MVC DSS Hydrologic Submodel Technical Documentation

The purpose of this memo is to document the logic and functioning of the hydrologic submodel that executes the water balance calculations behind the Middle Vernon Creek Decision Support System (MVC DSS). The document includes flow charts, formulas, and descriptions to outline the flow of information within the submodel. Moreover, rankings of various annual hydrological statistics for the historical dataset are provided at the end of the document to be used by the DSS users as a resource for selecting suitable simulation periods that meet the particular objectives/goals for each simulation.

1 Hydrological Submodel

The MVC DSS is comprised of a User Interface (UI) and a hydrologic submodel (HS) coupled together. The UI provides the user with functionality for setting up and initiating simulation runs, and for managing simulated output, whereas the HS conducts the water balance calculations for predicting flows and water levels throughout the watershed. Once a simulation run is initiated, the hydrological data are sent back and forth between the UI and HS in a two-phase process. In the first phase, referred to as the *water balance reconstruction*, the historical water balance for the watershed is reconstructed using the historical hydrological dataset for the period of interest to estimate any missing water balance components (e.g. inflow to Swalwell Lake). In the second phase, referred to as the *water balance simulation*, the reconstructed historical water balance is altered for simulating the potential hydrologic impacts of an alternative water management regime (e.g. different Swalwell Lake releases).

1.1 Water Balance Reconstruction

To predict the outcome of altering the water management regime in the watershed, it is necessary to quantify all aspects of the historical water balance (i.e. all flows and lake levels) for the watershed. Figure 1 outlines the process involved with reconstructing the historical water balance.

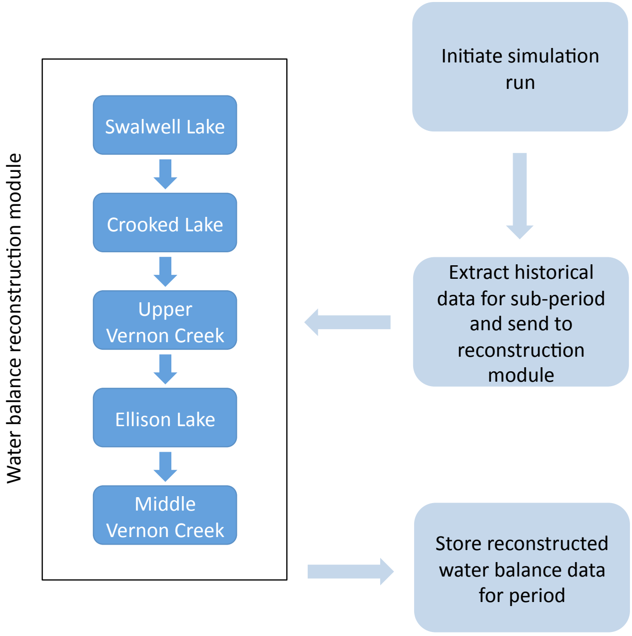

Figure 1. Flow chart describing the process for reconstructing the historical water balance.

After initiating the simulation run, the historical data are extracted from the data file and run through the water balance reconstruction module. The reconstruction module is comprised of a hierarchy of component water balances for individual portions of the watershed, and data from each prior component feeds into a subsequent component. The water balance equations are described below for each component of the watershed. The term on the left of each equation is calculated as the net sum (i.e. residual) of all terms on the right of the equation – the right side terms being measured or estimated independently from the water balance. All terms are expressed as rates in units of m^3/s.

The water balance reconstruction starts with solving the component water balance for Swalwell Lake,

$$SL_{qIn} = SL_{qOut} + \Delta SL_{vol} + SL_e - SL_p \qquad (1)$$

where SL_{qIn} is inflow to Swalwell Lake, SL_{qOut} is Swalwell Lake outflow, ΔSL_{vol} is the change in Swalwell Lake storage, and SL_e and SL_p are evaporation and precipitation on Swalwell Lake. While flow from Crooked Lake likely comprises a large portion of SL_{qIn} during spring freshet, it also implicitly incorporates inflow from Echo Creek, lateral inflows/outflows (i.e. groundwater flow and localized seepage) to Swalwell Lake, and error in all other terms. After estimating inflow to Swalwell Lake using the Swalwell Lake water balance, inflow to Crooked Lake from the upper watershed area, CL_{qIn}, is estimated using the water balance for Crooked Lake,

$$CL_{qIn} = SL_{qIn} + \Delta CL_{vol} + Cl_e - CL_p \qquad (2)$$

where ΔCL_{vol} is the change in Crooked Lake storage, and Cl_e and CL_p are evaporation and precipitation on Crooked Lake. The Crooked Lake water balance is calculated after calculating the Swalwell Lake water balance, even though it is upstream from Swalwell Lake. This order is necessary due to limitations in the availability of Crooked Lake outflow data making it necessary to use calculated Swalwell Lake inflow (i.e. SL_{qIn}) as a first approximation of Crooked Lake outflow. In either event, the Crooked Lake water balance is not required for the current scope of the DSS and is not implemented in the water balance simulation (Section 1.2); however, it was incorporated in the water balance reconstruction for potential future objectives pertaining to management of Crooked Lake water levels. After reconstruction of the component water balances for Swalwell and Crooked lakes, the water balance is solved for Upper Vernon Creek (UVC) between Swalwell and Ellison lakes using equation 3,

$$UV_{qLat} = EL_{qIn} + UV_{divDLC} + UV_{divOld} + UV_{divNew} - UV_{HW} - SL_{qOut} \tag{3}$$

where UV_{qLat} is net lateral inflow (i.e. groundwater flow and localized seepage) to UVC between Swalwell and Ellison lakes, including inflow from Clark Creek; EL_{qIn} is UVC inflow to Ellison Lake; UV_{divDLC}, UV_{divOld}, and UV_{divNew} are diversion rates for the District of Lake Country (DLC), historical licensed diversions, and current licensed diversions; UV_{HW} is the historical bypass flow from Okanagan Lake to UVC via the Hiram Walker facility, and SL_{qOut} is outflow from Swalwell Lake. UV_{qLat} is known to be negative (i.e. net outflow) at times due to large losses to groundwater outflow. The Ellison Lake water balance is subsequently solved using equation 4,

$$EL_{qLat} = EL_{qOut} + \Delta EL_{vol} + EL_{divEld} + EL_e - EL_p - EL_{qIn} \tag{4}$$

where EL_{qLat} is net lateral inflow to Ellison Lake, EL_{qOut} is Middle Vernon Creek (MVC) outflow from Ellison Lake, ΔEL_{vol} is the change in lake volume, EL_{divEld} is the diversion from Ellison Lake for Eldorado Ranch, EL_e and EL_p are evaporation and precipitation on Ellison Lake, and EL_{qIn} is UVC inflow to Ellison Lake. EL_{qLat} is also known to be negative at times, particularly during dry periods when lateral inflow (e.g. seepage, inflow from small tributaries along the lake) is exceeded by losses to groundwater outflow in the direction of MVC. The final component water balance is for MVC between Ellison Lake and Reimche Road,

$$MV_{qLat} = MV_{qR} + MV_{div} - EL_{qOut} \tag{5}$$

where MV_{qLat} is net lateral inflow to MVC, MV_{qR} is MVC flow at Reimche Road, and MV_{div} are diversion rates for licensed diversions on MVC.

After calculating the component water balances for the period of interest, the reconstructed water balance data are stored for use in the water balance simulation phase.

1.2 Water Balance Simulation

After the historical water balance is reconstructed for the watershed, as described in section 1.1, the water balance and management regime data are sent to the water balance simulation module for predicting the impacts of an altered water management regime on flows and lake levels at various locations in the watershed. Figure 2 outlines the simulation process.

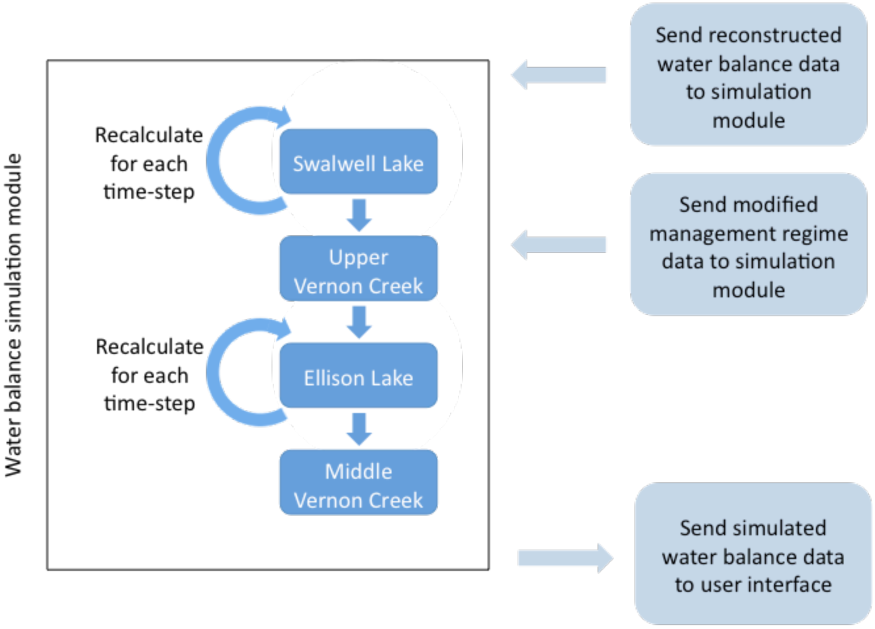

Figure 2. Flow chart describing the process for simulating the water balance of an alternative water management regime.

Similar to the reconstruction module, the simulation module is comprised of a hierarchy of component water balances for individual portions of the watershed, and data from each prior component feeds into a subsequent component. For the water balance equations described below, only new terms are defined and those with the subscripts "User" or "Sim" are user defined or simulated quantities, respectively.

The water balance simulation starts with simulating the component water balance for Swalwell Lake,

$$\Delta SL_{volSim} = SL_{qIn} + SL_{pSim} - SL_{eSim} - SL_{qOutSim} \quad (6)$$

where ΔSL_{volSim} is the simulated change in Swalwell Lake volume, SL_{pSim} and SL_{eSim} are simulated precipitation and evaporation on Swalwell Lake, and $SL_{qOutSim}$ is the simulated outflow from Swalwell Lake. As discussed in Section 1.1, the Crooked Lake water balance is not implemented in the water balance simulation as it is not required for the current scope of the DSS; however, its exclusion does not limit simulation of the downstream water balance because all flow from Crooked Lake is accounted for as a portion of the inflow to Swalwell Lake (i.e. SL_{qIn}). Because the rates of precipitation and evaporation on Swalwell Lake vary with lake surface area (i.e. rate in units of m^3/s is the product of precipitation or evaporation depth and lake surface area), the module steps through the Swalwell Lake water balance on a daily basis. It calculates the water balance for each day using the simulated lake surface area and volume (via simulated lake water level and corresponding surface area and volume lookup tables; Figure 3) from the end of the previous day coupled with current-day values for all other terms. For the first date of the simulation period, the initial lake surface area and volume default to the previous day's values from the historical dataset, but can be specified by the user via an alternative initial lake water level. $SL_{qOutSim}$ is the sum of the Swalwell Lake pipe outflow ($SL_{qOutPPUser}$; defaults to 0.1 m^3/s in the absence of a user defined quantity), which is regulated by DLC, and the Swalwell Lake spillway discharge ($SL_{qOutSWSim}$).

$$SL_{qOutSim} = SL_{qOutPPUser} + SL_{qOutSWSim} \tag{7}$$

$SL_{qOutSim}$ is limited from exceeding 10 m^3/s to ensure that unrealistic flows cannot be generated (historical maximum is 7.7 m^3/s). The spillway discharge is estimated using a stage-discharge rating curve (Figure 4). The rating curve can be defined by the user in the input data files. Available rating curve relations include linear, power law, and polynomial (up to 3rd order). For polynomial rating curves, the user must define minimum water level thresholds for flow over the spillway and for applying the stage-discharge rating curve. The simulation module interpolates flow linearly with water level between these points.

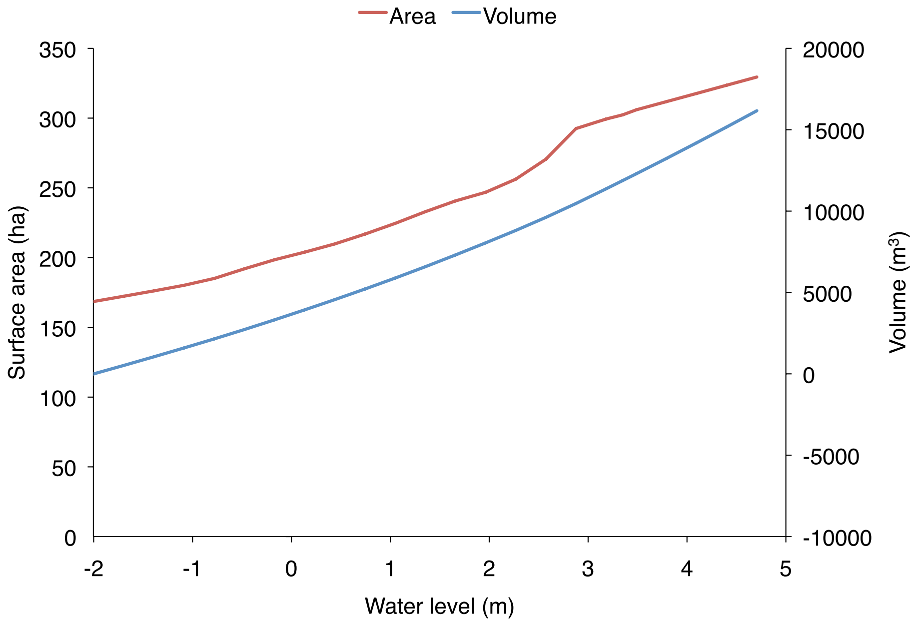

Figure 3. Graphical representation of the lookup table data for Swalwell Lake.

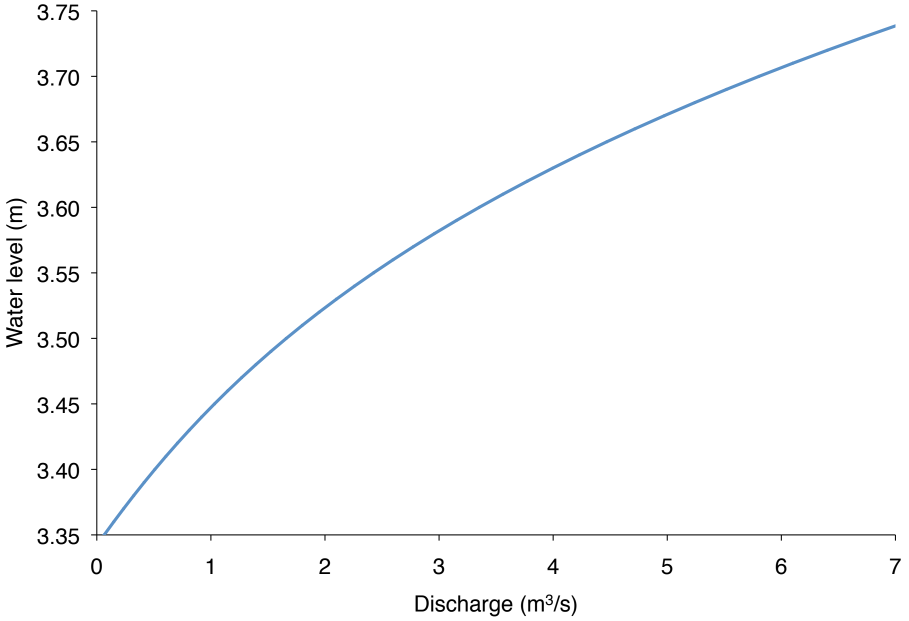

Figure 4. Stage-discharge rating curve for the Swalwell Lake spillway.

After simulating the Swalwell Lake water balance, the water balance is simulated for UVC between Swalwell and Ellison lakes using equations 7 through 9,

$$UV_{qLatDLCSim} = SL_{qOutSim} + UV_{qLat} - UV_{divDLCUser} \qquad (8)$$

$$UV_{qOthSim} = UV_{qLatDLCSim} - UV_{divOthUser} \qquad (9)$$

$$EL_{qInSim} = UV_{qOthSim} - UVMV_{qBPUser} \qquad (10)$$

where $UV_{qLatDLCSim}$ is UVC flow after accounting for lateral inflows along the reach (including Clark Creek flows) and the user defined DLC diversions ($UV_{divDLCUser}$), $UV_{qOthSim}$ is UVC flow after accounting for user defined diversions other than DLC diversions ($UV_{divOthUser}$), and EL_{qInSim} is UVC flow into Ellison lake after accounting for the user defined bypass flow from UVC to MVC ($UVMV_{qBPUser}$). $UV_{divOthUser}$ defaults to zero instead of the historical or current licensed diversion rates (i.e. UV_{divOld} and UV_{divNew} from equation 3), but can be adjusted in the user interface. Three successive equations are used so that the diversions can be limited at each step by flow availability. The Ellison Lake water balance is subsequently simulated using equation 10,

$$\Delta EL_{volSim} = EL_{qInSim} + EL_{qLat} + EL_{qOthUser} + EL_{pSim} - EL_{eSim} - EL_{divEldSim} - EL_{qOutSim} \qquad (11)$$

where ΔEL_{volSim} is the simulated change in Ellison Lake volume , $EL_{qOthUser}$ is user defined pumping inputs to Ellison Lake, EL_{pSim} and EL_{eSim} are simulated precipitation and evaporation on Ellison Lake, EL_{divEld} is the Eldorado Ranch diversion, and $EL_{qOutSim}$ is the simulated outflow from Ellison Lake. $EL_{qOthUser}$ defaults to zero instead of the rate of the historical bypass flow from Okanagan Lake to UVC via the Hiram Walker facility (i.e. UV_{HW} in equation 3); however, the historical Hiram Walker discharge inputs can be represented in the user interface as pumping inputs to Ellison Lake. The module steps through the Ellison Lake component water balance on a daily basis and calculates precipitation and evaporation on Ellison Lake similarly to that for Swalwell Lake. It also uses lookup tables for surface area and volume relationships with water level (Figure 5). Outflow from Ellison Lake is estimated using stage-discharge rating curves for the sandbag dam (Figure 6). The rating curves are handled similar to that for the Swalwell spillway, with the same options for defining the relations. An unlimited quantity of rating curves can be defined for each year within the raw data files and can be subsequently selected by the user on a weekly basis within the UI. Ellison outflow is limited from exceeding 10 m^3/s to ensure that unrealistic flows cannot be generated (historical maximum is 7.2 m^3/s)..

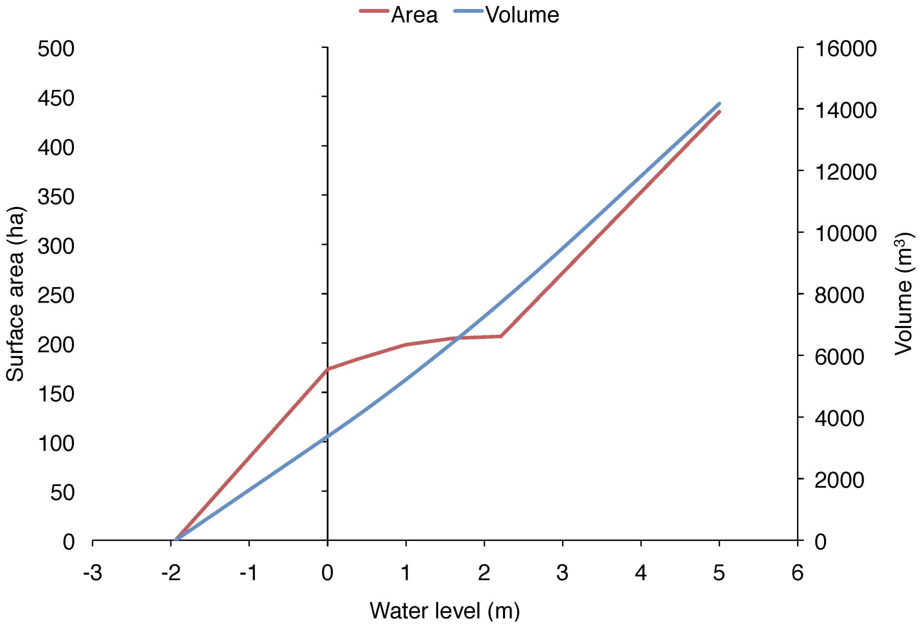

Figure 5. Graphical representation of the lookup table data for Ellison Lake.

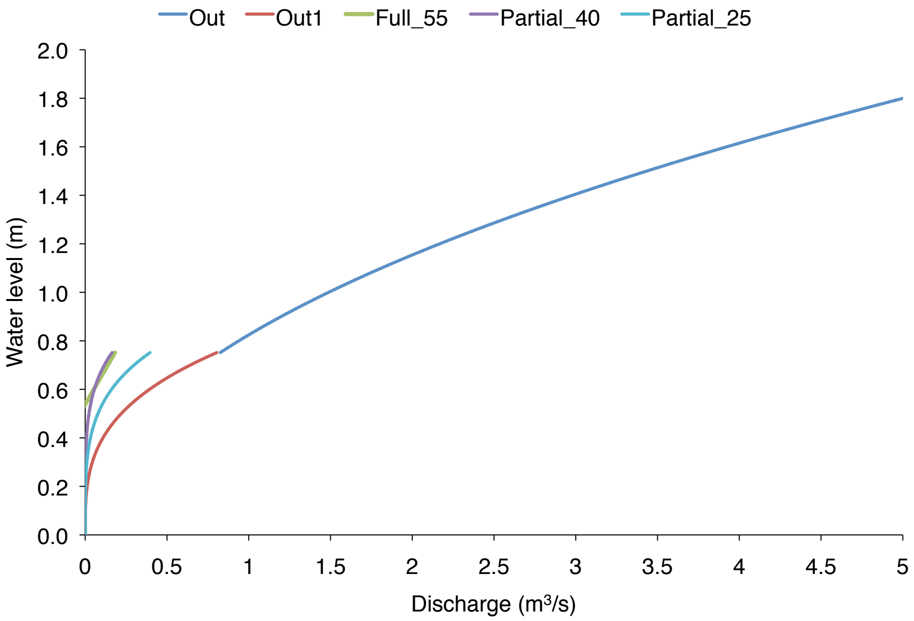

Figure 6. Stage-discharge rating curves for various 2013 configurations of the Ellison Lake sandbag dam. The y-axis extent for each rating curve is limited to the respective range of applicability.

After simulating the Ellison Lake water balance, the water balance is simulated for MVC between Ellison Lake and Reimche Road using equations 11 and 12,

$$MV_{qSim} = EL_{qOutSim} + UVMV_{qBPUser} + MV_{qOthUser} + MV_{qLat} \tag{12}$$

$$MV_{qRSim} = MV_{qSim} - MV_{div} \tag{13}$$

where MV_{qSim} is MVC flow after accounting for the user defined bypass flow from UVC to MVC, user defined pumping inputs to MVC ($MV_{qOthUser}$), and lateral inflows along the stream reach; and MV_{qRSim} is MVC flow at Reimche Road after accounting for licensed diversions along the reach. Similar to UVC, two successive equations are used so that the diversions can be limited at each step by flow availability.

After the water balance is simulated for the entire watershed, the simulated data are sent to the user interface for outputting.

1.3 Model Limitations

Users of the MVC DSS should be aware of several limitations that can impact the accuracy of the reconstructed and simulated water balance output. The most significant limitations are identified below.

- The accuracy of the simulated outflows over the Swalwell Lake spillway and the Ellison Lake sandbag dam are highly sensitive to how well the corresponding rating curves represent the stage-discharge relationships for the period(s) of simulation.

- MVC between Ellison Lake and Reimche Road has a long history of beaver activity that has impacted the accuracy of the corresponding discharge measurements to varying degrees. It also has impacted the stage-discharge relationships at the sandbag dam for some periods. Both of these factors can impact accuracy.
- The accuracy of the historical water balance data varies due to periodic changes that have occurred to the hydrologic monitoring programs within the watershed. As a result, the accuracy of the output varies accordingly.
- The user defined management data and the output data are represented as weekly values for user simplicity and to average out potential errors in the historical data; however, hydrological processes and real-world management actions do not operate at weekly intervals. This discrepancy can impact accuracy, particularly during high flow periods.

2 Ranking of Annual Hydrological Data

Ranking of annual hydrological statistics for the historical dataset are provided below. The results are provided as a resource for DSS users to use when selecting suitable simulation periods for meeting the particular objectives/goals for each simulation. As such, no interpretation and/or discussion of the results is provided. Results for 2012 and 2013 are excluded from several rankings, as appropriate, due to data limitations for late fall, winter, and early spring periods.

Table 1: Ranking of annual minimum flows (m^3/s) for Swalwell Lake, Ellison Lake, and MVC at Reimche Road.

Rank	Year	Minimum Swalwell Outflow	Year	Minimum Ellison Outflow	Year	Minimum Reimche Flow
1	1977	0.005	1977	-0.024	1977	0.001
2	1973	0.008	1975	-0.017	1975	0.008
3	1972	0.010	1979	-0.015	1979	0.010
4	1974	0.010	1978	-0.004	1978	0.021
5	1979	0.013	1974	0.001	1976	0.034
6	1975	0.015	1976	0.009	1974	0.042
7	1976	0.025	1973	0.020	1973	0.062
8	1978	0.054	1972	0.133	1972	0.153

Table 2: Ranking of annual mean flows (m^3/s) for Swalwell Lake, Ellison Lake, and MVC at Reimche Road.

Rank	Year	Mean Swalwell Outflow	Year	Mean Ellison Outflow	Year	Mean Reimche Flow
1	1974	0.68	1974	0.80	1974	0.84
2	1976	0.57	1972	0.66	1972	0.66
3	1972	0.53	1976	0.58	1976	0.61
4	1978	0.47	1978	0.53	1978	0.55
5	1975	0.44	1977	0.39	1977	0.42
6	1977	0.43	1975	0.35	1975	0.38
7	1979	0.40	1979	0.30	1979	0.33
8	1973	0.28	1973	0.19	1973	0.22

Table 3: Ranking of annual maximum flows (m^3/s) for Swalwell Lake, Ellison Lake, and MVC at Reimche Road.

Rank	Year	Maximum Swalwell Outflow	Year	Maximum Ellison Outflow	Year	Maximum Reimche Flow
1	1974	7.7	1974	7.3	1974	7.3
2	1975	6.0	2012	5.3	1977	5.0
3	1976	5.0	1977	5.0	1975	4.7
4	1977	4.2	1975	4.7	1978	4.3
5	1972	3.7	1978	4.2	1972	3.9
6	1978	3.4	1972	4.2	2013	3.6
7	2013	3.3	1976	3.5	1976	3.5
8	1979	2.6	2013	3.0	2012	3.1
9	2012	1.8	1979	1.9	1979	2.0
10	1973	0.9	1973	1.1	1973	1.2

Table 4: Ranking of annual minimum water levels (m) for Swalwell and Ellison Lakes.

Rank	Year	Minimum Swalwell Water Level	Year	Minimum Ellison Water Level (local datum)	Minimum Ellison Water Level (sea level datum)
1	1972	0.707	1979	0.577	424.475
2	1974	0.762	1973	0.653	424.551
3	1979	1.299	1972	0.659	424.557
4	1975	1.341	1978	0.686	424.584
5	1973	1.372	1977	0.695	424.593
6	1978	1.649	1974	0.698	424.596
7	1977	1.701	1975	0.774	424.672
8	1976	2.170	1976	0.854	424.752

Table 5: Ranking of annual maximum water levels (m) for Swalwell and Ellison Lakes.

Rank	Year	Maximum Swalwell Water Level	Year	Maximum Ellison Water Level (local datum)	Maximum Ellison Water Level (sea level datum)
1	2013	3.875	1974	2.301	426.199
2	1978	3.871	1975	2.009	425.907
3	1979	3.847	1972	1.914	425.812
4	2012	3.799	1977	1.853	425.751
5	1977	3.798	1976	1.835	425.733
6	1974	3.780	1978	1.756	425.654
7	1976	3.734	1979	1.658	425.556
8	1975	3.703	2013	1.397	425.295
9	1972	3.490	1973	1.317	425.215
10	1973	3.328	2012	1.296	425.194

Table 6: Ranking of annual total precipitation and evaporation (mm) for Ellison Lake.

Rank	Year	Total Ellison Precipitation	Year	Total Ellison Evaporation
1	1978	388	1979	898
2	1976	358	1973	882
3	1975	357	1974	869
4	1972	354	1977	857
5	1974	342	1975	845
6	1973	318	1972	823
7	1977	299	1978	822
8	1979	232	1976	776

Table 7: Ranking of the timing of first spill for the Swalwell spillway.

Rank	Year	Timing of First Spill (Day of Year)	Timing of First Spill (Date)
1	1977	119	29-Apr-77
2	1979	128	8-May-79
3	1976	130	9-May-76
4	1974	133	13-May-74
5	1978	133	13-May-78
6	1975	144	24-May-75
7	1972	145	24-May-72
8	1973	NA	NA