents summary tables for the input data (`*Input Summary`). One should review these tables to ensure that the input data are appropriate.

After HEC-5A has completed the simulation, the requested output is written to DSS. A series of ZWRITE lines indicate each Record written. Review those lines to ensure the desired output is written.

The HEC-5B performs an analysis of the run for errors. The output for this option should always be requested (**J3** Record, field 1, code 4). Only one output table was defined by **J8** Record input. The output of **JZ** Record data was not printed.

The output for the beginning of the simulation is shown in Table D.5. The first 10 periods indicate that the reservoir is at top-of-conservation (Level = 3.0). The "ideal" state for the reservoir is to remain there as long as passing inflow does not cause flooding and the specified demands are all met by passing the inflow amount. The Case for this condition is 0.03. A review of the downstream demands would indicate that diversions and minimum flow targets are being met during these periods.

The simulation continues passing inflow until period 91 (1 April 1986). On that period the reservoir Case indicates 10.00, which means the reservoir is releasing to meet the target at location 10, Willeyburg. Looking at the regulated flow at location 10 (Flow Reg) shows a value of 1030.00 and the shortage at that location (DeQ-Shor) is 0.00. Reviewing the input data shows a monthly minimum flow schedule for Willeyburg to be 1030 ft^3/s for April.

The simulation continues to operate for location 10 for all of April and most of May. Table D.6 shows the output starting at period 135 (15 May 1986). The May target is 1050 ft^3/s and the output shows Adam Reservoir is operating to meet that target up to period 145, when the Case changes to 0.00 indicating the reservoir is operating for itself to meet minimum desired flow. For eight days, the outflow is 450 ft^3/s to meet the reservoir minimum. (Note that during this time the Willeyburg regulated flow is greater than the 1050 ft^3/s minimum.) By June 2, the release is increased to meet the target of 1100 ft^3/s at Willeyburg.

Table D.5 User Output Table for the Initial Periods

*USERS. 1 User Designed Output (Dates shown are for END-of-Period)

Summary by Period Flood= 1

Location No=			55.	55.	55.	55.	40.	30.	20.	10.	10.
J8/JZ Codes=			55.220	55.130	55.120	55.100	40.030	30.030	20.040	10.040	10.060
			ADAM RESE	ADAM RESE	ADAM RESE	ADAM RESE	BAKERVILL	CONWAY RA	DAVISVILL	WILLEYBUR	WILLEYBUR
Period	Date:	Day	EOP Elev	Level	Case	Outflow	Diversio	Diversio	Flow Reg	Flow Reg	DeQ-Shor
1	1Jan86	Wed	1571.00	3.00	0.03	1286.29	75.00	5.30	1710.10	1763.36	0.00
2	2Jan86	Thu	1571.00	3.00	0.03	1236.81	75.00	5.30	1685.34	1744.41	0.00
3	3Jan86	Fri	1571.00	3.00	0.03	1206.08	75.00	5.30	1689.83	1716.32	0.00
4	4Jan86	Sat	1571.00	3.00	0.03	1024.40	75.00	5.30	1446.48	1478.01	0.00
5	5Jan86	Sun	1571.00	3.00	0.03	898.90	75.00	5.30	1310.10	1334.99	0.00
6	6Jan86	Mon	1571.00	3.00	0.03	821.26	75.00	5.30	1217.82	1243.53	0.00
7	7Jan86	Tue	1571.00	3.00	0.03	870.17	75.00	5.30	1234.89	1259.50	0.00
8	8Jan86	Wed	1571.00	3.00	0.03	764.82	75.00	5.30	1130.59	1143.19	0.00
9	9Jan86	Thu	1571.00	3.00	0.03	831.59	75.00	5.30	1195.47	1212.08	0.00
10	10Jan86	Fri	1571.00	3.00	0.03	827.67	75.00	5.30	1198.76	1222.55	0.00
:											
11 - 89 Omitted											
:											
90	31Mar86	Mon	1571.00	3.00	0.03	882.61	75.00	5.80	1319.90	1362.31	0.00
91	1Apr86	Tue	1571.01	3.00	10.00	591.04	75.00	7.30	994.35	1030.00	0.00
92	2Apr86	Wed	1571.03	3.00	10.00	570.61	75.00	7.30	1005.15	1030.00	0.00
93	3Apr86	Thu	1571.04	3.00	10.00	604.84	75.00	7.30	1010.29	1030.00	0.00
94	4Apr86	Fri	1571.05	2.99	10.00	607.36	75.00	7.30	1012.80	1030.00	0.00
95	5Apr86	Sat	1571.07	2.99	10.00	604.98	75.00	7.30	1008.21	1030.00	0.00
96	6Apr86	Sun	1571.10	2.99	10.00	603.90	75.00	7.30	1007.77	1030.00	0.00
97	7Apr86	Mon	1571.12	2.99	10.00	546.16	75.00	7.30			

Table D.6 User Output Table for the Middle of the Simuation

Period	Date:	Day	ADAM RESE EOP Elev	ADAM RESE Level	ADAM RESE Case	ADAM RESE Outflow	BAKERVILL Diversio	CONWAY RA Diversio	DAVISVILL Flow Reg	WILLEYBUR Flow Reg	WILLEYBUR DeQ-Shor
Location No=			55.	55.	55.	55.	40.	30.	20.	10.	10.
:											
135	15May86	Thu	1570.92	2.93	10.00	694.71	75.00	40.30	1007.78	1050.00	0.00
136	16May86	Fri	1570.92	2.93	10.00	617.96	75.00	40.30	987.83	1050.00	0.00
137	17May86	Sat	1570.93	2.93	10.00	570.32	75.00	40.30	982.72	1050.00	0.00
138	18May86	Sun	1570.94	2.93	10.00	550.30	75.00	40.30	984.08	1050.00	0.00
139	19May86	Mon	1570.94	2.93	10.00	545.44	75.00	40.30	986.63	1050.00	0.00
140	20May86	Tue	1570.94	2.93	10.00	546.68	75.00	40.30	984.69	1050.00	0.00
141	21May86	Wed	1570.94	2.93	10.00	528.46	75.00	40.30	977.74	1050.00	0.00
142	22May86	Thu	1570.94	2.93	10.00	506.50	75.00	40.30	975.48	1050.00	0.00
143	23May86	Fri	1570.94	2.93	10.00	559.64	75.00	40.30	994.07	1050.00	0.00
144	24May86	Sat	1570.94	2.93	10.00	492.74	75.00	40.30	969.47	1050.00	0.00
145	25May86	Sun	1570.97	2.93	0.00	450.00	75.00	40.30	1148.56	1298.82	0.00
146	26May86	Mon	1571.00	2.94	0.00	450.00	75.00	40.30	1449.41	1675.35	0.00
147	27May86	Tue	1571.04	2.94	0.00	450.00	75.00	40.30	1505.10	1711.13	0.00
148	28May86	Wed	1571.08	2.94	0.00	450.00	75.00	40.30	1511.64	1701.40	0.00
149	29May86	Thu	1571.12	2.94	0.00	450.00	75.00	40.30	1493.58	1677.15	0.00
150	30May86	Fri	1571.16	2.95	0.00	450.00	75.00	40.30	1491.29	1674.60	0.00
151	31May86	Sat	1571.19	2.95	0.00	450.00	75.00	40.30	1425.08	1578.12	0.00
152	1Jun86	Sun	1571.20	2.95	0.00	450.00	75.00	89.50	1167.42	1251.60	0.00
153	2Jun86	Mon	1571.19	2.95	10.00	683.61	75.00	89.50	1093.14	1100.00	0.00
154	3Jun86	Tue	1571.17	2.95	10.00	714.67	75.00	89.50	1074.12	1100.00	0.00
155	4Jun86	Wed	1571.16	2.95	10.00	699.76	75.00	89.50	1065.56	1100.00	0.00
156	5Jun86	Thu	1571.14	2.94	10.00	662.14	75.00	89.50	1058.73	1100.00	0.00
:											
157 - 365 Omitted											
		Sum =	573100.88	1061.53	1783.72	334423.41	27375.00	17221.38	528253.13	548595.25	0.00
		Max =	1571.22	3.00	20.00	5536.51	75.00	135.20	7695.86	7996.30	0.00
		Min =	1567.72	2.73	0.00	450.00	75.00	4.90	750.00	755.00	0.00
		PMax=	112.00	1.00	255.00	333.00	1.00	213.00	333.00	333.00	1.00
		Avg =	1570.14	2.91	4.89	916.23	75.00	47.18	1447.27	1503.00	0.00
		PMin=	280.00	279.00	145.00	145.00	1.00	335.00	255.00	259.00	1.00

The flow goal at Willeyburg continues to "control" the release determination for most of the periods, with an occasional release for the reservoir minimum and a few days in September operating for location 20, Davisville.

D.2 Multiple Reservoir System Model

Example 5 is a three reservoir system. Two storage reservoirs (Allen and James) operate in parallel to meet a downstream flow goals and the third (Brenda Lake) is a flow-through reservoir. Additionally, James Reservoir has seasonally varying minimum flow goals that are based on pool elevation. Figure D.2 is a diagram of the system. The input data are shown in two parts: Table D.7 shows the beginning of the input along with the data for the East Branch (Allen Reservoir to Dougville); and Table D.8 lists the input for the West Branch (James Reservoir to Dry Town) along with the time-series input data.

The job data define 5 reservoir levels, with level 3 as top-of-conservation, level 4 as top-of-flood control, and level 2 as top-of-buffer pool (**J1** Record). Net evaporation data are defined for all reservoirs in the system (**J6** Record). User designed tables are defined on the **J8** Records and are discussed in D.2.2 Reservoir System Output.

D.2.1 Reservoir System Data

Allen Reservoir data (location 444) provides monthly storage for the top of conservation (level 3) and constant storage values for the other 4 levels (**RL** Records). The starting storage is defined as an elevation (-1060.5). Allen Reservoir operates for three downstream locations (**RO** Record).

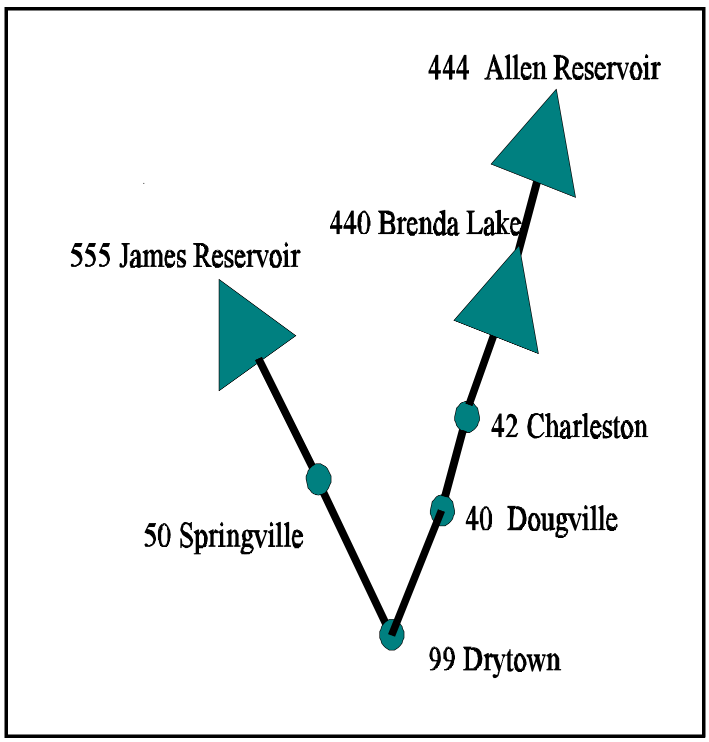

Figure D.2 Example 5 System Diagram

Note that the operation of Allen Reservoir through the downstream reservoir 440 can be accomplished only because the downstream reservoir is defined as a "flow-through reservoir." That is, *reservoir 440 does not store water and the releases from Allen will flow through to the downstream locations. If reservoir 440 were a operating storage reservoir, the upper reservoir should only operate to the lower reservoir (tandem operation) and the lower reservoir would then operate for the downstream locations.*

Table D.7 Example 5 Input Data - First Half (East Branch)

```
T1      EXAMPLE 5, Reservoir System Operating for Flow Augmentation
T2      3 Reservoir System, 2 Storage Reservoirs and 1 Flow-Thru Reservoir
T3      Flow Goals Based on Season and Reservoir Elevation (EXAMPLE5.DAT)
J1     0       1       5       3       4       2
J2    24     1.0       0       0       0       0       0
J3     4       0       0      -1       0      -1
J6  -8.4    -6.7    -6.1    -3.7     1.9     3.8     5.8     6.1     4.3     1.5
J6  -2.3    -5.1
J8444.10  444.12  444.13  555.13  555.12  555.10   99.04   99.02
J8444.12  444.10  400.12  400.10   42.04   40.04   99.04
J8555.12  555.13  555.22  555.06  555.10   50.03   99.04
J8444.12  444.10  400.24  400.03  400.21  400.12  400.10   99.04
C
RL   444 -1060.5
RL     1     180      -1          237810
RL     2     180      -1          242163
RL     3     180       0          377073  377073  377073  377073  438869  438869
RL                                438869  438869  438869  383564  383564  377073
RL     4     180      -1          472757
RL     5     180      -1          500000
RO     3      42      40      99
RS    17  237810  242164  260355  284879  311402  339972  355050  370670  377073
RS383564  403588  420922  438869  457441  472757  491029  500000
RQ    17   30400   31480   31700   31795   32064   32064   32390   32495   34310
RQ 37603   55100   69442  103500  137500  164684  181300  198000
RA    17    2158    2196    2353    2552    2754    2962    3060    3179    3230
RA  3275    3402    3530    3651    3770    3880    4030    4170
RE    17    1020    1022    1030    1040    1050    1060    1065    1070    1072
RE  1074    1080    1085    1090    1095    1099    1105    1110
CP   444   12600
IDALLEN RES
RT   444     400

RL  -400   17500     290    1500   17500   17500   19300
RO
RS     6     290     750    4000   11000   17501   19300
RQ     6       0   11900   46900   72749   85905   87400
RA     6      50      80     610     787     870     890
CP   400   99999
IDBRENDA LAKE
RT   400      42
DR   400                                                 0     125

CP    42   15000     600     320
IDCHARLESTON
RT    42      40

CP    40  999999     650     370
IDDOUGVILLE
RT    40      99
```

At Allen Reservoir, seventeen values define the basic storage-outflow-area relationship defined on the **RS, RQ, RA**, **RE** Records. The control point data for Allen Reservoir indicates a channel capacity of 12,600 ft^3/s, but no minimum flow requirements. Releases are transferred to location 444 without routing (**RT** Record).

Brenda Lake, location 400, is defined as a "flow-through" reservoir with the minus sign on the control point number (**RL** Record). Constant storage values are defined for the five levels. The reservoir cannot operate for a downstream location (**RO** Record) and six values define the storage-outflow-area relationship. The control point data indicates a constant diversion of 125 ft^3/s from the reservoir (**DR** Record).

Location 42, Charleston, has a channel capacity limit of 15,000 ft^3/s, a minimum desired flow goal of 600 ft^3/s and a minimum required goal of 320 ft^3/s (**CP** Record). Flow transfer to location 40 with no routing (**RT** Record).

Location 40, Dougville, has no channel capacity limit (99,999 ft^3/s), a minimum desired flow goal of 650 ft^3/s and a minimum required goal of 370 ft^3/s (**CP** Record). Flow transfers from location 40 to location 99 with no routing (**RT** Record). At this point, the data for the West Branch are entered because all upstream data must be defined before the data at location 99.

The input data for the second half of the model is shown in Table D-8. The data defines the West Branch from James Reservoir down to location 99, Drytown. James Reservoir, control point 555, starts at elevation 820.44 (**RL** Records). The storage for each level is defined with a separate (**RL** Record) and the top of conservation is seasonally varying, with the seven seasons defined on **CS** Record. The storage for the other four levels is constant. The reservoir operates for locations 50 and 99 (**RO** Record). Twenty-nine values define the storage-outflow-area-elevation relationships (**RS**, **RQ**, **RA**, and **RE** Records).

The reservoir's control point data indicates a minimum flow goal dependent on the reservoir pool elevation, **Guide Curve Operation** with **CG** Records. In this example, the operation is for minimum flow defined on the **QM** Record. A **CG** Record is required for each minimum flow defined. The first **CG** Record applies to the first minimum flow on the **QM** Record, etc. The first field indicates the data are elevations (minus sign) and the code 4 (left of decimal) indicates the data are specified for the top of the zone, while the code 2 indicates a linear transition between elevations. In this application, the decimal value is not used by the program but is defined to indicate the minimum flow value the **CG** data applies. For example, the first **CG** Record value -4.10 indicates that elevation data follow, that the top of the zone applies, and this input relates to the first 100 ft^3/s minimum flow (**QM** Record, field 2). The seven values of 725 are the elevations for this zone over the seven seasons (**CS** Record). The first field of the **QM** Record (-555) indicates minimum flow goals are based on location 555 elevation or level.

Table D.8 Example 5 Input Data - Second Half (West Branch)

```
RL   555 -820.44
RL     1     555      -1           10373
RL     2     555      -1           82891
RL     3     555       7          210492  210492  391749  391749  391749  210492
RL                                210492
RL     4     555      -1          471559
RL     5     555      -1          597164
RO     2      50      99
RS    29   10373   82884   89647  104879  113447  122709  132705  143514  155137
RS167612  181000  195280  210492  226656  243772  261860  280940  301031  322154
RS344288  367473  391749  417136  443713  471559  500734  531317  563427  597164
RQ    29     420    1200    1250    1310    1380    1460    1560    1670    1880
RQ  2000    2130    2270    2400    2540    2690    2830    2990    3110    4680
RQ  9800   15000   26000   37000   50000   66000   82000  100000  120000  140000
RA    29     182    3251    3516    4116    4452    4812    5196    5602    6024
RA  6462    6913    7373    7841    8317    8801    9293    9793   10298   10808
RA 11329   11862   12411   12988   13599   14246   14933   15665   16449   17293
RE    29     725     800     802     806     808     810     812     814     816
RE   818     820     822     824     826     828     830     832     834     836
RE   838     840     842     844     846     848     850     852     854     856
CP   555   11000
IDJAMES RES
RT   555      50
CS     7       1      15     121     182     274     350     365
CG -4.10     725     725     725     725     725     725     725
CG -4.10     790     790     820     820     820     790     790
CG -2.40     819     819     837     837     837     819     819
CG -4.48     824     824     842     842     842     824     824
QM  -555     100     100     400     480

CP    50  999999
IDSPRINGVILLE
RT    50      99
DR    50                                           1
QD    12      15      15      15      37      37      45      45      35      25
QD    20      15      15

CP    99   15000    1850
IDDRY TOWN
RT    99

ED
BF     2      40               86010100              24
ZR IN444  A=ROCKY RIVER B=ALLEN RES   C=FLOW-LOC INC F=COMPUTED
ZR IN400  A=ROCKY RIVER B=BRENDA LAKE C=FLOW-LOC INC F=COMPUTED
ZR IN42   A=ROCKY RIVER B=CHARLESTON  C=FLOW-LOC INC F=COMPUTED
ZR IN40   A=ROCKY RIVER B=DOUGVILLE   C=FLOW-LOC INC F=COMPUTED
ZR IN555  A=FALL RIVER  B=JAMES RES   C=FLOW-LOC INC F=COMPUTED
ZR IN50   A=FALL RIVER  B=SPRINGVILLE C=FLOW-LOC INC F=COMPUTED
ZR IN99   A=FALL RIVER  B=DRY TOWN    C=FLOW-LOC INC F=COMPUTED
EJ
ER
```

The downstream location, 50, does not have a limiting channel capacity (999,999 ft^3/s). Even though there are no minimum flow goals specified, there is a diversion from location 50 to location 99 (**DR** and **QD** Records). The **DR** Record indicates that the diversion schedule is monthly (filed 7) and that 100% of the diversion is returned (filed 6) to location 99. The monthly schedule is defined on the **QD** Records.

The last location, 99, requires a "system operation." Up to this point, the reservoirs are operating for the downstream locations that only they can serve. For location 99, Dry Town, both storage reservoirs can make releases to meet the defined maximum channel capacity of 15,000 ft^3/s and the minimum desired flow of 1,850 ft^3/s (**CP** Record). When there is a choice between the reservoirs, the additional releases will be made from the reservoir with the higher index level at the end of the previous period.

The **ED** Record defines the end of the system data and the **BF** Record defines the start of the time-series data. Forty periods, starting on 1 January 1986, of average daily flow (24 hours) will be used. Again, the flow data are read from a DSS file. No output will be written to a DSS file, because no **JZ** or **ZW** Records are input.

D.2.2 Reservoir System Output

The summary tables for the input data should be reviewed first to ensure that the data are appropriate. The summary tables of seasonal data (*Rule Curve Summary) are helpful because the days are converted to starting date and all storage values are listed. The Guide-Curve data are also summarized showing dates, zones, and operation codes.

The first output table (*USERS. 1) is defined by the first **J8** Record and shown in Table D.9. This table lists the Outflow, Case, and Level for the two storage reservoirs along with the Regulated and Natural Flow at Dry Town. This output arrangement shows the releases and the basis for the release and the resulting pool level. At the start, Allen is releasing to meet a flow goal at location 40 (Case = 40.00) and James is releasing for the goal at Dry Town (99). Looking at the reservoir Levels, one sees that James is at a higher Level than Allen; therefore, it should be making the additional release to meet Dry Town's flow goal of 1,850 ft^3/s. The 'Flow Reg' column shows that value is met. Allen continues to release for locations 40 or 42 until period 7. At periods 7 and 8, both reservoirs are operating for location 99 and their Levels are equal. The system allocation for release is meeting the downstream target and keeping the reservoirs "balanced" during these periods.

During periods 9 through 12, the local requirement of 480 ft^3/s controls the release from James (Case = 0.00), while Allen continues to release for location 99. During periods 13 through 15, both reservoirs again have a joint operation to meet the goal at location 99. Then, for the remainder of the simulation, the local requirement controls the release from James, and Allen operates to meet the target at location 99. Because the local requirement at James is based on the pool elevation, the minimum flow requirement starts decreasing from 480 ft^3/s after period 17. This would indicate the flow goal is on the linear transition zone 2. It drops from zone 4 into zone 2 because the elevation for zone 3 starts increasing from 819 to 837 feet on January 15 and the reservoir is near elevation 819.

Table D.9 Parallel System Operation for Dry Town (Example 5)

*USERS. 1 User Designed Output (Dates shown are for END-of-Period)

Summary by Period Flood= 1

		ALLEN RES	ALLEN RES	ALLEN RES	JAMES RES	JAMES RES	JAMES RES	DRY TOWN	DRY TOWN
Location No=		444.	444.	444.	555.	555.	555.	99.	99.
J8/JZ Codes=		444.100	444.120	444.130	555.130	555.120	555.100	99.040	99.020
Period	Date: Day	Outflow	Case	Level	Level	Case	Outflow	Flow Reg	Natural
1	1Jan86 Wed	180.19	40.00	2.75	2.79	99.00	653.30	1850.00	2335.42
2	2Jan86 Thu	141.16	40.00	2.75	2.79	99.00	633.29	1850.00	2121.43
3	3Jan86 Fri	186.66	40.00	2.76	2.78	99.00	592.52	1850.00	2036.40
4	4Jan86 Sat	339.26	42.00	2.76	2.78	99.00	605.56	1850.00	1848.07
5	5Jan86 Sun	401.06	40.00	2.77	2.77	99.00	622.93	1850.00	1713.82
6	6Jan86 Mon	409.00	40.00	2.77	2.77	99.00	628.77	1850.00	1658.18
7	7Jan86 Tue	561.37	99.00	2.77	2.77	99.00	499.95	1850.00	1570.21
8	8Jan86 Wed	627.81	99.00	2.76	2.76	99.00	498.15	1850.00	1499.64
9	9Jan86 Thu	627.60	99.00	2.76	2.76	0.00	480.00	1850.00	1522.47
10	10Jan86 Fri	641.65	99.00	2.76	2.76	0.00	480.00	1850.00	1515.90
11	11Jan86 Sat	670.05	99.00	2.75	2.75	0.00	480.00	1850.00	1480.25
12	12Jan86 Sun	680.85	99.00	2.75	2.75	0.00	480.00	1850.00	1485.42
13	13Jan86 Mon	708.83	99.00	2.75	2.75	99.00	507.22	1850.00	1390.11
14	14Jan86 Tue	671.27	99.00	2.74	2.74	99.00	540.53	1850.00	1416.29
15	15Jan86 Wed	666.75	99.00	2.74	2.74	99.00	535.71	1850.00	1421.33
16	16Jan86 Thu	713.31	99.00	2.74	2.73	0.00	480.00	1850.00	1501.42
:									
17 - 37 Omitted									
:									
38	7Feb86 Fri	623.30	99.00	2.65	2.57	0.00	361.25	1850.00	1798.48
39	8Feb86 Sat	684.69	99.00	2.65	2.56	0.00	359.29	1850.00	1740.80
40	9Feb86 Sun	763.36	99.00	2.64	2.56	0.00	357.40	1850.00	1589.80
	Sum =	25584.93	3608.00	108.62	107.32	1089.00	17908.91	73999.98	65786.95
	Max =	861.01	99.00	2.77	2.79	99.00	653.30	1850.00	2335.42
	Min =	141.16	40.00	2.64	2.56	0.00	357.40	1849.99	1390.11
	PMax=	34.00	7.00	6.00	1.00	1.00	1.00	1.00	1.00
	Avg =	639.62	90.20	2.72	2.68	27.23	447.72	1850.00	1644.67
	PMin=	2.00	1.00	40.00	40.00	9.00	40.00	33.00	13.00

The second output table (*USERS. 2) shows the operation down the East Branch, from Allen Reservoir down to Dry Town. Only the first 10 periods are shown in Table D.10. The results for Allen reservoir are the same as previously discussed (*USER. 1). Brenda Reservoir shows a Case of 0.03 for all periods. Because it was defined as a flow-through reservoir, the pool level stays at the starting top of conservation and the reservoir passes inflow. The reason the outflow form Brenda is more than the release from Allen Reservoir is the addition of incremental local flow between the two reservoirs. During the first six periods, Allen operates for locations 40 and 42. For those periods, notice that the regulated flow at those locations is the target minimum desired flow (650 ft^3/s for location 40 and 600 ft^3/s for location 42). Allen Reservoir then operates for location 99 for the remaining periods, as discussed above and shown in Table D.9.

Table D.10 East Branch Operation (Example 5)

```
 *USERS. 2    User Designed Output    (Dates shown are for END-of-Period)

                                      Summary by Period   Flood=       1
Location No=          444.     444.     400.     400.      42.      40.     99.
J8/JZ Codes=          444.120  444.100  400.120  400.100   42.040   40.040  99.040

                   ALLEN RES ALLEN RES BRENDA  BRENDA   CHARLEST DOUGVILL DRY TOWN
Period  Date:  Day    Case   Outflow   Case    Outflow  Flow Reg Flow Reg Flow Reg

     1  1Jan86 Wed    40.00   180.19     0.03   260.82   604.35   650.00  1850.00
     2  2Jan86 Thu    40.00   141.16     0.03   231.99   602.94   650.00  1850.00
     3  3Jan86 Fri    40.00   186.66     0.03   248.49   600.54   650.00  1850.00
     4  4Jan86 Sat    42.00   339.26     0.03   367.09   600.00   657.46  1850.00
     5  5Jan86 Sun    40.00   401.06     0.03   416.49   612.25   650.00  1850.00
     6  6Jan86 Mon    40.00   409.00     0.03   416.43   601.40   650.00  1850.00
     7  7Jan86 Tue    99.00   561.37     0.03   562.60   734.91   787.23  1850.00
     8  8Jan86 Wed    99.00   627.81     0.03   625.05   796.12   844.73  1850.00
     9  9Jan86 Thu    99.00   627.60     0.03   622.03   791.22   835.03  1850.00
    10 10Jan86 Fri    99.00   641.65     0.03   633.48   797.96   841.02  1850.00
     :
   11-40 Omitted
```

The third output table (*USER. 3) shows the operation on the West Branch, from James Reservoir down to Dry Town. Table D.11 lists the output for the first 20 periods (the output for Dry Town is not shown because it is the same as Table D.10). James Reservoir operates for location 99 (Case = 99.00) and for the minimum desired flow requirement defined at the reservoir (Case = 0.00). There is only a 15 ft^3/s diversion specified at location 50, which is far less than the minimum flow targets. During periods 9 through 12, the Guide Curve minimum flow is 480 based on the season and pool elevation. That is also true for periods 16 and 17. After January 15, the Guide Curve elevation is increasing causing the reservoir's operation Zone to shift from Zone 4, with the 480 ft^3/s target, to Zone 2 with a transition from 400 ft^3/s to 100 ft^3/s based on pool elevation.

Table D.11 West Branch Operation (Example 5)

```
 *USERS. 3    User Designed Output    (Dates shown are for END-of-Period)

                                            Summary by Period   Flood=      1
Location No=           555.      555.      555.      555.       555.       50.
J8/JZ Codes=           555.120   555.130   555.220   555.060    555.100    50.030

                     JAMES RES JAMES RES JAMES RES  JAMES RES  JAMES RES SPRINGVIL

  Period  Date:  Day   Case      Level   EOP Elev   DeQ-Shor   Outflow    Diversio

      1  1Jan86 Wed    99.00      2.79     820.36       0.00     653.30      15.00
      2  2Jan86 Thu    99.00      2.79     820.29       0.00     633.29      15.00
      3  3Jan86 Fri    99.00      2.78     820.23       0.00     592.52      15.00
      4  4Jan86 Sat    99.00      2.78     820.16       0.00     605.56      15.00
      5  5Jan86 Sun    99.00      2.77     820.08       0.00     622.93      15.00
      6  6Jan86 Mon    99.00      2.77     820.00       0.00     628.77      15.00
      7  7Jan86 Tue    99.00      2.77     819.93       0.00     499.95      15.00
      8  8Jan86 Wed    99.00      2.76     819.87       0.00     498.15      15.00
      9  9Jan86 Thu     0.00      2.76     819.81       0.00     480.00      15.00
     10 10Jan86 Fri     0.00      2.76     819.76       0.00     480.00      15.00
     11 11Jan86 Sat     0.00      2.75     819.70       0.00     480.00      15.00
     12 12Jan86 Sun     0.00      2.75     819.66       0.00     480.00      15.00
     13 13Jan86 Mon    99.00      2.75     819.59       0.00     507.22      15.00
     14 14Jan86 Tue    99.00      2.74     819.53       0.00     540.53      15.00
     15 15Jan86 Wed    99.00      2.74     819.46       0.00     535.71      15.00
     16 16Jan86 Thu     0.00      2.73     819.44       0.00     480.00      15.00
     17 17Jan86 Fri     0.00      2.72     819.41       0.00     480.00      15.00
     18 18Jan86 Sat     0.00      2.71     819.42       0.00     399.13      15.00
     19 19Jan86 Sun     0.00      2.70     819.44       0.00     397.45      15.00
     20 20Jan86 Mon     0.00      2.69     819.45       0.00     395.80      15.00
      :
   21-40 Omitted
```

User Tables 3 and 4, not shown, provide more detail for the reservoirs including elevation, evaporation, and diversions. For a review of those data, run the example data set and review the entire output file. The concluding error check indicates no errors for the simulation.

D.3 Firm Yield Determination

In water supply planning it is often desired to know the minimum conservation storage required to meet reservoir or downstream flow and diversion requirements. The solution is an iterative process of assuming different storage volumes until the minimum storage is found that will meet the requirements. The inverse is also common. Given a fixed storage volume, what is the maximum desired flow, required flow, or diversion which the reservoir will yield? In this case two of the three requirements are held fixed while the third is varied until the maximum is reached for a given reservoir storage. The maximum desired flow, for example, can be determined while holding the required flow and diversion constant.

The foregoing task of finding minimum conservation storage or maximum yield (desired flow, required flow or diversion) is handled in HEC-5 through its yield determination capability. In addition to water supply yield, the program can determine monthly firm energy and monthly plant factors for hydropower. The time interval of inflow for these options must be monthly. Also, only a single reservoir or up to four independent reservoirs in a system, can be analyzed. Each reservoir must be processed for its own independent set of flow requirements or conservation storage. An upstream reservoir's yield, operating for a downstream control point can be accomplished, but tandem reservoir operation yield cannot be determined.

D.3.1 Firm Yield Options

Time-period options. The standard selection of the simulation periods are available using this capability. These are period-of-record, partial record, and critical period. Period-of-record and partial record options are specified using the **BF** Record, discussed previously. For the critical period, the options are specified on the **J7** Record, Field 8. These options include: specifying the time periods desired for the simulation run; specifying a monthly reservoir drawdown duration; and specifying a duration equal to 70 times the ratio of conservation storage to mean annual flow. These are referred to as the "critical period" options. In addition, there also exists the capability to simulate using several combinations of critical period and period-of-records simulations. For this option, a code is input in field 9, **J7** Record. However, two basic approaches are suggested: Use the entire period-of-record (field 9 = 0 or 1); or use the multiple series of critical-period analysis followed by the period-of-record simulation (field 9 = 6).

Using the critical period analysis with the **J7** Record, field 9 = 6 allows for both critical period and period-of-record simulation. A check is made to see if the storage (or flow, or diversion) computed for the assumed critical period can be maintained for the period-of-record. If the assumed critical period is in fact, the true critical period, then the firm yield can be maintained for the period-of-record. If the drawdown using the period-of-record is greater than the drawdown using the assumed critical period, and not within the specified allowable error, then a new critical period is selected and the storage optimized. This capability also applies to desired flow, required flow and diversions.

Reservoir conservation storage. To determine required conservation storage to meet specified demands, the **J7** Record, field 1 is set to the location number (control point number) and the conservation storage above the top of buffer pool will be determined by specifying .0, (e.g., 55.0 would determine storage for reservoir 55). In field 8 specify 2 to start with an initial critical duration equal to 70 times the ratio of conservation storage to mean annual flow. An allowable error ratio (positive and negative) is specified in field 10. This is the ratio of the storage error (difference between the target drawdown storage and the minimum storage in the simulation) to the total conservation storage above the target drawdown storage. When reservoir storage is being determined, the desired and required flow requirements may be specified for either the reservoir or a downstream control point. When determining any yield (required or desired flow or diversions), the water yield must be at the reservoir unless the downstream control point (**J7** Record, field 5) is specified.

Maximum desired flow. This option determines the maximum desired flow available during the critical period or period-of-record given a specified volume of conservation storage. Other system requirements such as diversions and required flow are met as specified. Note however, that required flow is not competitive with desired flow because it is not drawn upon until the storage reaches the top of buffer at which time desired flow is no longer met. In field 1 of the **J7** Record a 55.2 would indicate that the maximum desired flow (.2) at control point 55 will be determined. The other input on the **J7** Record are the same as used for the storage determination. The pattern for the monthly varying desired flow is specified using the **QM** Record. Also, a constant or period varying desired flow may also be utilized. The desired flows are required as input on the **MR** Records in order to provide an initial estimate of the flows that vary by period.

Maximum required flow. This option determines the maximum required flow for the critical period or period-of-record that can be maintained through the period of historical flow data given a specified volume of conservation storage. Other system requirements such as diversions and desired flows are met as specified. Again, the **J7** Record specifies this option with a control point number plus a .3 in field 1. The other input on the **J7** Record are the same as for the storage determination. An initial estimate for a constant required flow is input on the **CP** Record, field 4. Monthly and period varying required flow may also be determined.

Maximum monthly diversion. This option determines the maximum diversion flow for the critical period or period-of-record. A given volume of conservation storage, with other system requirements being met, is specified. Both desired and required flow requirements may be competitive with diversions since the diversion requirement applies to storage above and below the buffer level. The required input on the **J7** Record is a control point number plus .4 input on field 1, where the control point number is the location for the diversion. The other input data on the **J7** Record are the same as previously described. An initial estimate of the monthly varying diversion is input on the **QD** Record.

Maximum value of all reservoir yields. By specifying a control point number plus .9 in field 1 of the **J7** Record, all yields (i.e., desired flow, required flow and diversion) are determined for a given storage at the reservoir. Each of the yields is multiplied iteratively by the same constant until the drawdown storage is within the target error specified. All yields must be at the reservoir.

Maximum yield at a downstream control point. In addition to determining maximum reservoir yields, the maximum yield can also be determined at a downstream control point. This option is accomplished by defining the downstream control point number to be analyzed in field 5 of the **J7** Record.

D.3.2 Firm Yield Model Data

Example 6 provides a firm-yield determination of diversions from reservoir location 111. Table D.12 lists the input data file. Andrew Reservoir has a specified monthly diversion and minimum flow schedule. The reservoir also operates for location 99, Zola, which has a minimum desired flow goal of 65 ft^3/s.

Table D.12 Firm Yield Determination (Example 6)

```
T1        HEC-5 Example 6, Firm Yield Determination    (EXAMPLE6.DAT)
T2        Firm Yield Determination of Diversion, DR and QD (J7.1 = 111.4)
T3        Blue River, Andrew Reservoir to Zola, Monthly Flow Data 1980-92
J1     0       1       5       3       4       2
J2    24     1.0               0
J3     4       0       0       0       0      -1
J7 111.4                                                  2       6       0
JZ111.11  111.13  111.03  111.10  111.05  111.06   99.04   99.05   99.06

C ====================== Andrew Reservoir =======================
RL   111  218000    7500    9500  218000  361800  552600
RO     1      99
RS    10    7500    9500   46900   66120  111800  218000  350000  361800  445200
RS552600
RQ    10    2700    2740    3800    4060    4400    4800    5200    5200   55000
RQ118700
RA    10     402     410    1390    1830    2790    4670    6520    6930    8294
RA  9498
R3  -2.6    -1.4    -1.2     -.6    -1.5     2.3     4.5     4.7     3.1     0.5
R3  -1.9    -2.5
CP   111    4800              10
IDANDREW RES
RT   111      99
DR   111                                             1
QD    12    10.5    10.5    10.5    15.2    25.7    43.3    43.3    43.3    25.7
QD  15.2    10.5    10.5
QM    20      20      20      20      25      35      50      50      45      30
QM    20      20

C ====================== Zola ===================
CP    99   14500      65
IDZOLA
RT    99

ED
BF     2     144       0     80010100             720                     1900
ZR=IN  A=BLUE RIVER  C=FLOW-LOC INC  F=COMPUTED FLOWS
ZW     A=BLUE RIVER  F=FIRM YIELD RESULTS
EJ
ER
```

The added **J7** Record calls for a yield determination and defines the objectives. The first field indicates location 111, the reservoir, and the decimal value indicates the target demand to process (i.e., .4 requests maximize diversions based on the schedule defined on the **QD** Record). Field 8 value is 2, requesting a critical period determination, based on the reservoir storage to mean annual flow ratio, and an output table showing the critical flow periods for 1 to 60 months. Field 9 has the recommended value 6, indicating that after the critical period results are determined there will be a test with the full flow sequence. And, if the full-record simulation finds another critical period, a subsequent analysis would be performed and tested. Up to three sequences will be performed, first analyzing the critical period and then testing with the full record. The last field defines the error tolerance. A zero input accepts the default of a 100 acre-ft negative error and a 1% of storage positive error. This allows the minimum storage to be 100 acre-feet below the minimum pool and up to .01 times the conservation storage as an acceptable minimum storage.

The remainder of the model data is similar to the previous examples. The program will simulate the operation with the defined data. After the first simulation, the program will adjust the diversion schedule by a ratio in an attempt to meet the maximum diversions while keeping the minimum storage within the storage error tolerance. The simulation output is described in the following section.

D.3.3 Firm Yield Output

As with the other examples, the output provides an input listing, followed by a summary of input. Unique to this example is the tabulation of the flow data read from the DSS file. With the firm-yield application, the data are formatted into the standard card-image format. Following the input listing is the table of flow-duration used to define the initial estimate of critical period. The output table is shown in Table D.13. The table is provided for 1 to 60 periods (months), showing the minimum volume and associated periods, the average flow, the average flow plus conservation storage, and the estimated storage for durations of 1 to 11 months, and dependable capacity if determination of installed capacity is desired.

The critical period is then estimated by the program based on the conservation storage to average annual flow ratio, shown at the end of the table. Based on the Ratio 0.693, the program estimated a critical duration of 49 months and the data for that duration is shown in the last line of the table, after the 60 month duration line. While the minimum flow for that duration begins in period 38, the program roles the start date back to the beginning of a year, period 25. The first cycle to find the maximum diversion schedule will be processed with the flow data from period 25 to 91.

Table D.13 Flow-Duration Table to Define Critical Period

DUR	VOL-DUR	PER-START	PER-END	Q-RIVER	Q+QSTOR	EST-STG	DEP CAP
1.	0.	47.	47.	0.	3454.	3115.	0.
2.	0.	46.	47.	0.	1727.	6230.	0.
3.	3.	46.	48.	1.	1152.	9165.	0.
4.	5.	46.	49.	1.	865.	12159.	0.
5.	10.	45.	49.	2.	693.	14972.	0.
6.	25.	44.	49.	4.	580.	17182.	0.
7.	67.	43.	49.	10.	503.	17762.	0.
8.	74.	42.	49.	9.	441.	20454.	0.
9.	158.	42.	50.	18.	401.	18498.	0.
10.	296.	41.	50.	30.	375.	13282.	0.
11.	702.	40.	50.	64.	378.	0.	0.
12.-30. *OMITTED*							
:							
31.	5850.	29.	59.	189.	300.	0.	0.
32.	6130.	29.	60.	192.	299.	0.	0.
33.	6596.	29.	61.	200.	305.	0.	0.
34.	7529.	28.	61.	221.	323.	0.	0.
35.	8001.	27.	61.	229.	327.	0.	0.
36.	8480.	26.	61.	236.	331.	0.	0.
37.	8963.	37.	73.	242.	336.	0.	0.
38.	9144.	36.	73.	241.	332.	0.	0.
39.	9444.	35.	73.	242.	331.	0.	0.
40.	9786.	29.	68.	245.	331.	0.	0.
41.	9874.	31.	71.	241.	325.	0.	0.
42.	9906.	31.	72.	236.	318.	0.	0.
43.	9974.	30.	72.	232.	312.	0.	0.
44.	10077.	30.	73.	229.	308.	0.	0.
45.	10208.	29.	73.	227.	304.	0.	0.
46.	10511.	41.	86.	229.	304.	0.	0.
47.	10729.	41.	87.	228.	302.	0.	0.
48.	11135.	40.	87.	232.	304.	0.	0.
49.	11483.	38 .	86.	234.	305.	0.	0.
50.	11701.	38.	87.	234.	303.	0.	0.
51.	11949.	36.	86.	234.	302.	0.	0.
52.	12167.	36.	87.	234.	300.	0.	0.
53.	12467.	35.	87.	235.	300.	0.	0.
54.	12726.	31.	84	236.	300.	0.	0.
55.	12765.	31.	85.	232.	295.	0.	0.
56.	12814.	31.	86.	229.	290.	0.	0.
57.	12882.	30.	86.	226.	287.	0.	0.
58.	13013.	29.	86.	224.	284.	0.	0.
59.	13231.	29.	87.	224.	283.	0.	0.
60.	14086.	29.	88.	235.	292.	0.	0.
49.	11483.	38.	86.	234.	305.	0.	0.

START-PER	END-PER	DATE
25	91	82010100

CON-STG	QMEAN	RAT-STG/Q	DRAW-DUR	APPROX. DEP CAP.
208500.	415.	0.693	49.	0.

The routing cycles and trial runs are summarized in the output table labeled "*OPTRY." The descriptions of the output data are provided in Appendix F. At the end of each trial, the minimum storage achieved is evaluated to determine if the demand can be increased or needs to be decreased. The program temporarily adds 500,000 acre-feet to the minimum storage to support demands greater than the available water supply can. If the minimum storage is below the adjusted target minimum (TAR-MIN-STG), the program can use the storage deficit to estimate how much to adjust the demand. Likewise, when the minimum is above the target, the increase in demand can be estimated based on the surplus water in storage distributed over the draw-down duration. The program computes the adjustment factor, shown as "MULTIPLIER= x.xxx" where x.xxx is the adjustment. Then the program performs another cycle with the adjusted demand.

The output for the ninth, and final, cycle is shown in Table D.14. (Note, the format has been slightly modified to fit the page.) The ninth cycle summary shows that the minimum storage was 77 acre-ft. above the minimum (509577 vs. 509500), within the minimum positive storage error of 100 acre-feet. Therefore, this cycle result is considered accepted and the next phase of analysis begins. The estimated diversion schedule is shown under "Firm Yield Optimization Results" and the final multiplier is shown as "DIVRAT(NDIV) = 9.895099" near the end of the summary. The program will now apply the determined diversion schedule with the period-of-record data, 144 periods.

Table D.15 shows "ROUTING CYCLE= 2.," the summary table for the simulation using the entire period-of-record. (Again, the format has been slightly modified.) The output is similar to that shown in Table D.14. The primary purpose for this iteration is to ensure that the results from the critical period analysis does reflect the most critical flow sequence. If it does, the results for the entire period-of-record should be the same. However, there is always a chance that a more critical period exists in the flow set. Reviewing the data near the end of the table shows the same results were obtained with the period-of-record. That is, the minimum storage was only 77 acre-ft. above minimum pool and the diversion multiplying factor is the same. One can verify this result by running a simulation using the multiplying factor in the ninth field of the diversion record (**DR**), or the diversion data (**QD** Records) can be changed to the values shown in the output labeled "Optimized Monthly Diversions." A test run with the multiplying factor confirmed the results.

Table D.14 Output for the Last Cycle of Trial 1

```
**********************************************************************************

 ROUTING CYCLE=       1   OPT TRIAL=       9

         AVG. CRITICAL DRAW DOWN RESULTS FROM PER       5  TO      34

      INFLOW      POW-REL      EL-BTW     DRAW-RAT      DIV-Q      EVAP-P
      -59.70        0.00        0.00        1.00       239.10        2.17
RELEASE     STORAGE       ELEV       EN-REQ
52.50     593602.38       0.00        0.00

         AVG. ROUTING PERIOD RESULTS FROM PER       1  TO      67

      INFLOW      POW-REL      HEAD      DRAW-RAT     QSPILL    TAILWATER
      52.91        0.00        0.00        1.00       52.65        0.00
RELEASE      H.TOP-C     H-BOT-C
  81.98        0.01        0.00

  OP TRIAL  ERROR-RAT ERR-STG  TAR-MIN-STG MIN-STG PER-MIN-STG TOP-STG   LOC.TYP
         9  0.000368       77.  509500.    509577.        34   718000.   111.40

                            *******************

 ANN DES Q  ANN REQ Q  ANN DIV Q     INS CAP  ANN FIRM E   AVG ANN E
      29.6      10.00     217.86          0.          0.          0.


   ITYOPT=   4  MULTIPLIER=       1.000180    DIVRAT(NDIV)=       9.895099

      ASSUMED   NEXT-ASSUM         PTWO         EST3   ER-IMPROVE   EST-BOUND
       103.90      103.92      103.92      103.91       305.19       103.92
BNDMAX       BNDMIN   ERR-BN-MAX   ERR-BN-MIN
104.01       103.90      -380.81        76.63

  =================== Firm Yield Optimization Results ====================
  Location: 111     Optimized Monthly Diversions:
                    103.90    103.90    103.90    150.41    254.30    428.46
                    428.46    428.46    254.30    150.41    103.90    103.90


           DUR       VOL-DUR         PER-START         PER-END        Q-RIVER
          115.        39459.            29.            143.           343.
Q+QSTOR        EST-STG        DEP CAP
  447.             0.             0.


      START-PER        END-PER          DATE
              1            144      80010100

        CON-STG          QMEAN      RAT-STG/Q       DRAW-DUR   APPROX. DEP CAP.
        718000.           415.          2.386          115.              0.
```

Table D.15 Summary Table for Cycle 2

```
*********************************************************************************
 *OPTRY

 ROUTING CYCLE=       2   OPT TRIAL=       1

ALL. PERC NEGATIVE ERROR= 0.950  POSITIVE ERROR= 0.9500  IND FOR ONE MORE TRY= 0

       AVG. CRITICAL DRAW DOWN RESULTS FROM PER      29  TO      58

      INFLOW      POW-REL      EL-BTW     DRAW-RAT      DIV-Q      EVAP-P
       -59.70        0.00        0.00        1.00      239.10        2.17

RELEASE     STORAGE       ELEV       EN-REQ
 52.50   593602.38       0.00        0.00

       AVG. ROUTING PERIOD RESULTS FROM PER       1  TO     144

      INFLOW      POW-REL      HEAD      DRAW-RAT     QSPILL    TAILWATER
       197.57        0.00        0.00        1.00      165.34        0.00

    RELEASE      H.TOP-C     H-BOT-C
 194.92        0.01        0.00

  OP TRIAL  ERROR-RAT ERR-STG  TAR-MIN-STG  MIN-STG PER-MIN-STG TOP-STG   LOC.TYP
        1   0.000368     77.        509500.  509577.         58   718000.   111.40

                            *******************

 ANN DES Q ANN REQ Q ANN DIV Q     INS CAP  ANN FIRM E   AVG ANN E
      29.6     10.00    217.86          0.          0.          0.

   ITYOPT=   4  MULTIPLIER=       1.000143    DIVRAT(NDIV)=       9.895099


      ASSUMED   NEXT-ASSUM         PTWO         EST3   ER-IMPROVE   EST-BOUND

       103.90       103.91         0.00       103.91         1.00         0.00

       BNDMAX       BNDMIN   ERR-BN-MAX   ERR-BN-MIN
 100000000.00       103.90         0.00        76.63

  =================== Firm Yield Optimization Results ====================
  Location: 111     Optimized Monthly Diversions:
                    103.90    103.90    103.90    150.41    254.30    428.46
                    428.46    428.46    254.30    150.41    103.90    103.90

 New Critical Period=   -28.064     0.000     0.000
```