# Powell Operational Rules Outline for the Midterm Probabilistic Model

Revisions:

* Rev. 1, 23 July 2010 *Cameron Bracken*
* Rev. 2, 26 July 2010 *Cameron Bracken*
* Rev. 2, 27 July 2010 *Cameron Bracken*
* Rev. 3, 29 July 2010 *Cameron Bracken*
* Rev. 4, 12 August 2010 *Cameron Bracken*
* Rev. 5, 19 August 2010 *Cameron Bracken*

## Data

### Data Object

PowellData

* Steady Flow Experiment October Minimum Release = 492 kaf
* Non Steady Flow Experiment October Minimum Release = 600 kaf
* November Minimum Release = 700 kaf
* December Minimum Release = 800 kaf

Table 1: Powell Monthly Disaggregations (in KAF) of Annual Release Volumes. Patterns taken from FEIS.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Annual Volume (MAF)** | **7.0** | **7.48** | **7.8** | **8.23** | **9.0** | **9.5** |
|
| **OCT** | 600 | 600 | 600 | 600 | 600 | 600 |
| **NOV** | 600 | 500 | 600 | 600 | 600 | 600 |
| **DEC** | 800 | 600 | 600 | 800 | 800 | 800 |
| **JAN** | 662 | 800 | 800 | 800 | 800 | 850 |
| **FEB** | 540 | 600 | 600 | 600 | 650 | 650 |
| **MAR** | 450 | 600 | 600 | 600 | 650 | 650 |
| **APR** | 450 | 450 | 600 | 600 | 600 | 650 |
| **MAY** | 450 | 530 | 600 | 600 | 650 | 800 |
| **JUN** | 540 | 600 | 600 | 650 | 800 | 900 |
| **JUL** | 720 | 800 | 800 | 850 | 1000 | 1050 |
| **AUG** | 720 | 800 | 800 | 900 | 1050 | 1100 |
| **SEP** | 468 | 600 | 600 | 630 | 800 | 850 |

Table : Powell Monthly Disaggregations (in KAF) of Annual Release Volumes. Patterns extrapolated from the difference between 9.0 and 9.5 MAF and modified to fit environmental and bypass restrictions.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Annual Volume (MAF)** | **10.0** | **10.5** | **11.0** | **11.5** | **12.0** | **12.5** | **13.0** | **13.5** | **14.0** | **14.5** | **15.0** | **15.5** | **16.0** |
|
| **OCT** | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 |
| **NOV** | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 |
| **DEC** | 800 | 850 | 850 | 850 | 850 | 850 | 850 | 850 | 850 | 850 | 850 | 850 | 850 |
| **JAN** | 900 | 900 | 900 | 900 | 900 | 900 | 900 | 900 | 900 | 900 | 1050 | 1050 | 1050 |
| **FEB** | 650 | 650 | 700 | 800 | 800 | 800 | 800 | 800 | 900 | 900 | 900 | 900 | 900 |
| **MAR** | 650 | 650 | 700 | 800 | 900 | 950 | 950 | 950 | 1090 | 1090 | 1090 | 1090 | 1090 |
| **APR** | 700 | 750 | 900 | 1000 | 1000 | 1050 | 1100 | 1225 | 1485 | 1485 | 1485 | 1485 | 1485 |
| **MAY** | 950 | 1000 | 1050 | 1100 | 1050 | 1150 | 1250 | 1535 | 1535 | 1535 | 1535 | 1535 | 1535 |
| **JUN** | 1000 | 1150 | 1200 | 1225 | 1225 | 1285 | 1395 | 1485 | 1485 | 1485 | 1485 | 1685 | 2085 |
| **JUL** | 1100 | 1200 | 1250 | 1300 | 1440 | 1535 | 1535 | 1535 | 1535 | 1735 | 1910 | 2010 | 2010 |
| **AUG** | 1150 | 1200 | 1250 | 1275 | 1535 | 1535 | 1535 | 1535 | 1535 | 1735 | 1910 | 2010 | 2010 |
| **SEP** | 900 | 950 | 1000 | 1050 | 1100 | 1245 | 1485 | 1485 | 1485 | 1585 | 1585 | 1685 | 1785 |

Blue indicates max environmental flows =25,000 cfs steady for entire month.

Red indicates that bypass flows are included.

Table 3: Lake Powell Equalization Elevation Table

|  |  |
| --- | --- |
| **Water Year** | **Elevation (feet)** |
| 2008 | 3636 |
| 2009 | 3639 |
| 2010 | 3642 |
| 2011 | 3643 |
| 2012 | 3645 |
| 2013 | 3646 |
| 2014 | 3648 |
| 2015 | 3649 |
| 2016 | 3651 |
| 2017 | 3652 |
| 2018 | 3654 |
| 2019 | 3655 |
| 2020 | 3657 |
| 2021 | 3659 |
| 2022 | 3660 |
| 2023 | 3662 |
| 2024 | 3663 |
| 2025 | 3664 |
| 2026 | 3666 |

Table 4: Powell Release Tiers

|  |  |
| --- | --- |
| **Projected Powell Jan1 Elevation** | **Tier** |
| >= Eq. Level for WY | Equalization |
| < Eq. Level and >= 3575 ft. | Upper Elevation Balancing |
| < 3575 ft. and >= 3525 | Mid-Elevation Release |
| < 3525 ft. | Lower Elevation Balancing |

Table 5: Releases for steady flow experiment

|  |  |
| --- | --- |
| Annual Volume (MAF) | Oct/Nov Steady flow (cfs) |
| ≤ 9 | 8000 |
| 10 | 10000 |
| 11 | 12000 |
| 12 | 16000 |
| 13 | 18000 |
| 14 | 22000 |
| 15 | 25000 |

### Required User Data Input

* Steady Flow experiment year flag
* First Year Teir

## Rules

In order of priority

### Set Steady Flow Experiment Release

*Execution Constraint*: Current year is a steady flow experiment year (user input)

*Description*: This rule uses the monthly reductions calculated from the previous and subtracts these reductions from the already set monthly releases. It also sets October to the steady flow release in the first place as well as setting september release according to the steady flow experiment guidelines in Table 5.

IF October

Powell.Outflow[] = Powell.Outflow[t-1]

IF September

Set accoring to steady flow guidelines

ELSE April – August

Powell.Outflow[] = Powell.Outflow[] – Monthly reduction

This rule is designed to run independently of the normal outflow rule so that if it is turned off the outflow is still set correctly.

*Slots Set*:

Powell.Outflow

### Set Steady Flow Reductions

*Execution Constraint*: Current year is a steady flow experiment year (user input), Month is April.

*Description*: The release in September and October must be steady and equal according to . This may require reductions to meet the annual volume requirement. Reductions are made in the following order:

1. Reduce July to 800 kaf
2. Reduce August to 800 kaf
3. Reduce June to 800
4. Reduce June to 600
5. Reduce April to 500
6. Reduce May to 500

In October set the steady flow experiment release to be equal to September. In April look ahead and calculate the amount of reduction required in July, August, June, May, and April based on the reduction order above. The idea is to go backwards starting from July and add reductions to each monthly volume until there is no more need to reduce (ie, the minthly releases sum up to the preset annual release).

There are two basic forms of functions used to calcualte the monthly reductions. The first is for the first (July) reduction where it is checked if reduction is necessary and if not, then the excess water is put in July.

IF the release with the steady flow restriction is greater than the annual release volume then

Min(Release Difference, Amount to reduce July to 800 KAF)

ELSE

Put the excess water in July

For the other months (August, June, April and May) the functions look similar without the check

Min(Release Difference – amount previously reduced, Amount to reduce month X to Y KAF)

This rule is designed to run independently of the normal outflow rule so that if it is turned off the outflow is still set correctly.

*Slots Set*:

PowellSteadyFlowExperiment.1\_ReduceJuly

PowellSteadyFlowExperiment.2\_ReduceAugust

PowellSteadyFlowExperiment.3\_ReduceJune\_1

PowellSteadyFlowExperiment.4\_ReduceJune\_2

PowellSteadyFlowExperiment.5\_ReduceApril

PowellSteadyFlowExperiment.6\_ReduceMay

### Set Powell Outflow

*Execution Constraint*: None

*Description*: The Tier rules set the annual volume once in August. This rule simply looks up the monthly release volume from Table 1 or Table 2 interpolating if necessary.

Find the columns bracketing the actual annual release volume from the release volume table. Interpolate between columns depending on the month.

*Slots Set*:

Powell.Outflow

### Set Lower Elevation Balancing Release

*Execution Constraint*: Tier is Lower Balancing

*Description*: Release to equalize Powell and Mead. Ensure that the release is between 7 and 9.5 MAF. Release according to the set release patterns (interpolate in between limits if release is between 7 and 9.5 MAF).

Powell Annual Volume = EqualizationRelease()

*Slots Set*:

Powell.AnnualReleaseVolume

### Set Mid-Elevation Release

*Execution Constraint*: Tier is Mid Release

*Description*: If the Mead Jan1 projected elevation is greater than or equal to 1025 ft then release 7.48 MAF/yr, otherwise release 8.23 MAF/yr.

IF Mead.Elevation[Jan 1] >= 1025

Powell Annual Volume = 7.48 MAF

ELSE

Powell Annual Volume = 8.23 MAF

*Slots Set*:

Powell.AnnualReleaseVolume

### Set Upper Balancing April Only

*Execution Constraint*: Tier is Upper and Month is April

*Description*: In April it is possible to change the annual release volume when in the upper balancing tier. If the august projected Mead Jan 1 Elevation and the April Projected Mead EOWY elevation are greater than 1075 and the powell projected EOWY elevation is greater than 3575 then set the release to equalze the two reservoirs. Ensure the release is no greater than 9 MAF and no less than 8.23 MAF

IF Mead.Elevation[Jan1] > 1075 ft

AND Mead.Elevation[EOWY] > 1075 ft

AND Powell.Elevation[EOWY] > 3575

EnsureLimits(EqualizationRelease(),8.23,9)

*Slots Set*:

Powell.AnnualReleaseVolume

### Set Upper Balancing Release

*Execution Constraint*: Tier is Upper Balancing

*Description*: If the Mead EDWY elevation is less than 1075 ft. then release to equalize Mead and Powell storage by the end of the water year. Ensure that the release is between 7 and 9 MAF. If this release is greater than 8.23 then check that Oct, Nov, Dec volume is greater than 2 MAF.

If the Mead EDWY elevation is greater than or equal to 1075 ft then release 8.23. In April readjustment is allowed, though this rule will not need to check because the Tier will have already been reset to equalization if necessary. If the Mead end of water year elevation projected on April 1 is less than or equal to 1075 ft. and the Powell end of water year projected elevation is greater than or equal to 3575 ft. then release to equalize Mead and Powell storage by the end of the water year. Ensure that the release is between 8.23 and 9 MAF.

IF Mead.Elevation[Jan 1] >= 1075

Powell Annual Volume = 8.23 MAF

ELSE IF EqualizationRelease() >= 9 MAF

Powell Annual Volume = 9 MAF

ELSE IF EqualizationRelease() <= 7 MAF

Powell Annual Volume = 7 MAF

ELSE IF EqualizationRelease() >= 8.23 MAF

Powell Annual Volume = EqualizationRelease()

ELSE

# Need to check the OND Release

Powell Annual Volume = EqualizationRelease()

*Slots Set*:

Powell.AnnualReleaseVolume

### Set Equalization Release

*Execution Constraint*: Tier is Equalization

*Description*: Release steady to meet the Equalization level at end of water year or such that Powell and Mead storage are equal by the end of the water year. Release above this amount if necessary to avoid spills. If this release causes Mead elevation to be less than 1105 ft then increase release until the first of the following is met:

1. Powell Storage equals Mead storage at the end of the water year
2. Mead elevation is 1105 ft. at the end of the water year
3. Powell Elevation at the end of the water year is 20 feet below the equalization level.

IF Mead Equalization Elevation > 1105 ft

Powell Annual Volume = EqualizationRelease()

ELSE IF Mead Equalization Level Elevation > 1105 ft

Powell Annual Volume = EqualizationLevelRelease()

ELSE

Powell Annual Volume = EqualizationLevelMinus20FtRelease()

*Slots Set*:

Powell.AnnualReleaseVolume

### Reset Upper Tier to Equalization

*Execution Constraint*: April and Currently in Upper Balancing Tier

*Description*: If the current tier is upper and the projected Powell elevation on April 1 is greater than equalization level then change to Equalization tier.

*Slots Set*:

PowellData.ReleaseTier

### Set Release Tier

*Execution Constraint*: August

*Description*: Sets the Powell Release Tier for the next water year. Use the previously determined Jan1 elevation then look up the tier from . The teir determination along with the annual release volume will determine the release pattern for individual months.

IF Powell Jan 1 Elevaton > Equalization Level

Equalization

ELSE IF Powell Jan 1 Elevaton >= 3575

Upper

ELSE IF Powell Jan 1 Elevaton >= 3525

Mid

ELSE

Lower

*Slots Set*:

PowellData.ReleaseTier

### Project EDWY Conditions

*Execution Constraint*: This rule is only allowed to fire once

*Description*: Projects Powell and Mead end of water year (EDWY) elevation/storage. Also if the rule is ran in August, then the January 1 Powell elevation is projected as well. The end of water year elevation may be referenced in any month but the Jan1 elevation is only needed in August to set the release tier for the water year.

*Slots Set*:

PowellData.PowellEDWYElevation,

PowellData.PowellEDWYStorage,

PowellData.MeadEDWYElevation,

PowellData.MeadEDWYStorage

If August then set PowellData.PowellJan1Elevation

### Project EDWY Gains and Losses

*Execution Constraint*: This rule is only allowed to fire once

*Description*: Projects all the components of Powell and Mead’s gains and losses. These values are used in the “Project EDWY Conditions rule.” See the ProjectPowellEDWYElevation() and the ProjectMeadEDWYElevation() functions for full descriptions of all the components.

*Slots Set*:

PowellData.PowellForecastedInflowVolumeUntilEDWY, PowellData.PowellEstimatedReleaseVolumeUntilEDWY,

PowellData.PowellEstimatedEvapUntilEDWY,

PowellData.PowellEstimatedBankStorageUntilEDWY

PowellData.MeadInflowBelowUntilEDWY

PowellData.MeadGainsBelowPowellVolumeUntilEDWY

PowellData.MeadDemandsBelowUntilEDWY

PowellData.MeadEstimatedBankStorageUntilEDWY

PowellData.MeadEstimatedEvapUntilEDWY

PowellData.MohaveEstimatedEvapUntilEDWY

PowellData.MohaveEstimatedDeltaStorageUntilEDWY

PowellData.HavasuEstimatedEvapUntilEDWY

PowellData.HavasuEstimatedDeltaStorageUntilEDWY

### Assume 8.23 for Projections

*Execution Constraint*: This rule is only allowed to fire once

*Description*: Sets the preliminary annual release volume to 8.23 so that projections can be made.

*Slots Set*:

Powell.AnnualReleaseVolume

## Functions

NOTE: Only major functions are documented here,for information on minor functions and utility functions, see the RPL code and comments therein. Functions are numbered for reference but the order has no significance.

### EqualizationRelease()

*Description*: Release for the current month to equalize Powell and mead storage at the end of the WY. The end of water year storage in mead and powell already has the built into it an 8.23 release volume so half the difference between them will be the amount above or belo 8.23 to equalize the reservoirs at the end of the water year (approxamately because approxamate evap calcualtions are made).

AnnualReleaseVolume + (PowellEOWYStorage + MeadEOWYStorage)/2

### EqualizationLevelRelease() & EqualizationLevel20ftBelowRelease()

*Description*: These functions return the annual release volume necessary to draw down powell to the Equalization level and 20 feet below the equalization level respectively. These functions are used by the equalization rule.

EqualizationRelease() + Extra water to get to Eq level or 20 ft below

### ProjectPowellEDWYElevation()

*Description*: This function will return the end of water year elevation in Lake Powell, assuming Powell contines to release in its current pattern for the remaining portion of the year.

StorageToElevation(Powell Gains – Powell Losses)

**Powell Gains:**

* *Previous Storage* – The storage in Powell at the prevous timestep
* *Powell Inflow* – The total volume of inflow below Mead. This is calculated by summing the forecasted inflow volume into Powell from the current timestep to the End of the water year.

**Powell Losses:**

* *Release Volume*  – Total volume of release from Powell.
* *Evap* – An estimate of the total evap volume from Powell. Use the average surface area and multiply by the sum of the evap coefficients from the current time step to the end of the water year.
* *Bank Storage* – An estimate of the total bank storage loss from Powell. Bank storage is the change in storage less the evap times the bank storage coefficient.

### ProjectMeadEDWYElevation()

*Description*: This function will return the end of water year elevation in Lake Mead. Lake Mead is demand driven so release is the difference in total gains and losses below Mead.

StorageToElevation(Mead Gains – Mead Losses)

**Mead Gains:**

* *Previous Storage* – The storage in Mead at the prevous timestep
* *Inflow Below Mead* – The total volume of local inflow below Mead. This is calculated by summing all the local inflows in the “BelowMead” sub basin. Use the 24- month study function SumGainsBelowVolume()
* *Powell Release* – The total volume of release from Powell assuming operations continue
* *Inflow Between Powell and Mead* – The total volume of inflow between Powell and Mead

**Mead Losses:**

* *Demands Below Mead* – Total volume of demand below Mead. This is calculated by summing all the demands in the “BelowMead” sub basin. Use the 24 month study function SumAllDiversionsBelowVolume()
* *Mead Evap* – An estimate of the total evap volume from Mead. Use the average surface area and multiply by the sum of the evap coefficients from the current time step to the end of the water year.
* *Mead Bank Storage* – An estimate of the total bank storage loss from Mead. Bank storage is the change in storage less the evap times the bank storage coefficient.
* *Mohave Evap* – An estimate of the total evap volume from Mojave. Must use the Mojave rule curve and the evaporation coefficients to estimate a volume.
* *Mohave Regulation* – The total change in storage between the current timestep and the end of the water year in Mojave. Use a modiefied version of the 24 month study’s ComputeDeltaTargetStorage() function.
* *Havasu Evap* – An estimate of the total evap volume from Havasu. Must use the Havasu rule curve and the evaporation coefficients to estimate a volume.
* *Havasu Regulation* – The total change in storage between the current timestep and the end of the water year in Havasu. Use a modiefied version of the 24 month study’s ComputeDeltaTargetStorage() function.

### ProjectPowellJan1Elevation()

*Description*: This function returns the projected January 1 Powell elevation. All the involved calcualtions are done previously in the EOWY functions so only OND needs to be estimated.

Jan1Elevation = EOWYStorage

+ OND Inflow Volume

- Estimated OND Release volume

– Estimated OND Evap and Bank Storage.

### ProjectPowellJan1Elevation()

*Description*: This function returns the projected January 1 Mead elevation. All the involved calcualtions are done previously in the EOWY functions so only OND needs to be estimated.

Jan1MeadElevation =

MeadEOWYStorage

+ OND Powell release

+ OND Gains above Mead

+ OND gains below Mead

- OND Diversions Mead

– Estimated Mead OND Evap and Bank Storage

– Estimated Mohave OND Evap and Bank Storage

– Estimated Havasu OND Evap and Bank Storage

– Estimated Mohave OND Delta Storage

– Estimated Havasu OND Delta Storage