Introduction

This Chapter describes the SSARR reservoir regulation method
(Operation SSARRESV) which is based on the Streamflow Simulation and
Reservoir Regulation System (SSARR) developed by the North West River
Forecast Center and the North Pacific Division of the US Army Corps of
Engineers.

The method routes streamflows from upstream to downstream points
through lake storage and reservoirs under free flow or controlled-flow
modes of operation. Flows may be routed as a function of
multivariable relationships involving backwater effects from a
downstream reservoir.

The reservoir regulation options are:

    FREEFLOW - free flow (lake routing)
    SETQ   - outflow specified (CFS; CMS)
    SETH   - reservoir elevation specified (FT; M)
    SETS   - reservoir storage specified (ACFT; TCUM)
    SETDQ   - change in storage specified (CFSD/DAY; CMSD/DAY)
    SETDH   - daily change of elevation specified (FT/DAY; M/DAY)
    SETDS   - daily change of storage specified (ACFT/DAY; TCUM/DAY)

All the units follow the NWSRFS units convention except TCUM which
stands for thousand cubic meters.

The regulation options can change over time and are not specified as
part of a Segment definition but are specified at run-time using the
SSARREG MOD (see Section VI.5.3C-FCEXEC-MOD-SSARREG) as a sequence of
regulation options, dates and values. The method used to compute
outflow changes between the observed and forecast periods. The
specified regulation options are only used to determine the outflow
and elevation during the forecast period. During the observed portion
of a SSARRESV run, observations are used to determine the outflow and
elevation based on the procedures.

When reservoir operations are specified in terms of storage change
(SETH, SETS, SETDQ, SETDH, SETDS) the reservoir outflow is being
calculated as being parallel to the inflow hydrograph and separated by
the stipulated volume amount. When the storage change differs from
one period to the next, an instantaneous change in flow must
necessarily be utilized. Such a condition is illustrated in Figure 1.
Since an instantaneous flow change can occur, Operation SSARRESV
requires two instantaneous outflow time series: the first contains the
flow at the start of a time period and the second contains the flow at
the end of the period. Optionally, a mean outflow time series can be
generated (average of flows at the start and end of the period).
Inflow to Operation SSARRESV can be a single inflow time series or a
pair of inflow time series (start and end of period flows) depending
on which other Operations are used to generate the inflow (see Chapter
II.4-SUMPOINT). The typical data type code to use for start of period

discharges is SQIB and for end of period discharges is SQIE.

A description of symbols commonly used in this text is in Table 1.

The general reservoir regulation rules for a computational interval starting at time t_1 and bracketed by regulation options specified at times T_i and T_{i+1} are as follows:

1. If no regulation option is specified then:

   - If the outflow/elevation curve is available then FREEFLOW is used.
   - If the outflow/elevation curve is not available then inflow will be passed.

2. If the regulation options at T_i and T_{i+1} are the same then the regulation value is linearly interpolated between the values specified at T_i and T_{i+1}.

3. If the regulation options at T_i and T_{i+1} are different then:

   - If the specified option at T_{i+1} is SETH or SETS then the regulation option at T_{i+1} is used and the regulation value is linearly interpolated using the computed value from t_1 and the specified value at T_{i+1}.
   - If the specified option at T_{i+1} is neither SETH nor SETS then FREEFLOW is used.

Operation SSARRESV is normally used for a single reservoir without backwater effect but it can also be used for a single reservoir with backwater effect from tributary flow. A reservoir without backwater effect is referred to as a non-backwater reservoir and a reservoir with backwater effect is referred to as a backwater reservoir. A maximum of two reservoirs, where the outflow from the upstream reservoir is affected by backwater from the downstream reservoir, are permitted in Operation SSARRESV. If there are a pair of reservoirs then both reservoirs are included in a single SSARRESV Operation. The upstream reservoir is always referred to as the backwater reservoir. The downstream reservoir can be a non-backwater reservoir or a backwater reservoir. If the downstream reservoir is a backwater reservoir then only the backwater effect from tributary flow is allowed in Operation SSARRESV.

Operation SSARRESV can also be used to simulate a station in the river with backwater effect from a downstream reservoir. A station with backwater effect is referred to as a backwater station. A backwater station must always be used together with a downstream reservoir and included in a single SSARRESV Operation.

Freeflow Lake Routing

The FREEFLOW lake routing method is used to route floods through a natural lake or a reservoir under free flow condition.

Input parameters needed in lake routing are as follows:

    S = F(H) or H = F(S) - elevation/storage curve

    Q = G(H) or Q = G(S) - outflow/elevation/storage curve

    HMIN - minimum pool elevation allowed

The routing of flow through natural lakes is based on free-flow
conditions, i.e., elevation-outflow relationships are fixed and
outflow is determined by hydraulic head. The basic routing method
relies on the law of continuity in the storage equation:

$$\left[\frac{I_1 + I_2}{2}\right] * dt - \left[\frac{Q_1 + Q_2}{2}\right] * dt = S_2 - S_1$$

and the outflow/storage curve:

    $Q_2 = F(S_2)$

The two unknowns S_2 and Q_2 can be solved from the two equations by an
iterative procedure depicted in Figure 2. The initial estimate for
outflow (Q_2) is assumed to equal the outflow at period start (Q_1). An
outflow value Q_T is then determined by solution of the continuity
equation and the storage equation, according to the elevation-storage
relationships that are entered in table form. The Q_T value is then
tested and the process repeated until an acceptable outflow is
obtained. This iterative process insures an accurate solution of lake
routing.

Once the reservoir storage is computed the reservoir elevation can be
interpolated from the elevation/storage curve:

    $H_2 = F(S_2)$

If H_2 is less than HMIN, H_2 is reset to HMIN and a new outflow, Q_2 is
computed to bring the elevation to HMIN:

    $H_2 = HMIN$

    $S_2 = F(H_2)$

    $dQ = (S_1 - S_2)/dt$

    $Q_2 = I_2 + dQ$

    and

    $Q_{1n} = I_1 + dQ$

If no outflow/elevation curve is given then inflow is passed thus:

    $Q_2 = I_2$

and

$Q_{1n} = I_1$

and

$H_2 = H_1$

and

$S_2 = S_1$

Reservoir Without Backwater Effect

The method described herein is used to route floods through a single reservoir or through the downstream reservoir of a two-reservoir system. In either case the reservoir is assumed to have no backwater effects.

Input parameters needed in a reservoir without backwater effect include the parameters described in lake routing plus HMAX:

   HMAX - Maximum pool elevation allowed. If inflow is less than hydraulic capacity, this elevation will be maintained by passing inflow. If inflow exceeds hydraulic capacity then FREEFLOW will be used.

   QMIN - Minimum reservoir release for fishery or other water use for as long as the reservoir elevation is above HMIN.

There are six different ways available in Operation SSARRESV to regulate a reservoir.

1. SETQ - Outflow Specified

```
Time                 =  T_i   T_{i+1}
Regulation option =  IX    1
Outflow               =  X     Q_{i+1}
```

   where IX is the reservoir regulation option
          X   is the regulation value associated with the regulation option IX

   IX may be any reservoir regulation options from 0 to 6 and X may be outflow, pool elevation, pool storage, delta outflow, delta elevation or delta storage depending on the regulation option IX.

   If IX $\ne$ 1 then the regulation option is changed. The option at T_{i+1} is different from the option at T_i. H_2, Q_2 and S_2 are solved using the FREEFLOW mode.

   If IX = 1 then the same options are used at T_i and T_{i+1}. Therefore, X = Q_i and the specified outflow, Q_2, is computed by linear interpolation from the following equation:

$$Q_2 = Q_i + \left[\frac{Q_{i+1} - Q_i}{T_{i+1} - T_i}\right] * (t_2 - T_i)$$

Once the specified outflow, Q_2 is known, S_2 is computed from the continuity equation:

$$S_2 = S_1 + \left[\frac{I_1 + I_2}{2}\right] * dt - \left[\frac{Q_1 + Q_2}{2}\right] * dt$$

Then compute the pool elevation from the elevation/storage curve:

$$H_2 = F(S_2)$$

If $H_2 >$ HMAX then set $H_2 =$ HMAX or if $H_2 <$ HMIN then set H_2 to HMIN. If H_2 is revised then recompute S_2 from $S_2 = F(H_2)$ and then Q_2 and Q_{1n} as follows:

$$dQ = (S_1 - S_2)/dt$$

$$Q_2 = I_2 + dQ$$

and

$$Q_{1n} = I_1 + dQ$$

If H2 > HMIN and $Q_2 <$ QMIN then set Q_2 to QMIN; and recompute H_2 and S_2.

The hydraulic capacity corresponding to the reservoir elevation H_2 is interpolated from the outflow/elevation curve:

$$QC = F(H_2)$$

If $Q_2 >$ QC, recompute H_2, Q_2 and S_2 from the FREEFLOW mode.

2. SETH - Pool Elevation Specified

```
Time                =  T_i   T_{i+1}
Regulation option   =  IX    2
Elevation           =  X     H_{i+1}
```

where IX is the reservoir regulation option
       X   is the regulation value associated with the regulation
           option IX

IX may be any reservoir regulation options from 0 to 6 and X may be outflow, pool elevation, pool storage, delta outflow, delta elevation or delta storage depending on the regulation option IX.

If IX ≠ 2 then the regulation option is changed. The option at T_{i+1} is different from the option at T_i. The pool elevation, H_2, is computed by linear interpolation using the computed elevation at t_1

and the specified elevation at T_{i+1}.

$$H_2 = H_1 + \left[\frac{H_{i+1} - H_1}{T_{i+1} - t_1}\right] * (t_2 - t_1)$$

If IX = 2 then the same options are used at T_i and T_{i+1}. Therefore, X = H_i and H_2 is computed by linear interpolation from the following equation:

$$H_2 = H_i + \left[\frac{H_{i+1} - H_i}{T_{i+1} - T_i}\right] * (t_2 - T_i)$$

If H_2 > HMAX then set H_2 = HMAX.
If H_2 < HMIN then set H_2 = HMIN.

Once H_2 is determined, S_2 is interpolated from the elevation-storage curve:

   $S_2 = F(H_2)$

   then

   $dQ = (S_1 - S_2)/dt$

   and

   $Q_2 = I_2 + dQ$

   and

   $Q_{1n} = I_1 + dQ$

If H2 > HMIN and Q_2 < QMIN then set Q_2 to QMIN; and recompute H_2 and S_2 according to the procedures given in the SETQ section.

The hydraulic capacity corresponding to the reservoir elevation H_2 is interpolated from the outflow/elevation curve:

   $QC = F(H_2)$

If Q_2 > QC, recompute H_2, Q_2 and S_2 from the FREEFLOW mode.

3. SETS - Pool Storage Specified

```
Time                =  T_i   T_{i+1}
Regulation option   =  IX    3
Storage             =  X     S_{i+1}
```

where IX is the reservoir regulation option
       X   is the regulation value associated with the regulation
           option IX

IX may be any reservoir regulation options from 0 to 6 and X may be

outflow, pool elevation, pool storage, delta outflow, delta elevation or delta storage depending on the regulation option IX.

If IX ≠ 3 then the regulation option is changed. The option at T_{i+1} is different from the option at T_i. The reservoir storage, S_2, is computed by linear interpolation using the computed storage at t_1 and the specified storage at T_{i+1}:

$$S_2 = S_1 + \left[\frac{S_{i+1} - S_1}{T_{i+1} - t_1}\right] * (t_2 - t_1)$$

If IX = 3 then same options are used at T_i and T_{i+1}. Therefore $X = S_i$ and S_2 is computed by linear interpolation from the following equation:

$$S_2 = S_i + \left[\frac{S_{i+1} - S_i}{T_{i+1} - T_i}\right] * (t_2 - T_i)$$

To solve for the rest of the unknowns H_2 must be computed from the elevation/storage curve:

$$H_2 = f(S_2)$$

If H_2 > HMAX then set H_2 = HMAX or if H_2 < HMIN then set H_2 to HMIN. If H_2 is revised then $S_2 = F(H_2)$ is recomputed and:

$$dQ = (S_1 - S_2)/dt$$

$$Q_2 = I_2 + dQ$$

and

$$Q_{1n} = I_1 + dQ$$

If H2 > HMIN and Q_2 < QMIN then set Q_2 to QMIN; and recompute H_2 and S_2 according to the procedures given in the SETQ section.

The hydraulic capacity corresponding to the reservoir elevation H_2 is interpolated from the outflow/elevation curve:

$$QC = F(H_2)$$

If Q_2 > QC, recompute H_2, Q_2 and S_2 from the FREEFLOW mode.

4. SETDQ - Delta Outflow Specified

```
Time                =  T_i   T_{i+1}
Regulation option   =  IX    4
Delta outflow       =  X     dQ_{i+1}
```

where IX is the reservoir regulation option
        X   is the regulation value associated with the regulation
            option IX

IX may be any reservoir regulation options from 0 to 6 and X may be outflow, pool elevation, pool storage, delta outflow, delta elevation or delta storage depending on the regulation option IX.

If IX ≠ 4 then the regulation option is changed. The option at T_{i+1} is different from the option at T_i. H_2, Q_2 and S_2 are solved using the FREEFLOW mode.

If IX = 4 then the same options are used at T_i and T_{i+1}. Therefore, X = dQ_i and the outflow change in one period, dQ, is computed by linear interpolation from the following equation:

$$dQ = dQ_i + \left[\frac{dQ_{i+1} - dQ_i}{T_{i+1} - T_i}\right] * (t_2 - T_i)$$

The solution procedure to follow is first to compute S_2 from:

   $S_2 = S_1 + dQ * dt$

Then compute H_2 from the elevation/storage curve:

   $H_2 = f(S_2)$

If H_2 > HMAX then set H_2 = HMAX or if H_2 < HMIN, reset H_2 = HMIN. If H_2 is revised S_2 and dQ are recomputed as follows:

   $S_2 = F(H_2)$.

   otherwise

   $dQ = (S_1 - S_2)/dt$

   $Q_2 = I_2 + dQ$

   and

   $Q_{1n} = I_1 + dQ$

If H2 > HMIN and Q_2 < QMIN then set Q_2 to QMIN; and recompute H_2 and S_2 according to the procedures given in the SETQ section.

The hydraulic capacity corresponding to the reservoir elevation H_2 is interpolated from the outflow/elevation curve:

   $QC = F(H_2)$

If Q_2 > QC, recompute H_2, Q_2 and S_2 from the FREEFLOW mode.

5. SETDH - Daily Change of Elevation Specified

```
Time                         =  T_i   T_{i+1}
Regulation option            =  X     5
Daily change of Elevation    =  X    dH_{i+1}
```

where IX is the reservoir regulation option
       X   is the regulation value associated with the regulation
           option IX

IX may be any reservoir regulation options from 0 to 6 and X may be
outflow, pool elevation, pool storage, delta outflow, delta
elevation or delta storage depending on the regulation option IX.

If IX ≠ 5 then the regulation option is changed. The option at T_{i+1}
is different from the option at T_i. H_2, Q_2 and S_2 are solved using
the FREEFLOW mode.

If IX = 5 then the same options are used at T_i and T_{i+1}. Therefore X
= dH_i and the elevation change in one period, dH, is computed by
linear interpolation from the following equation (the change of
elevation is specified on a daily basis):

$$dH = dH_i + \left[\frac{dH_{i+1} - dH_i}{T_{i+1} - T_i} \right] * (t_2 - T_i)$$

The solution procedure to follow is first to compute H_2 from

   $H_2 = H_1 + dH * (dt/24)$

If H_2 > HMAX then set H_2 = HMAX
If H_2 < HMIN then set H_2 = HMIN

Once H_2 is determined, S_2 is interpolated from the elevation-storage
curve:

   $S_2 = F(H_2)$

   then

   $dQ = (S_1 - S_2)/dt$

   and

   $Q_2 = I_2 + dQ$

   and

   $Q_{1n} = I_1 + dQ$

If H2 > HMIN and Q_2 < QMIN then set Q_2 to QMIN; and recompute H_2 and
S_2 according to the procedures given in the SETQ section.

The hydraulic capacity corresponding to the reservoir elevation H_2
is interpolated from the outflow/elevation curve:

   $QC = F(H_2)$

If Q_2 > QC, recompute H_2, Q_2 and S_2 from the FREEFLOW mode.

6. SETDS - Daily Change of Storage Specified

```
Time                     =  T_i   T_{i+1}
Regulation option        =  IX    6
Daily change of Storage  =  X     dS_{i+1}
```

where IX is the reservoir regulation option
     X   is the regulation value associated with the regulation
       option IX

IX may be any reservoir regulation options from 0 to 6 and X may be outflow, pool elevation, pool storage, delta outflow, delta elevation or delta storage depending on the regulation option IX.

If X ≠ 6 then the regulation option is changed. The option at T_{i+1} is different from the option at T_i. H_2, Q_2 and S_2 are solved using the FREEFLOW mode

If IX = 6 then the same options are used at T_i and T_{i+1}. Therefore, X = dS_i and the storage change in one period, dS, is computed by linear interpolation from the following equation (the change of storage is specified on a daily basis):

$$dS = dS_i + \left[\frac{dS_{i+1} - dS_i}{T_{i+1} - T_i} \right] * (t_2 - T_i)$$

The solution procedure to follow is first to compute S_2 from:

$$S_2 = S_1 + dS * (dt/24)$$

Then compute H_2 from the elevation storage curve:

$$H_2 = f(S_2)$$

If H_2 > HMAX then set H_2 = HMAX or if H_2 < HMIN then set H_2 to HMIN. If H_2 is revised then $S_2 = F(H_2)$ is recomputed and:

$$dQ = (S_1 - S_2)/dt$$

$$Q_2 = I_2 + dQ$$

and

$$Q_{1n} = I_1 + dQ$$

If H2 > HMIN and Q_2 < QMIN then set Q_2 to QMIN; and recompute H_2 and S_2 according to the procedures given in the SETQ section.

The hydraulic capacity corresponding to the reservoir elevation H_2 is interpolated from the outflow/elevation curve:

$$QC = F(H_2)$$

If Q_2 > QC, recompute H_2, Q_2 and S_2 from the FREEFLOW mode.

Reservoir with Backwater Effect from Downstream Reservoir

The method described herein is used to route floods through the
upstream reservoir of a two-reservoir system in which the upstream
reservoir is backwater affected by the downstream reservoir. The
upstream reservoir may also include the backwater effect from
tributary flow and local flow occurred in between the two reservoirs.
The method used for solving the backwater reservoir in a two-reservoir
system is presented herein. A backwater reservoir with backwater
effect solely from tributary flow will be discussed in the next
section.

Input parameters for solving a reservoir with backwater effect from a
downstream reservoir are as follows:

   S = F(H) or H = F(S) - Elevation/storage curve

   Q = B(H, HH)   - Three variable backwater curve controlled by
                           downstream reservoir elevation, HH

                           or

   Q = B(H, QQ)   - Three variable backwater curve controlled by
                           downstream reservoir outflow, QQ

   HMAX   - Maximum pool elevation for the backwater
                           reservoir above which backwater routing will
                           be used

   HMIN   - Minimum pool elevation for the backwater
                           reservoir

The governing equations used for a backwater reservoir problem are
similar to a non-backwater reservoir except the three variable
backwater curve.

From the continuity condition:

$$\left[\frac{I_1 + I_2}{2}\right] * dt - \left[\frac{Q_1 + Q_2}{2}\right] * dt = S_2 - S_1$$

From the elevation/storage curve:

   $H_2 = F(S_2)$

From the three variable backwater curve:

   $Q_2 = B(H_2, HH_2)$

   or

   $Q_2 = B(H_2, QQ_2)$

Notice that there are four unknowns ,Q_2, S_2, H_2 and HH_2 or (QQ_2),in the above three equations. Four unknowns cannot be solved from only three equations. However if HH_2 or QQ_2 are lagged by one time step then:

    $Q_2 = B(H_2, HH_1)$

    or

    $Q_2 = B(H_2, QQ_1)$

The four unknown variables have been reduced to three, Q_2, H_2 and S_2. The three unknowns can then be solved from the above three equations: the continuity equation, the elevation/storage curve and the backwater curve. The iterative solution technique is similar to a non-backwater reservoir and is given in Figure 2. Due to the lagging of HH or QQ, short computational periods should be used to minimize the computational error.

All the reservoir regulation options described in sections for a non-backwater reservoir are also applicable to a backwater reservoir. The only difference is that the hydraulic capacity for a backwater reservoir is computed from the backwater curve:

    $QC = B(H_2, HH_1)$

    or

    $QC = B(H_2, QQ_1)$

The outflow from the upstream reservoir, Q_2, is then used as inflow to the downstream reservoir. If the downstream reservoir is a non-backwater reservoir then the solution technique described earlier is used to complete the computational process. If the downstream reservoir is a backwater reservoir then the backwater reservoir is allowed to have backwater effect only from tributary flow. The solution technique will be discussed in the following section.

Any tributary flow and/or local flow, if existed, must be occurred in between the upstream and downstream reservoirs; and they should be added to the outflow from the upstream reservoir, Q_2, before they are used as inflow to the downstream reservoir.

Reservoir with Backwater Effect Solely from Tributary Flow

The method described herein is used to route floods through a backwater reservoir with backwater effect solely from tributary flow. In Operation SSARRESV a backwater reservoir of this type is allowed to be used only either as a single reservoir or as the downstream reservoir of a two-reservoir/station system.

Input parameters are as follows:

    $S = F(H)$ or $H = F(S)$ - Elevation/storage curve

```
Q = B(H, QQ)                - Three variable backwater curve controlled
                              by tributary flow, QQ

HMAX                        - Maximum pool elevation for the backwater
                              reservoir above which backwater routing
                              will be used

HMIN                        - Minimum pool elevation for the backwater
                              reservoir
```

The problem associated with a backwater reservoir affected solely by
tributary flow is similar to, but easier than, a reservoir problem
backwater controlled by a downstream reservoir. The reasons are that
only one control parameter, flow, needs to e considered and that the
tributary flow, QQ, is assumed to have been computed elsewhere prior
to Operation SSARRESV.

From the continuity condition:

$$\left[\frac{I_1 + I_2}{2}\right] * dt - \left[\frac{Q_1 + Q_2}{2}\right] * dt = S_2 - S_1$$

From the elevation/storage curve:

$$H_2 = F(S_2)$$

From the three variable backwater curve:

$$Q_2 = B(H_2, QQ_2)$$

Since the tributary flow time series is assumed to have been computed
from another Operation prior to Operation SSARRESV, QQ_2 is a known
variable. The three unknowns, Q_2, S_2 and H_2 can be solved from the
three equations: the continuity equation, the elevation/storage curve
and the backwater curve. The iterative solution technique is similar
to the reservoir Operation with backwater effect from a downstream
reservoir.

All the reservoir regulation options described in sections for a non-
backwater are also applicable a backwater reservoir. The only
difference is that the hydraulic capacity of a backwater reservoir is
computed from the backwater curve:

$$QC = B(H_2, QQ_2)$$

Station Using Three-Variable Table Lookup Without Backwater Routing

The three variable table lookup is available both in Operation
SSARRESV and Operation LOOKUP3 however their functions are slightly
different. In Operation SSARRESV the three variable table and the
regulation options from the downstream reservoir are solved
simultaneously. In Operation LOOKUP3 the discharge or elevation time
series at the downstream control point is determined apriori from

another Operation. Therefore if the flow from the upstream station
could impose significant change to the elevation of the downstream
reservoir or if the downstream reservoir is to be regulated to achieve
certain desired flow conditions at the upstream station then Operation
SSARRESV should be used. If the backwater effect at the backwater
station is solely due to tributary flow or if the downstream reservoir
will be operated without regarding the flow condition at the upstream
station then Operation LOOKUP3 (three-variable table lookup) should be
used.

The method described herein is used to route floods through the
upstream station of a station-reservoir system in which the upstream
station is backwater affected by the downstream reservoir. Similar to
a backwater reservoir, a backwater station in the river may include
backwater effect from tributary flow and local flow.

The stage-discharge relationships for a backwater station is specified
in a three-variable table when no backwater routing is required. Only
the three-variable relation curve is needed to solve a backwater
station problem:

   $H = T(HH, Q)$ -   Three variable relation curve controlled by
                                     downstream reservoir elevation, HH.

                                  or

   $H = T(QQ, Q)$ -   Three variable relation curve controlled by
                                     downstream reservoir outflow, QQ.

From the three-variable relation curve:

   $H_2 = T(HH_2, Q_2)$

   or

   $H_2 = T(QQ_2, Q_2)$

Q_2 is inflow to the station and is computed elsewhere prior to
Operation SSARRESV and therefore is assumed to be a known variable.
However there are still two unknowns left, H_2 and HH_2 or (QQ_2). A
problem cannot be solved with two unknown and only one equation.

However HH_2 or QQ_2 are lagged by one time step then:

   $H_2 = T(HH_1, Q_2)$

   or

   $H_2 = T(QQ_1, Q_2)$

The two unknown variables have been reduced to one, H_2. Given HH_1 or
QQ_1 as first independent variable and Q_2 as second independent
variable, H_2 can be interpolated through a three-variable table lookup.
Due to the lagging of HH or QQ, short computational periods should be
used to minimize the computational error.

In Operation SSARRESV inflow is assume to be equal to outflow at a backwater station. Therefore the flow at the upstream station, Q_2, is then used as inflow to the downstream reservoir. The solution technique for the downstream reservoir, either a backwater or a non-backwater reservoir, is used to complete the computational process.

Any tributary flow and/or local flow, if existed, must be occurred in between the upstream station and the downstream reservoir; and they should be added to the outflow from the upstream station, Q_2, before they are used as inflow to the downstream reservoir.

Method to Generate Results from Observed Data

All the observed data are assumed to have been obtained at the end of a time period. Different generation procedures are used depending on types of available observed data.

Seven cases of different combinations of observed data are possible:

  Case 1. Only observed instantaneous discharge (OQ) is available
  Case 2. Only observed mean discharge (OQM) is available
  Case 3. Only observed pool elevation (OH) is available
  Case 4. Both observed instantaneous and mean discharge are available
  Case 5. Both observed instantaneous discharge and pool elevation are available
  Case 6. Both observed pool elevation and mean discharge are available
  Case 7. All three types of observed data are available

Depending on the combinations of observed data, different procedures need to be utilized to generate the results. The procedures used in each of the seven cases are presented separately as follows:

Case 1 - Only observed instantaneous discharge is available

   Step A. Generate instantaneous discharges:

      Since observed data are obtained at period end instantaneous discharge at period end is equal to observed, Q_2 = OQ, whenever observed instantaneous discharges are available. If observed instantaneous discharges are missing then the missing discharges are generated from two adjacent non-missing discharges by linear interpolation. The process is repeated throughout the entire time series to generate all the instantaneous discharges at period end.

      Once all the instantaneous discharges at period end are determined the instantaneous discharge at period start, Q_{1n}, can be computed as follows:

         $dQ = Q_2 - I_2$

         and

$Q_{1n} = I_1 + d$

Step B. Generate mean discharge from $QM = (Q_2 + Q_{1n})/2$

Step C. Generate pool elevations and storages:

Let $IM = (I_1 + I_2)/2$ then compute pool storage, S_2, from
continuity equation using mean discharge, QM, generated from step
B:

$S_2 = S_1 + (IM - QM) * dt$

then interpolate pool elevation, H_2, from elevation/storage
curve:

$H_2 = F(S_2)$

Case 2 - Only observed mean discharge is available

Step A. Generate mean discharges:

Set $QM = OQM$, whenever observed mean discharges are available.
If observed mean discharge are missing then the missing mean
discharges are generated from two adjacent non-missing mean
discharges through linear interpolation.

Step B. Generate instantaneous discharges:

First compute the mean inflow, IM, then dQ using the mean
discharge, QM, generated from step A:

$IM = (I_1 + I_2)/2$

and

$dQ = QM - IM$

then

$Q_2 = I_2 + dQ$

and

$Q_{1n} = I_1 + dQ$

Step C. Generate pool elevations and storages:

First compute pool storage, S_2, using continuity equation and
mean discharge generated from Step A:

$S_2 = S_1 + (IM - QM) * dt$

Then interpolate pool elevation, H_2, from elevation/storage
curve:

$$H_2 = F(S_2)$$

Case 3 - Only observed pool elevations available

Step A. Generate pool elevations and storages:

First compute pool storages corresponding to all observed pool elevations from pool elevation/storage curve:

$$OS = F(OH)$$

Set $S = OS$, whenever observed pool elevations are available. Whenever observed pool elevations are missing the pool storages are generated from two adjacent non-missing storages through linear interpolation. The interpolated storages then used to compute pool elevation from pool elevation/storage curve:

$$H_2 = F(S_2)$$

Step B. Generate instantaneous discharges:

First compute dQ from pool storages, S_2, determined from step A:

$$dQ = (S_1 - S_2)/dt$$

then

$$Q_2 = I_2 + dQ$$

and

$$Q_{1n} = I_1 + dQ$$

Step C. Generate mean discharge from $QM = (Q_2 + Q_{1n})/2$

Case 4 - both observed instantaneous and mean discharge are available

Step A. If observed instantaneous discharges are available at period start and end, compute mean discharge from:

$$QM = (Q_2 + Q_{1n})/2$$

Step B. The computed mean discharges from Step A are used to supplement the observed mean discharge time series in dealing with missing data. If observed mean discharge is missing and observed instantaneous discharges at period start and end are available then the missing mean discharge will be replaced by the mean discharge computed from the observed instantaneous discharges. A composite time series that combines observed instantaneous and mean discharges is evolved as a new mean discharge time series.

Step C. Generate missing mean discharges in the composite time series in Step B. The missing mean discharges are generated from two adjacent non-missing mean discharges through linear

interpolation.

Step D. Generate instantaneous discharges using the Step B procedure in Case 2

Step E. Replace all instantaneous discharges with observed instantaneous discharges if they are available.

Step F. Generate pool elevations and storages using the Step C procedure in Case 2

Case 5 - both observed instantaneous discharge and pool elevation available

Step A. Assuming only observed pool elevation is available, generate pool elevations, storages and instantaneous discharges using the step A and B procedures in Case 3.

Step B. Replace all instantaneous discharges with observed instantaneous discharges if they are available.

Step C. Generate mean discharge from $QM = (Q_2 + Q_{1n})/2$

Case 6 - both observed mean discharge and pool elevation are available

Step A. Assuming only observed mean discharge is available, generate mean and instantaneous discharges using the Step A and B procedures in Case 2.

Step B. Generate pool elevations and storages:

First compute pool storages corresponding to all observed pool elevations from elevation/storage curve:

$OS = F(OH)$

Set pool storage to OS, $S_2 = OS$, whenever observed pool elevations are available. Whenever observed pool elevations are missing, pool storage is computed from continuity equation:

$S_2 = S_1 + (IM - QM) * dt$

Then interpolate pool elevation from elevation/storage curve:

$H_2 = F(S_2)$

Case 7 - All three types of observed data available

Step A. Assuming only observed instantaneous and mean discharges are available, generate instantaneous and mean discharges using the procedures given in Case 4.

Step B. Then generate pool elevations and storages using the Step B procedure given in Case 6

Method to Back-compute Inflow from Observed Pool Elevation and Discharge

Depending on the combinations of the observed data, different procedures are used to generate the instantaneous discharges at period start and end, mean discharges and pool elevations. The generated results can then be used to back-compute the inflow at period start and end and mean inflow.

First compute the pool storage from the generated pool elevation from pool elevation/storage curve at period start:

$S_1 = F(H_1)$

and the pool storage at period end:

$S_2 = F(H_2)$

Then compute the mean inflow from the continuity equation:

$IM = (S_2 - S_1)/dt + QM$

Then compute the change in flow to conserve storage volume change from:

$dQ = QM - IM$

Then the inflow at period end as:

$I_2 = Q_2 - dQ$

and the inflow at period start as:

$I_{1n} = Q_{1n} - dQ$

Table 1. Description of symbols

| Symbol	Description
I_1, I_2	Inflows at the time period start and end
Q_{1n}	Revised outflow at the time period start to account for volume change; equals Q_1 if no volume change occurred
Q_1, Q_2	Outflows at the time period start and end
QQ_1, QQ_2	Control flows at the time period start and end
QC	Hydraulic capacity, maximum discharge capacity of all discharge facilities
H_1, H_2	Pool elevations at the time period start and end
HH_1, HH_2	Control elevations at the time period start and end
S_1, S_2	Pool storages at the time period start and end
t_1, t_2	Time at the time period start and end
dt	Time duration = $t_2 - t_1$
T_i	Beginning time of a pair of consecutive time stamp for regulation option bracketing t2
T_{i+1}	Ending time of a pair of consecutive time stamp for regulation option bracketing t2
IX	Regulation option corresponding to time stamp T_i
X	Regulation value corresponding to regulation option IX
Q_i, Q_{i+1}	Regulation outflows corresponding to T_i and T_{i+1}
H_i, H_{i+1}	Regulation elevations corresponding to T_i and T_{i+1}
S_i, S_{i+1}	Regulation storages corresponding to T_i and T_{i+1}
dQ_i, dQ_{i+1}	Regulation delta-outflows corresponding to T_i and T_{i+1}, respectively
dH_i, dH_{i+1}	Regulation delta-elevations corresponding to T_i and T_{i+1}, respectively
dS_i, dS_{i+1}	Regulation delta-storages corresponding to T_i and T_{i+1}, respectively

Figure 1. Instantaneous flow change
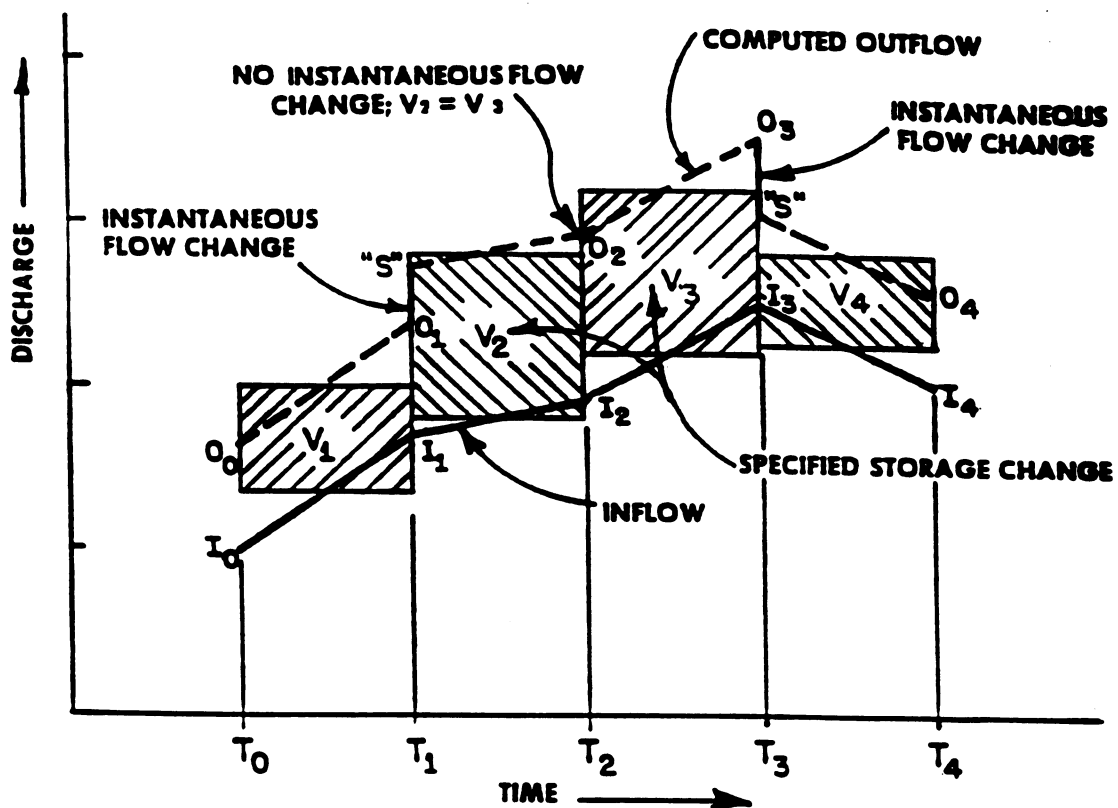
Figure 2. Lake and backwater routing techniques used in SSARR