Screening Level Analysis for Reservoir Sediment Management

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ERDC
Engineer Research and Development Center

- Classification of Sediment Management Alternatives: Three Processes
  - Reducing the sediment yield from the watershed into the reservoir
  - Minimizing sediment deposition in the reservoir
  - Increasing or recovering volume by removing sediment previously deposited in the reservoir
- Estimation of Success based on Parameterization
- Estimating Trap Efficiency
- Using RESCON as a Screening tool for Reservoir Flushing

Why Empirical Methods?

- As engineers we love to build models (physical and/or numerical)
- We can dream up dozens of ways to manage sediment, but we can’t build a model for each one.
- How do we narrow down the list to just a few methods that have a reasonable change of success.

Trap Efficiency Methods

- From Measured survey data and water quality sampling
- Churchill (1948) developed a trap efficiency curve for settling basins, small reservoirs, flood retarding structures, semi-dry reservoirs, and reservoirs that are frequently sluiced.
- Brune (1953) developed an empirical relationship for estimating the long-term reservoir trap efficiency for large storage or normal pond reservoirs based on the correlation between the relative reservoir size and the trap efficiency.

Trap Efficiency Methods

- Both methods based on Tennessee Valley Authority reservoirs in the southeastern United States.
- A general guideline is to use the Brune method for large storage or normal ponded reservoirs and the Churchill curve for settling basins, small reservoirs, flood retarding structures, semi-dry reservoirs, or reservoirs that are continuously sluiced.

Brune Method of Sediment Trap Efficiency

From Morris and Fan (1998) Reservoir Sedimentation, McGraw-Hill

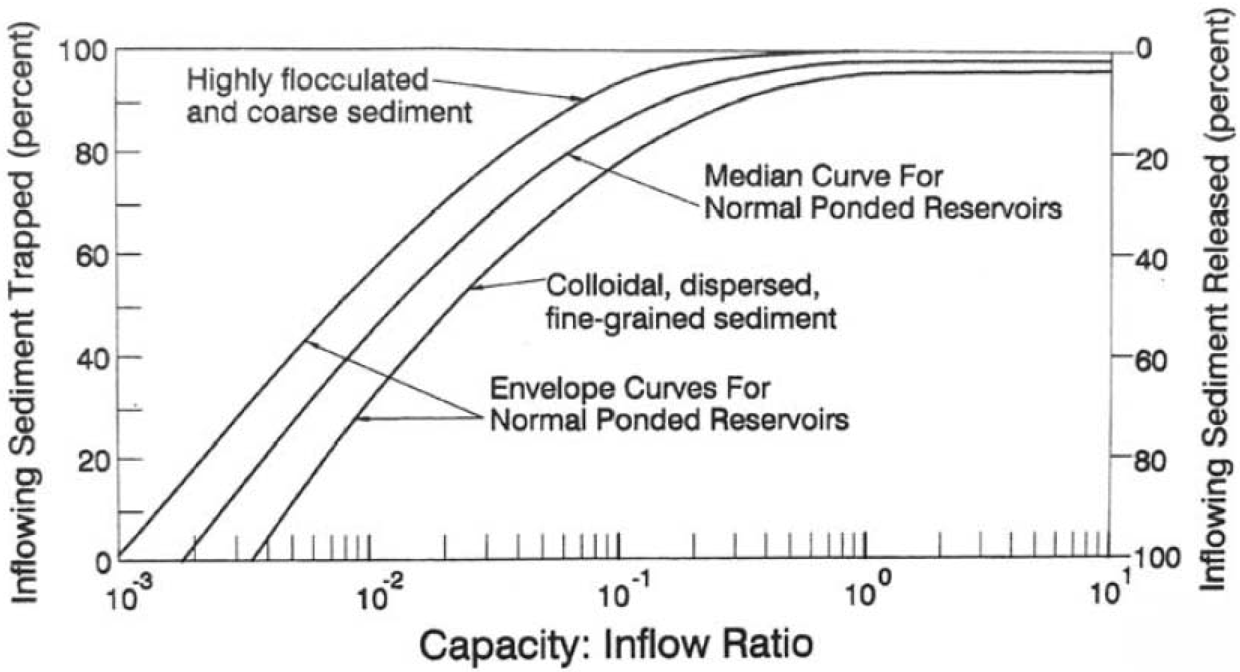
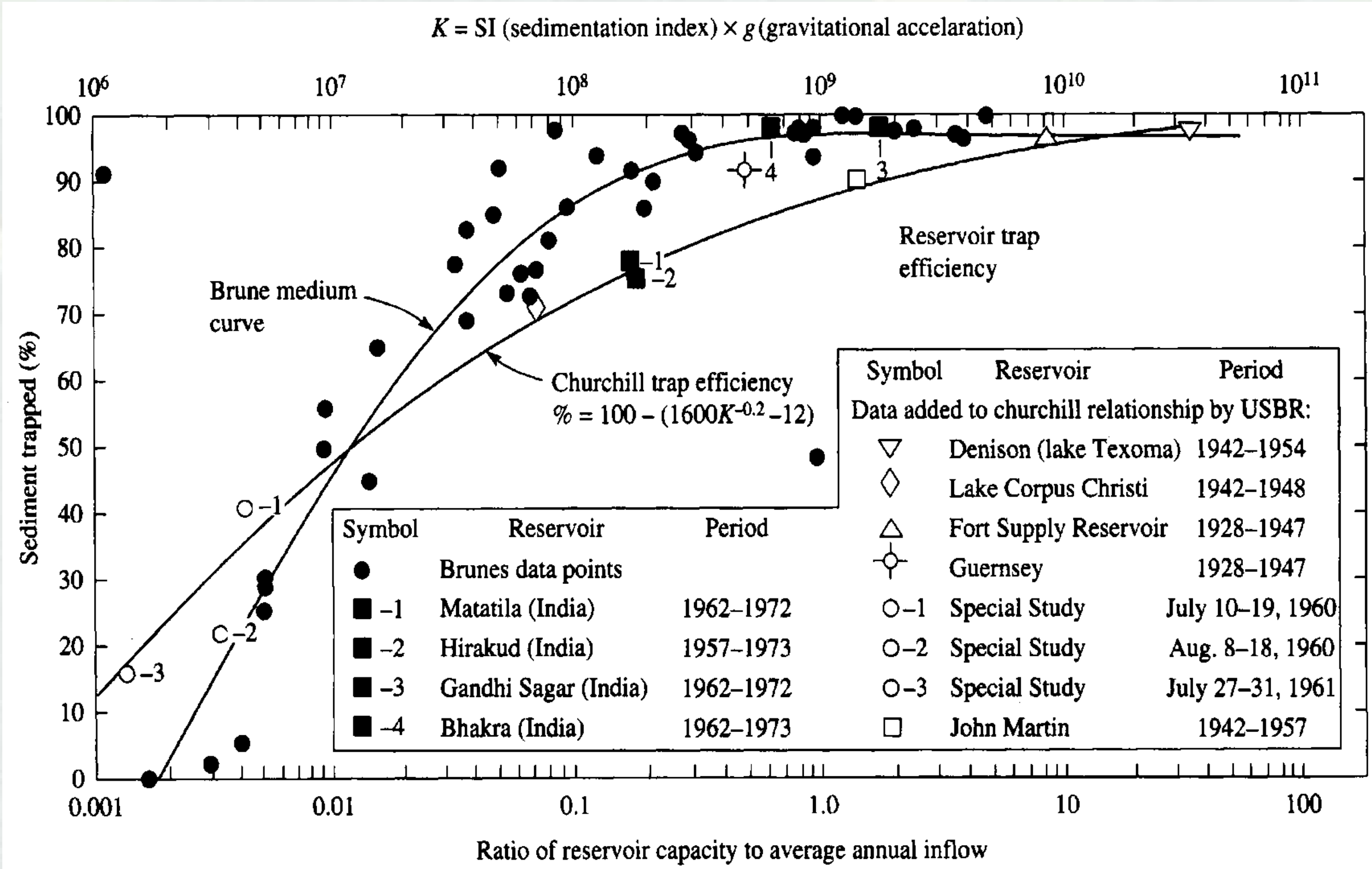


FIGURE 10.15 Brune curve for estimating sediment trapping or release efficiency in conventional impounding reservoirs *(adapted from Brune. 1953).*

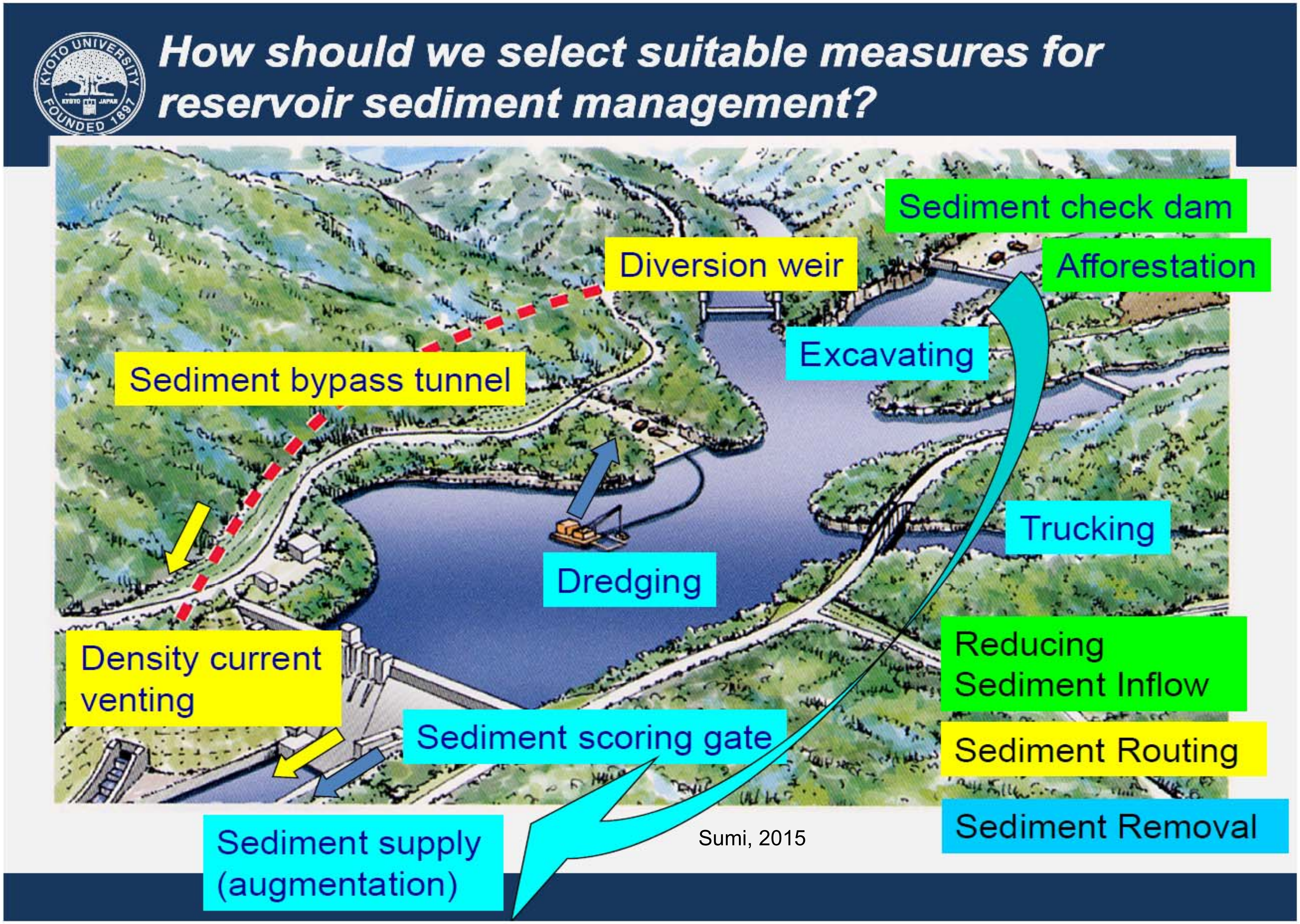
Churchill Method

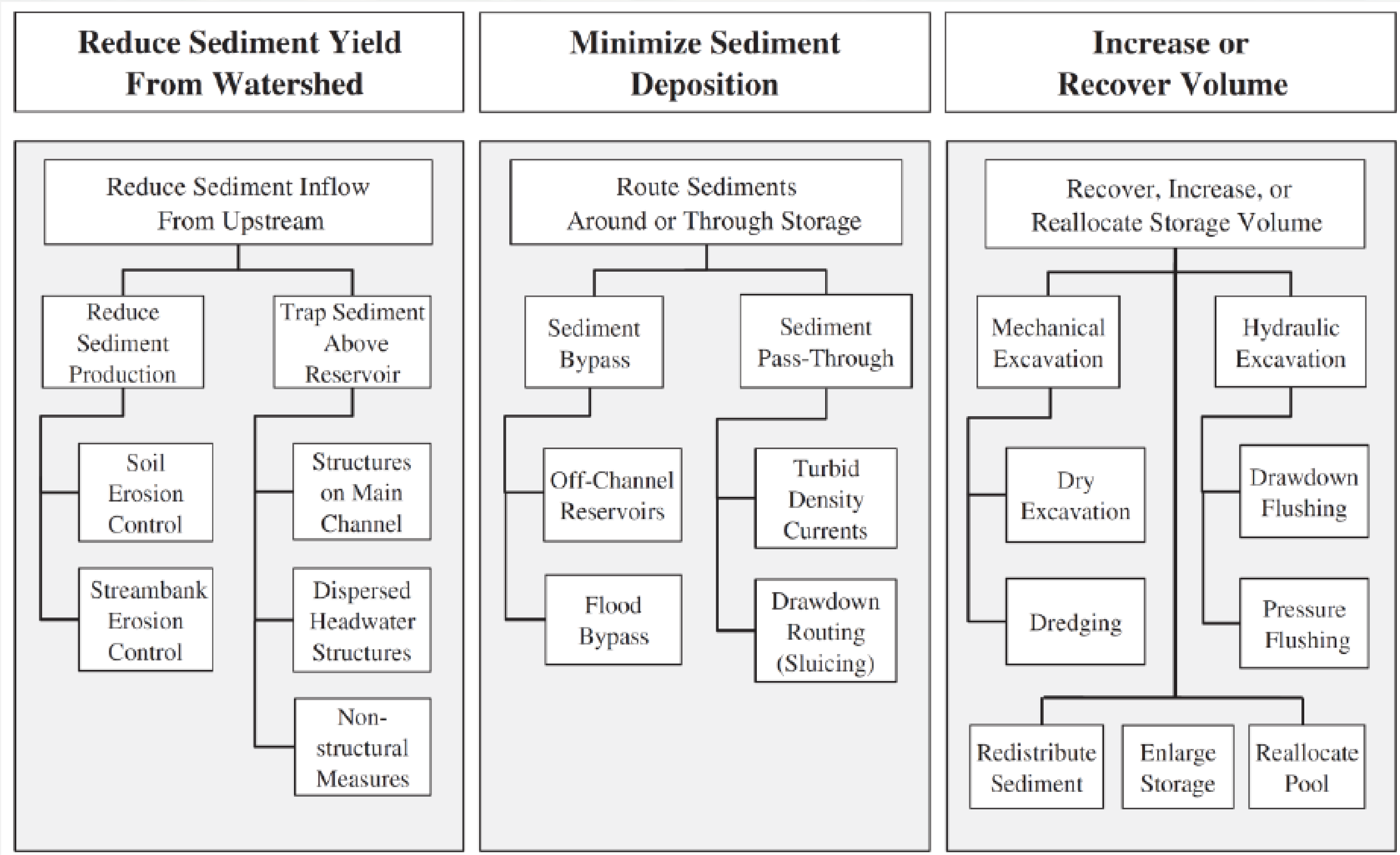
- Uses a relationship between the percent of incoming sediment passing through a reservoir and the sedimentation index of the reservoir
- The Churchill curve has been converted to a dimensionless expression by multiplying the sedimentation index by g, acceleration due to gravity.

Churchill **Reservoir Sediment Trap Efficiency**



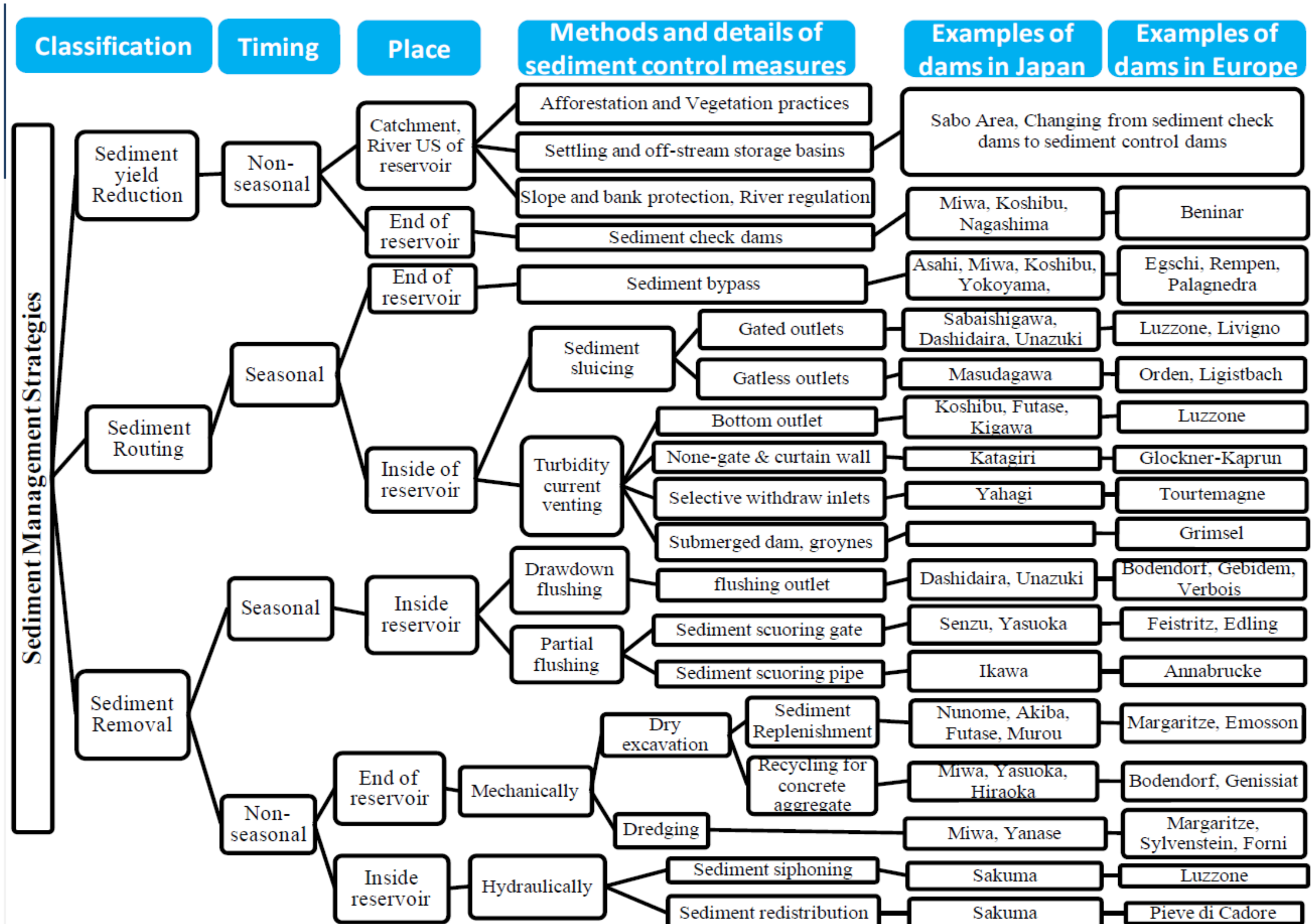
Review of Sediment Management Methods





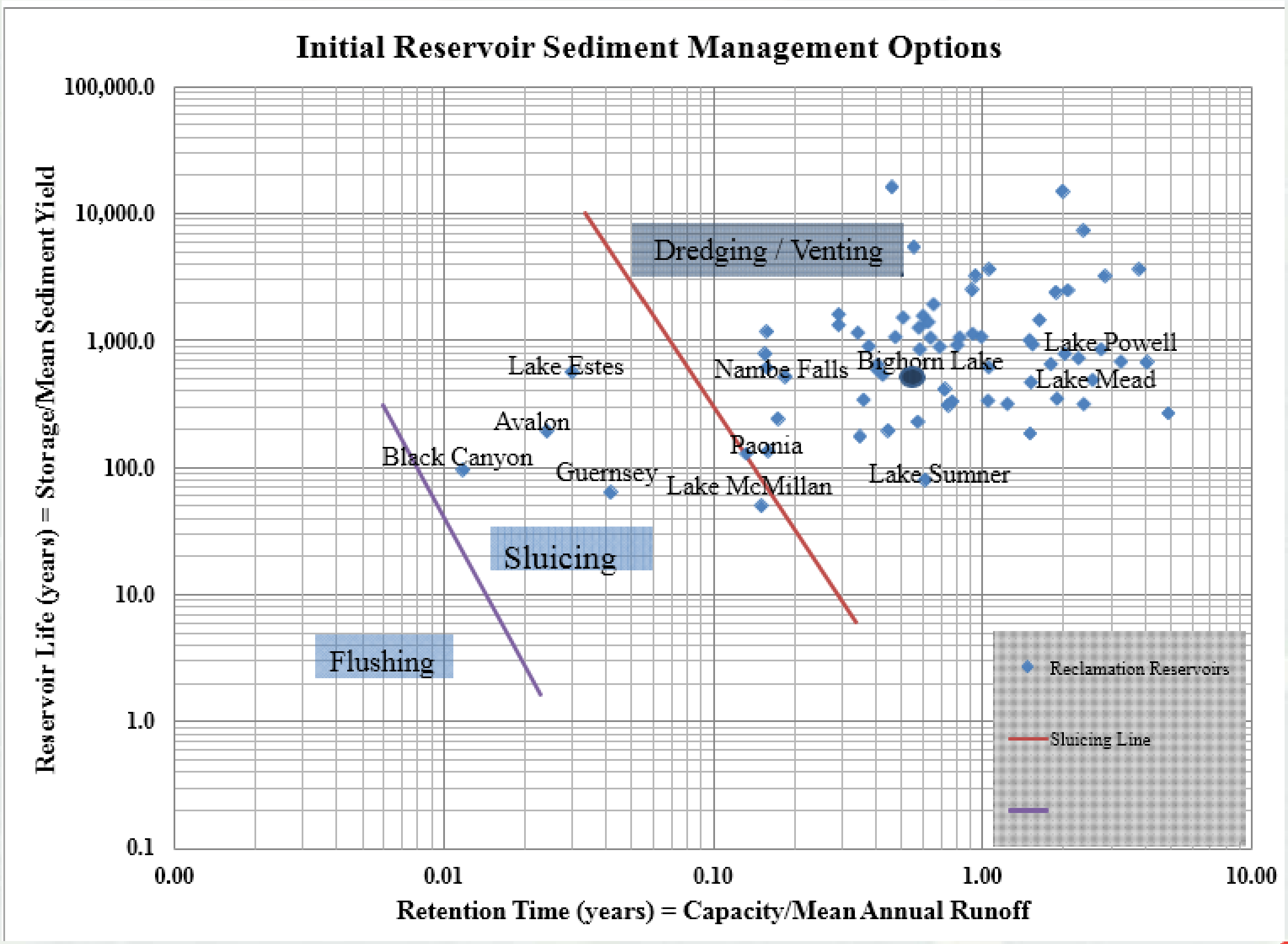
Kondolf, 2014

It can be done!



Source: T.Sumi and S.A. Kantoush ICOLD Annual Meeting, Luzern 2011

Basoon and Roseboom type plot



Kimbrel et al., 2015

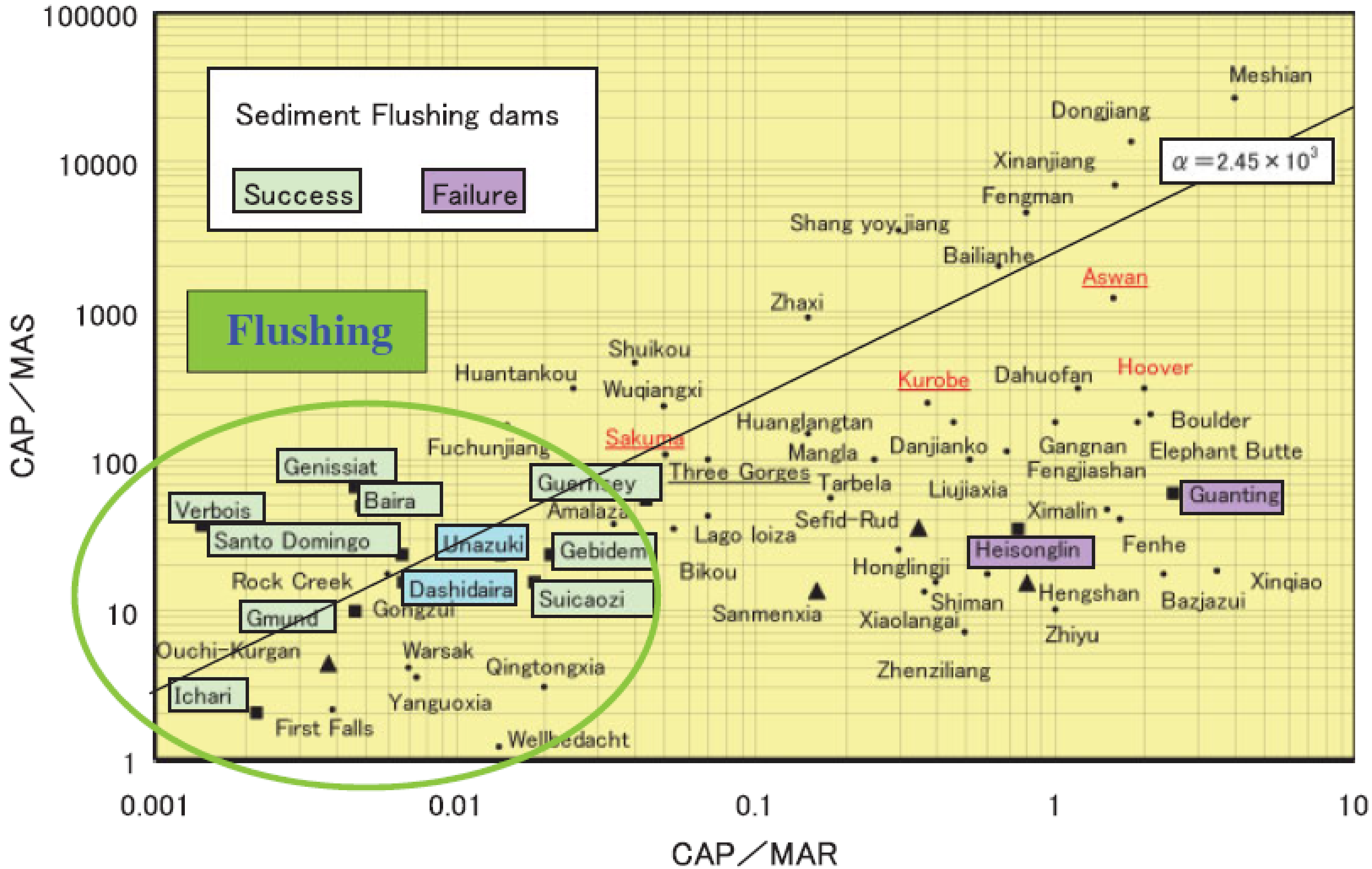


Figure 9. Plot of flushing projects from diverse environments showing that successful cases are characterized by impoundment ratios of 0.4 or less. That is, reservoir storage capacity divided by mean annual runoff (inflow to the reservoir) should be less than 0.4.

Kondolf, 2014

Research on an Economic and Engineering model on Reservoir Sedimentation Management (RESCON)

- The need existed for an economic framework that should respond to two key questions:
  - Are the extra costs of sediment management worthwhile in terms of extending the productive life of a reservoir?
  - It is economical to extend the life of a reservoir indefinitely?
- RESCON examines the economics of Flushing, dredging, Hydrosuction, and Trucking
- RESCON 2.0 includes Sluicing, Bypass, Density Current Venting and the ability to vary hydrologic parameters to account for climate change.

RESCON Workshop

- Background
  - ►Reservoir Conservation Toolkit for examining reservoir management
  - ►Developed in 2000-2003 primarily as a screening tool for reservoir economics
  - ►It is a useful first review of possible management techniques
  - ►**It is not a design tool, only a screening tool (primarily for reservoir flushing)**

RESCON Workshop

- Source Data
  - ► RESCON determines the efficiency of flushing based on the sediment balance ratio (SBR) from Atkinson (1996). The dataset from this paper has few data points from reservoirs with flushing activities
- Limitations
  - ► RESCON is a screening tool, which can help determine if flushing is possible, it does not provide information about the hydrograph, timing, or efficiency of a flush. A positive result in RESCON does not guarantee that flushing will be effective.

Disclaimer: This program has been produced in good faith to aid practitioners in the field to undertake initial screening of options at a pre-feasibility level. The program should be used by experienced practitioners and the results critically reviewed. The authors of this program cannot take any responsibility for decisions made based on the results it produces.

Directions for use:

1. Please make sure macros are activated.
2. User inputs should be made only in the worksheets named 'User Input (Checklist)' and 'User Input (Env. Safeguard)'. Do not make any changes to the other worksheets.
3. The information requested in the cells highlighted yellow must be provided. Default values are suggested in many cases, but the user should review these and make appropriate changes.

4. Input cells which are not highlighted do not require an input. The values reported in these cells are explained under "Description". The user is encouraged to provide their own estimates instead of the suggested default values. However, if the default is calculated with an equation, that equation will be lost when a new value is typed in the cell. To return to the default equations and values, click [GO BACK TO DEFALUT VALUE].

5. After entering all data (including Environmental Safeguards - if desired), press the calculate button.

6. Results are displayed under "Flushing Tech Results", "HSRS Tech Results" , and "Econ. Results & Conclusions."

Inputs are required in YELLOW cells

Reservoir Geometry

Parameter	Units	Description	Value
S_o	(m^3)	Original (pre-impoundment) capacity of the reservoir	709,621,270
S_e	(m^3)	Existing storage capacity of the reservoir	525,736,802
W_{bot}	(m)	Representative bottom width for the reservoir--use the widest section of the reservoir bottom near the dam to produce worst case for criteria	2,500.0
SS_{res}		Representative side slope for the reservoir. 1 Vertical to SS_{res} Horizontal.	1.0
EL_{max}	(m)	Elevation of top water level in reservoir--use normal pool elevation.	368.3
EL_{min}	(m)	Minimum bed elevation--this should be the riverbed elevation at the dam.	352.1
EL_f	(m)	Water elevation at dam during flushing - this is a function of gate capacity and reservoir inflow sequence. Lower elevation will result in a more successful flushing operation.	363
L	(m)	Reservoir length at the normal pool elevation.	25000
h	(m)	Available head--reservoir normal elevation minus river bed downstream of dam	16.2

Water Characteristics

V_{in}	(m^3)	Mean annual reservoir inflow (mean annual runoff)	28,384,760,000
Cv	(m^3)	Coefficient of Variation of Annual Run-off volume. Determine this from statistrical analysis of the annual runoff volumes	1
T	(^oC)	Representative reservoir water temperature	30.0

Sediment Characteristics

ρ_d	(tonnes/m^3)	Density of in-situ reservoir sediment. Typical values range between 0.9 - 1.35.	1.20
M_{in}	(metric tonnes)	Mean annual sediment inflow mass.	4,889,890
Ψ	1600, 650, 300, 180	Select from: 1600 for fine loess sediments; 650 for other sediments with median size finer than 0.1mm; 300 for sediments with median size larger than 0.1mm; 180 for flushing with Qf < 50 m^3/s with any grain size.	300
Brune Curve No	1 2 3	Is the sediment in the reservoir: (1) Highly flocculated and coarse sediment (2) Average size and consistency (3) colloidal, dispersed, fine-grained sediment	2
Ans	3 or 1	This parameter gives the model a guideline of how difficult it will be to remove sediments. Enter "3" if reservoir sediments are significantly larger than median grain size (d_{50}) = 0.1mm or if the reservoir has been impounded for more than 10 years without sediment removal. Enter "1" if otherwise.	3
Type	1 or 2	Enter the number corresponding to the sediment type category to be removed by hydrosuction dredging: 1 for medium sand and smaller; 2 for gravel.	1

Removal Parameters

HP	1 or 2	Is this a hydroelectric power reservoir? Enter 1 for yes; 2 for no.	1
Q_f	(m^3/s)	Representative flushing discharge. This should be calculated with reference to the actual inflows and the flushing gate capacities.	1,700
T_f	(days)	Duration of flushing after complete drawdown.	14
N	(years)	Frequency of flushing events (whole number of years between flushing events)	10
D	(feet)	Assume a trial pipe diameter for hydrosuction. Should be between 1 - 4 feet.	2.0
NP	1, 2, or 3	Enter the number of pipes you want to try for hydrosuction sediment removal. Try 1 first; if hydrosuction cannot remove enough sediment, try 2 or 3.	3
YA	Between 0 and 1	Maximum fraction of total yield that is allowed to be used in HSRS operations. This fraction of yield will be released downstream of the dam in the river channel. It is often possible to replace required maintenance flows with this water release. Enter a decimal fraction from 0 - 1.	0.3
CLF	(%)	Maximum percent of capacity loss that is allowable at any time in reservoir for Flushing. For an existing reservoir, this number must be greater than the percentage of capacity lost already. Sustainable solutions will attempt to remove sediment before this percent of the reservoir is filled	100
CLH	(%)	Maximum percent of capacity loss that is allowable at any time in reservoir for Hydrosuction. For an existing reservoir, this number must be greater than the percentage of capacity lost already. Sustainable solutions will attempt to remove sediment before this percent of the reservoir is filled	100
CLD	(%)	Maximum percent of capacity loss that is allowable at any time in reservoir for Dredging. For an existing reservoir, this number must be greater than the percentage of capacity lost already. Sustainable solutions will attempt to remove sediment before this percent of the reservoir is filled	100

CLT	(%)	Maximum percent of capacity loss that is allowable at any time in reservoir for Trucking. For an existing reservoir, this number must be greater than the percentage of capacity lost already. Sustainable solutions will attempt to remove sediment before this percent of the reservoir is filled	100
ASD	(%)	Maximum percent of accumulated sediment removed per dredging event. Sustainable removal dredging will be subject to this technical constraint.	100
AST	(%)	Maximum percent of accumulated sediment removed per trucking event. Sustainable removal trucking will be subject to this technical constraint.	100
MD	(m3)	Maximum amount of sediment removed per dredging event. The user is warned if this constraint is not met, but the program still calculates the NPV. Use default value unless better information is available.	1,000,000
MT	(m3)	Maximum amount of sediment removed per trucking event. The user is warned if this constraint is not met, but the program still calculates the NPV. Use default value unless better information is available	500,000
Cw	(%)	Concentration by weight of sediment removed to water removed by traditional dredging. Maximum of 30%. Do not exceed this default unless you have studies for your reservoir showing different dredging expectations.	30

Run Identifier: Gavins Point Dam/Lewis and Clark Lake - Current Conditions from 2011 Survey

User Input Sheet 1 of 2

RESCON PROGRAM

Version A01: April 11, 2003

GO BACK TO DEFAULT VALUE

CALCULATE RESULTS NOW

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- Outputs are on the next tab after all parameters have been input in

Flushing Feasibility Criteria Calculations

Developed from: Atkinson, E. 1996. The Feasibility of Flushing Sediment from Reservoirs, TDR Project R5839, Rep. OD 137. HR Wallingford.

Results Summary

The following are Atkinson's empirical criteria and guidelines. The required and suggested values, and calculated values for your user inputs are included. When the SBR criterion is met, the program will calculate economic results for your reservoir. Please also note the results of the other criterion and guidelines below.

Criterion	Required	Calculated	Notes
SBR	> 1	**0.54**	Can be flushed if > 1, otherwise not.
LTCR	preferably > 0.35	**0.07**	Use caution if < 0.35.
Guidelines	**Suggested**	**Calculated**	**Notes**
DDR	> 0.7	0.34	Additional confirmation to assist in deciding whether flushing is feasible.
FWR	> 1	0.21	
TWR	~ 1	0.22	
SBR_d	> 1	1.98	

Helpful hint: If SBR is less than one: try increasing frequency of flushing by decreasing the value assigned to the parameter "N" on the User Inputs page.

Conclusion

NOT Technicallyfeasible to have sustainable flushing solution because annual inflow of sediments exceeds annual volume which can be flushed. Values in table below are therefore invalid. The reservoir will NOT be examined for flushing feasibility.

Days of Complete Drawdown Flushing	**14**	days
Flushing Flowrate	**1,700**	(m^3/s)
Max. Possible Mass Sediment Flushed	**1.69E+07**	(metric tons)

- What can we change to flush more sediment?
- Change to 14 days every year?
- Reduce sediment inflow mass to 2,000,000 metric tonnes?
- Sediment median size finer than 0.1mm?