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Improvement of Reservoir Releases—Alternative Release Strategies

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Purpose

This technical note describes a spreadsheet calculational procedure (DILUTE) for estimating alternate releases from different outlet devices to meet a specific release dissolved oxygen target.

Background

When low dissolved oxygen (DO) concentrations occur in release from a Corps of Engineers reservoir, an option for increasing the level of DO leaving the tailrace is a supplemental release through an aerating outlet. For example, during nongeneration periods, a small discharge of poor-quality water can pass through the hydroturbines because of wicket gate leakage. Without some improvement technique, the water leaving the tailrace area would be very low in DO. The DO concentration of the water leaving the tailrace area can be improved by diluting this poor-quality water with highly aerated water from another outlet at the project. Sluiceway, spillway, or overflow weir releases are most often used in this enhancement technique. Generally, the flow from a spillway, sluiceway, or an overflow weir will have a much higher DO concentration than the poor-quality discharge. A flow-weighted average can be used to estimate the required release from the aerating outlet to provide a desired average DO level exiting the tailrace area.

To estimate the required release from the alternate source, the DO of the alternate release must be calculated. The spreadsheet DILUTE calculates the oxygen concentration in the releases through the aerating outlet and uses this concentration in the flow-weighted averaging process to estimate the required release discharge.

Computational Formulas

For gated and ungated ogee crests (Figure 1), the reaeration efficiency can be estimated with

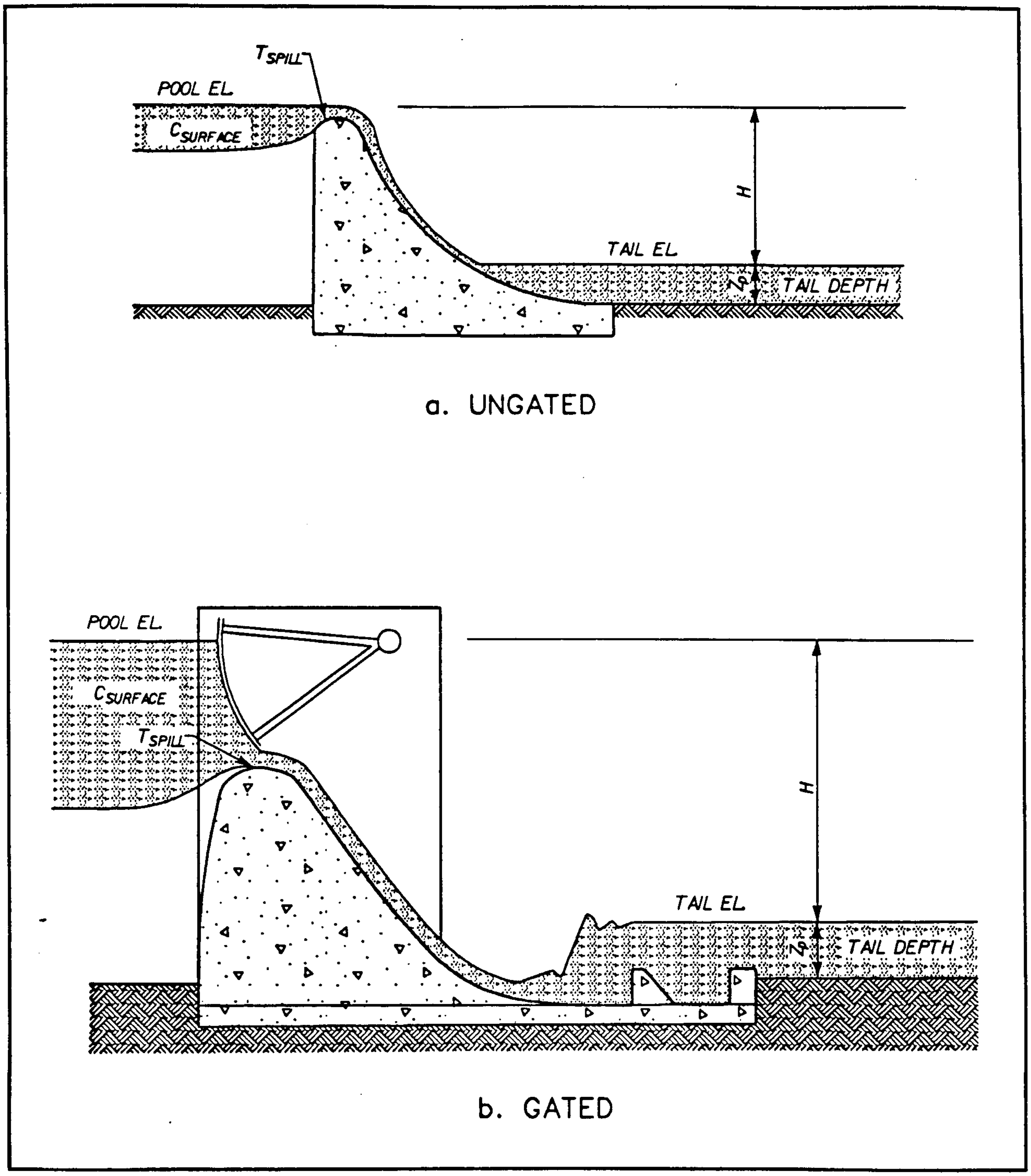

Figure 1. Ogee crests

$$E = 1 - \exp\left(\frac{-0.08H}{1+0.02q} - 0.062 Z_p\right) \qquad (1)$$

where

E = reaeration efficiency (that is, the proportion of upstream deficit that is satisfied by oxygen uptake through the structure)

H = head across the structure, ft

q = unit discharge, cfs/ft

Z_p = tailwater depth, ft

This relationship was developed by Rindels and Gulliver (1991) and showed a standard error of 16 percentage points.

The oxygenation efficiency of flow over a sharp-crested weir or fixed bulkheads (Figure 2) can be predicted with Avery and Novak's (1978) relationship

$$E = 1 - \left(\frac{1}{1 + 0.64 \times 10^{-4} F_j^{1.787} R^{0.533}}\right)^{1.1149} \qquad (2)$$

where F_j is the Froude number of the jet, given by

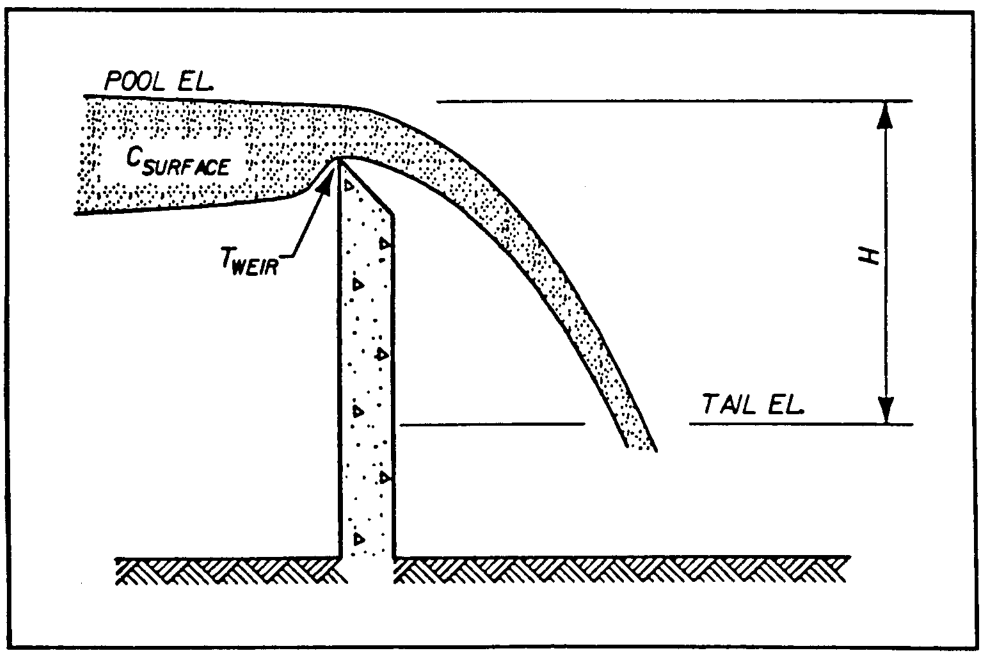

Figure 2. Sharp-crested overflow weir

$$F_j = \frac{(2g)^{0.25} H^{0.75}}{q^{0.5}}$$

and g is the acceleration of gravity (32.2 ft-sec^{-2}), and R is the Reynolds number of the jet defined by

$$R = \frac{q}{2\nu}$$

where ν is the kinematic viscosity. Predictions resulted in a standard error of 17 percentage points.

The aeration characteristics of releases from a sluiceway or hollow-cone valve have not been extensively studied. However, for a hollow-cone valve, cursory studies show that using a reaeration efficiency of 90 percent should result in reasonable estimates for dilution. No recommendations can be made for sluiceway flow because of the extreme variability of hydraulic conditions and reaeration capabilities.

The release DO concentration C_{alt} can then be estimated with

$$C_{alt} = E\left(C_s - C_u\right) + C_u \tag{3}$$

where C_u and C_s are the upstream and saturation concentrations for DO.

Implementation

The reaeration of releases from the following alternate sources has been characterized and is included in the spreadsheet calculations: gated or ungated spillways, sharp-crested overflow weirs, and hollow-cone valves. The discharge rate and DO concentration of the poor-quality water source must be measured or estimated. The discharge from the alternate release source can then be estimated, resulting in the dilution of the poor-quality water with the higher quality release to give a desired final DO. The flow-weighted average is calculated with the following mass balance:

$$Q_{final} C_{final} = Q_{poor} C_{poor} + Q_{alt} C_{alt} \tag{4}$$

$$Q_{final} = Q_{poor} + Q_{alt} \tag{5}$$

where Q_{final}, Q_{poor}, and Q_{alt} are the total flow, leakage through the turbines, and the spillway release, respectively, and C_{final}, C_{poor}, and C_{alt} are the desired DO release from the tailrace area, the DO concentration of the poor-quality water, and the supplemental release DO concentration, respectively. Adjustment for temperature is included in the spreadsheet.

Constraints, Limitations, and Costs

Some limitations, obviously, are associated with this improvement alternative: (1) the final release DO will be less than the release DO of the aerating outlet, because of dilution with the poor-quality release, and (2) the target DO cannot be greater than the DO concentration of the aerating outlet because the target would not be achievable. There may also be operational limitations regarding the relative discharge available for improvements. For example, "cracking" a flood control gate may result in more spillway release than needed for dilution of the poor-quality water.

Spreadsheet Operation

To execute the spreadsheet in QuattroPro, the file DILUTE.WQ1 must be opened. In LOTUS 1-2-3, the file DILUTE.WK1 must be retrieved.

DILUTE is a menu-driven spreadsheet that guides the user through the spreadsheet activities with a main menu and three submenus. The options on the main menu (Figure 3) are OGEE CRESTS, CONE VALVES, WEIRS, QUIT THIS MENU, SAVE THIS WORKSHEET, and EXIT QPRO. To choose an option on the main menu, press the first letter, highlight the option name with directional keys and press ENTER, or click the option name with a mouse. If OGEE CREST, CONE VALVES, OR WEIRS is chosen, the program goes to a submenu and allows the user to input variables to make calculations.

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OGEE CRESTS
CONE VALVES
WEIRS
QUIT THIS MENU
SAVE THIS WORKSHEET
EXIT QPRO
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Figure 3. Main menu

The submenus (Figure 4) are identical (with options for INPUT VALUES, PRINT RESULTS, RETURN TO MAIN MENU, QUIT THIS MENU, and SAVE THIS WORKSHEET), but are designed to input variables and obtain results for ogee crests, cone valves, and sharp-crested weirs. The following paragraphs describe the information needed to run the spreadsheet program and outlines use of each of the menu options.

INPUT VALUES PRINT RESULTS RETURN TO MAIN MENU QUIT THIS MENU SAVE THIS WORKSHEET

Figure 4. Submenus

Input Values

To input variables for calculation, choose INPUT VALUES by pressing the letter I, highlighting "INPUT VALUES" and pressing ENTER, or clicking INPUT VALUES with a mouse.

If supplemental flow will be released over OGEE CRESTS, the following data (Figure 5) are necessary for input:

GATED AND UNGATED OGEE CRESTS				
INPUT VARIABLES				
Pool El	Tail El	WSpill	Tail Depth	CSurface
260.0	200.0	50.0	4.0	8.0
TSpill	QPoor	TPoor	CPoor	CTarget
24.0	25.0	16.0	1.0	5.0
RESULTS				
QSpill	CSpill	QFinal	CFinal	TFinal
29.1	8.4	54.1	5.0	705.9

Figure 5. Ogee crests

- Pool El (Upstream pool elevation, ft)
- Tail El (Tailwater elevation, ft)
- WSpill (Width of operating spillway, ft)
- Tail Depth (Depth of tailwater, ft)
- CSurface* (Oxygen concentration of surface water, mg/L)
- TSpill* (Temperature of water released through spillway, °C)

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* $C_{Surface}$, T_{Spill}, $T_{ConeValve}$, and T_{Weir} are DO concentrations and temperature, respectively, of the water withdrawn from the reservoir for release (prior to saturation). These may be estimated with surface or epilimnetic values or by predictions of withdrawal by SELECT (Davis et al. 1987).

- QPoor (Discharge of poor-quality release water, ft^3/sec^{-1})
- TPoor (Temperature of poor-quality release water, °C)
- CPoor (Oxygen concentration of poor water quality, mg/L)
- CTarget (Dissolved oxygen release target, mg/L)

The program then calculates the results for

- QSpill (Required flow through the spillway, cfs)
- CSpill (Oxygen concentration of spillway releases, mg/L)
- QFinal (Total flow, sum of leakage and spillway releases, ft^3/sec)
- CFinal (Required DO level to be released from the tailrace area)
- TFinal (Flow-weighted average release temperature, °C)

Information needed to calculate for CONE VALVES (Figure 6) is as follows:

CONE VALVES				
INPUT VARIABLES				
CPoor	QPoor	TPoor	TConeValve	CTarget
1.0	30.0	16.0	25.0	5.0
RESULTS				
QValve	QFinal	CFinal	TFinal	
47.3	77.3	5.0	1189.6	

Figure 6. Cone valves

- CPoor (Oxygen concentration of poor-quality water quality, mg/L)
- QPoor (Discharge of poor-quality release water, ft^3/sec^{-1})
- TPoor (Temperature of poor-quality release water, °C)
- TConeValve* (Temperature of water released through cone valve, °C)
- CTarget (Dissolved oxygen release target, mg/L)

with results of

- QValve (Required flow through the cone valve, cfs)
- QFinal (Total flow, sum of leakage and cone valve release, ft^3/sec)
- CFinal (Required DO level to be released from the tailrace area)

- TFinal (Flow-weighted average release temperature, °C)

To calculate for WEIRS (Figure 7):

- Pool El (Upstream pool elevation, ft)
- Tail El (Tailwater elevation, ft)
- WWeir (Width of operating weir, ft)
- TWeir* (Temperature of weir releases, °C)
- CSurface* (Oxygen concentration of surface water, mg/L)
- QPoor (Discharge of poor-quality release water, ft^3/sec^{-1})
- TPoor (Temperature of poor-quality release water, °C)
- CPoor (Oxygen concentration of poor-quality water quality, mg/L)
- CTarget (Dissolved oxygen release target, mg/L)

SHARP-CRESTED WEIRS				
INPUT VARIABLES				
Pool El	Tail El	WWeir	TWeir	CSurface
100.0	95.0	20.0	25.0	4.0
	QPoor	TPoor	CPoor	CTarget
	30.0	16.0	0.0	5.0
RESULTS				
QWeir	CWeir	QFinal	CFinal	TFinal
351.6	6.2	381.6	5.0	24.3

Figure 7. Sharp-crested weirs

The program then calculates the results for

- QWeir (Required flow over the weir, cfs)
- CWeir (Oxygen concentration of weir releases, mg/L)
- QFinal (Total flow, sum of leakage and weir flow, ft^3/sec)
- CFinal (Required DO level to be released from the tailrace area)
- TFinal (Flow-weighted average temperature, °C)

The information for ogee crests, cone valves, and weirs is input into the spreadsheet in the shaded areas shown in Figures 5-7.

It should be noted that the user cannot work anywhere else in the spreadsheet except in the locations for INPUT VARIABLES when the INPUT VALUES menu option has been chosen. Pressing escape returns the user to the spreadsheet menu.

Example

During nongeneration, leakage of poor-quality water through the turbine causes the accumulation and ultimate release of poor-quality water from a hydropower facility. With a leakage rate of 25 cfs, leakage DO concentration of 1.0 mg/L, what release should be made from a gated spillway to obtain a diluted release DO of 5.0 mg/L?

Other observations and data required are as follows: leakage water temperature of 16 °C (observed); upstream pool and tailwater elevations, 260 ft and 200 ft, respectively; spill width of 50 ft, spill water temperature and DO withdrawn from reservoir through spillway of 24 °C and 8.0 mg/L, respectively; and a tailwater depth of 4.0 ft. The withdrawal temperature and DO can be estimated with SELECT (Davis and others 1987).

Results (Figure 5) of applying Equations 1, 2, 5, and 6 with the DILUTE spreadsheet for OGEE CRESTS show that a spillway release of approximately 29 cfs is required to meet the DO objective in the tailwater.

Print Results

To print the tables showing the input variables and the results, press the letter P, highlight the letter P and press ENTER, or click PRINT RESULTS with a mouse. This will print the table with the input variables and the results.

Quit This Menu

The QUIT THIS MENU option bypasses the menu and goes directly to the spreadsheet. This allows the user to change formulas within the spreadsheet to meet specific requirements, if desired. To return to the menu, press ALT-M (the ALT key pressed simultaneously with the letter M key).

Return to Main Menu

When RETURN TO MAIN MENU is chosen, the DILUTE spreadsheet goes from one of the submenus back to the main menu.

Save This Worksheet

SAVE THIS WORKSHEET saves any changes or input in the spreadsheet.

Exit QPro

EXIT QPRO saves the spreadsheet and exits the software program.

Summary

If releases from an alternative outlet are an acceptable method of improving release DO from a Corps project, use of the relationships presented herein can aid operational decisions regarding appropriate discharge levels. However, the generic nature of the predictive equations must be considered when adopting an operational procedure based on these calculations. Some adjustments on a project-by-project basis will probably be necessary to optimize the operation of alternative release strategies.

Obtaining this Program

DILUTE was designed to run on a 386, 486, or Pentium IBM-compatible personal computer using QuattroPro (Dilute.WQ1) or Lotus 1-2-3 (Dilute.WK1). Copies of this spreadsheet can be obtained by sending a preformatted 5-1/4- or 3-1/2-inch floppy diskette to

U.S. Army Engineer Waterways Experiment Station
ATTN: CEWES-HS-L
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Please indicate which version (QuattroPro or Lotus) is desired.

References

Avery, S. T., and Novak, P. (1978). "Oxygen transfer at hydraulic structures," *Journal of the Hydraulics Division, ASCE,* 104 (HY11), 1521-40.

Davis, J. E., Holland, J. P., Schneider, M. L., and Wilhelms, S. C. (1987). "SELECT: A numerical one-dimensional model for selective withdrawal," Instruction Report E-87-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Rindels, A. J., and Gulliver, J. S. (1990). "Oxygen Transfer at Spillways," *Air-Water Mass Transfer*, S. C. Wilhelms and J. S. Gulliver, eds., American Society of Civil Engineers, New York, pp 524-533.

Point of Contact

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