US Army Corps of Engineers
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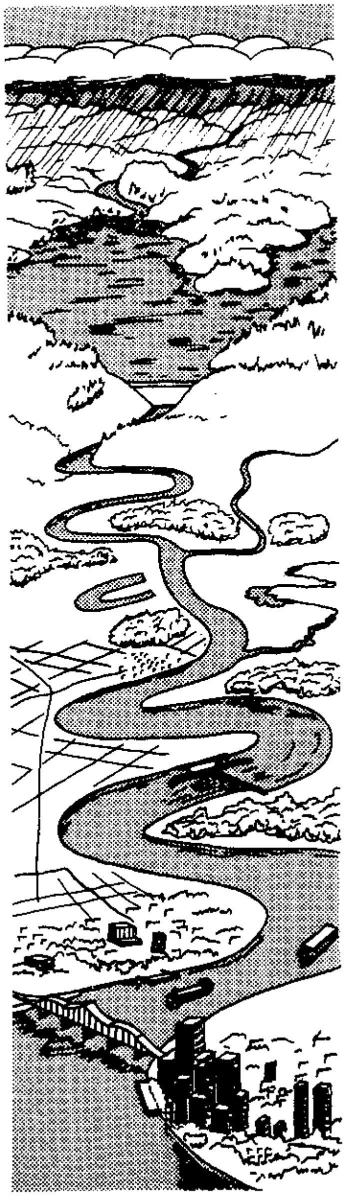

WOTS / Water Operations Technical Support

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Bubble plume from the destratification system installed at East Sidney Lake, New York

Pneumatic Destratification System Design Using a Spreadsheet Program

by
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The thermal stratification which occurs at most reservoirs and lakes during the summer results from solar radiation heating of the surface waters. This stratification inhibits the transfer and circulation of oxygen-rich surface waters with the bottom waters. As the summer progresses and the stratification becomes more pronounced, the natural chemical and biological reactions in the bottom waters deplete the dissolved oxygen, leaving the lower layers void of oxygen. Under these anoxic conditions many undesirable reactions, such as the resuspension of dissolved iron and manganese, nutrient cycling, and hydrogen sulfide gas production, are possible.

One way to improve reservoir quality is to prevent or reduce thermal stratification through some form of destratification system which continually mixes epilimnetic and hypolimnetic waters. This action prevents the reservoir from setting up density gradients that inhibit vertical mixing and allows dissolved oxygen from the surface and epilimnion to be circulated throughout the water column. A number of systems, ranging from direct-drive surface mixers to pumps, air guns, and bubble column systems, have been designed to accomplish this (Lorenzen and Fast 1977, Bohac and others 1983, Holland and Dortch 1984, Holland and Tate 1984, and Johnson 1984).

Perhaps the design that has been the most thoroughly investigated and tested in reservoir applications is destratification by a continuous bubble column. For this design, a steady flow of bubbles is introduced into the water column from a diffuser located along the bottom of the lake (Figure 1). As the bubbles rise to the surface, they entrain water at depth and create a flow of water from the hypolimnion to the surface. The plume, with its entrained hypolimnetic water reaches the surface and spreads out horizontally until it plunges (due to its greater density) and reaches a neutral density level where it then continues to spread horizontally. This density-driven circulation pattern continues until the water above the level of the diffuser mixes fully and the density difference from top to bottom of the water column is essentially zero. At this point, the circulation cells maintain the destratification by continually mixing the waters.

Davis (1980) provides guidelines for the design, installation, and operation of a linear bubble column diffuser. This system uses an oilless compressor to force the desired airflow down to the lake bottom and out a diffuser. The diffuser consists of a long length of polyvinyl chloride (PVC) pipe with a line of holes drilled into the pipe to allow the air to escape at measured intervals. This diffuser allows the bubble plume to set up long vertical recirculation cells on either side of

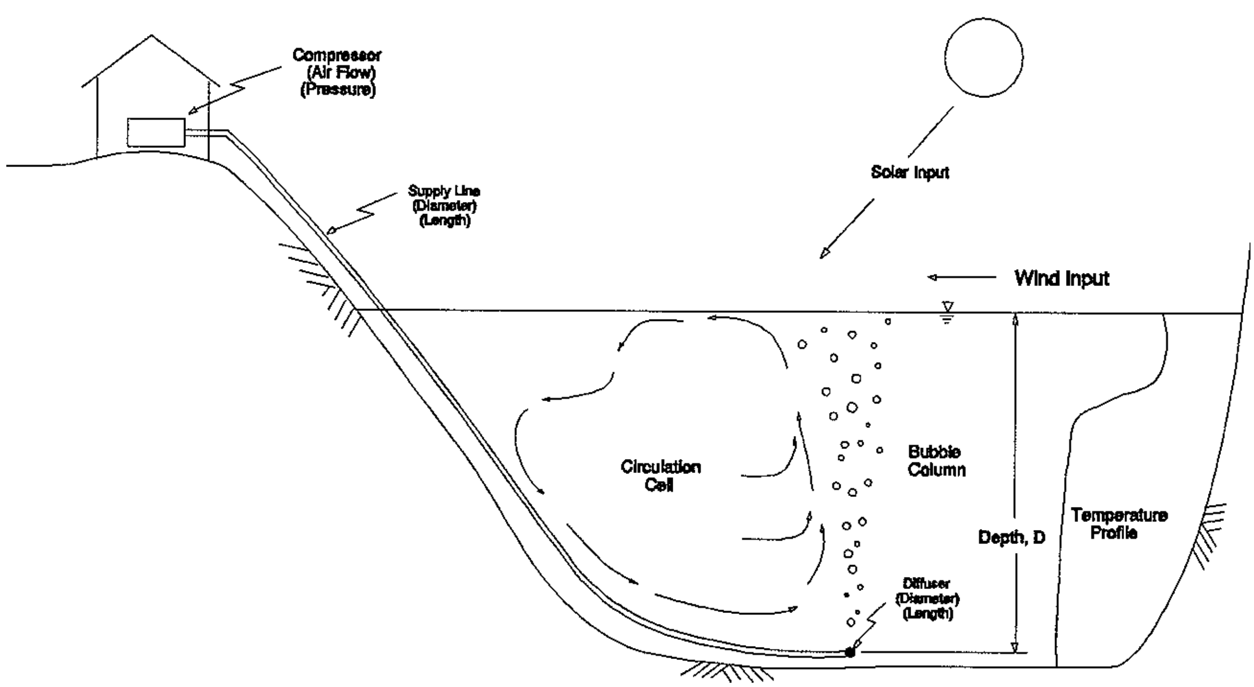

Figure 1. Schematic diagram of the components and input requirements of a pneumatic linear bubble column diffuser

the diffuser rather than in a circular pattern as is common in point source systems.

Davis' design guidelines are based on several factors including temperature profile, lake volume-capacity curve, surface area of the lake, depth of the diffuser, and desired time to destratify the lake. Calculations are made to size the airflow rate based on the lake's thermal or density stability (the difference between the potential energy of the fully mixed and stratified lake system). The length of the diffuser is based on the airflow rate and in turn on the residual pressures in the diffuser. The air pressure the compressor is required to deliver is based on friction and bend losses through the supply lines and diffuser, the hydrostatic head above the diffuser, and the residual pressures necessary to deliver a specified airflow through a single hole in the diffuser.

Many of these calculations are set up in Davis (1980) in graphical formats for generalized reservoirs. A more exact design can be made by performing the calculations by hand which can be a long and tedious process and may require the investigator to perform many time-consuming calculations, especially to determine the stability of the reservoir (for each temperature profile) and the final pressure requirements. Determination of the system requirements for an average size reservoir may involve over 175 calculations for each temperature profile examined. Rather than doing the calculations by hand, they can be performed quickly and accurately using a spreadsheet, saving the investigator much time and effort.

Spreadsheet Operations

Many engineers and planners will be familiar with computer spreadsheet programs, such as Lotus 1-2-3, Microsoft Excel, and others. Spreadsheets are particularly well suited for multiple mathematical operations on a column or columns of related numbers. They are commonly used to manipulate large amounts of related data for accounting, or data collection and interpretation, and other uses. One particular advantage is that a series of calculations can be rapidly performed on a range of numbers and the results easily observed. If necessary, the formulas can be easily changed and the corresponding results reexamined.

Davis' design procedures are well suited for incorporation into a spreadsheet. A spreadsheet can be easily configured to calculate the potential energy of a lake under both mixed and stratified conditions and calculate the resulting stability. These computations are based on the volume-capacity curve of the lake as well as the temperature profile and depth of water above the diffuser line. Other calculations follow a linear sequence of steps (meaning that one answer depends on the previous calculations). This is true except for the pressure calculations which have to be made to determine the airflow through the diffuser and ultimately the pressure requirements of the compressor.

To determine the required pressures in the system, the spreadsheet must assume some losses for bends and joints and calculate friction losses through the supply line and the diffuser. With the exception of the diffuser, the calculations are straightforward. To determine the pressure component of the diffuser requires an iterative process. This process is started by making an initial calculation of diffuser length, determining the resulting pressures (most importantly the absolute hydrostatic pressure and the internal absolute pressure within the diffuser pipe) and entering a chart provided by Davis (1980) to determine the resulting free airflow through a single hole. With this free airflow provided, along with the spacing of the holes in the diffuser and the total airflow required, a new calculated diffuser length can be determined. This estimate can be substituted back into the equations and the system pressures recalculated until the substituted length matches the new length. By hand, this process can take ten or twelve iterations, provided the investigator is familiar with the airflow graph. By using the spreadsheet, the final answer is usually converged on within six trials.

Operation

Operation of the spreadsheet requires the following information:

- Surface area of the lake (to calculate solar input).

- Volume-capacity curve (for energy calculations).
- Typical temperature profiles (for energy calculations).
- Depth of water above the diffuser (for energy calculations).
- Time period desired to achieve destratification (for energy input calculations).
- Internal diameter of the diffuser line (for pressure calculations).
- Internal diameter of the supply line (for pressure calculations).
- An approximate length of the supply line (for pressure calculations).

This information is input into the spreadsheet in the appropriate locations (shown as shaded areas in Figure 2). The program then uses these data to perform the necessary calculations through the remainder of the spreadsheet. The output results as well as other pertinent information are contained in the design summary portion

GENERALIZED WORKSHEET TO SIZE A DESTRATIFICATION SYSTEM
WORKSHEET B CALCULATES ENERGY AND STABILITY REQUIREMENTS
PRESS F9 TO RECALCULATE AFTER DATA CHANGES

DESIGN SUMMARY: GENERAL LAKE, SOMEWHERE USA

SURFACE AREA (m2)	1011750	
DEPTH TO DIFFUSERS (m)	10	
LAKE VOLUME ABOVE DIFFUSER (m3)	10117500	
% OF TOTAL VOLUME ABOVE DIFFUSER	20.0%	
TIME TO DESTRATIFY (days)	5	
COMPRESSOR REQUIRED (cfm)	306	+/- CHANGE
AT (psi)	135	-0.12282
DIFFUSER LENGTH REQUIRED (m)	339	-0.04247
INTERNAL DIA OF DIFFUSER (mm)	35	
SUPPLY LINE LENGTH (m)	500	
INTERNAL DIA OF SUPPLY LINE (mm)	45	

GENERAL LAKE INFORMATION

SURFACE AREA (Ac)	250
DEPTH (D) ABOVE DIFFUSERS (m)	10

DEPTH m	TEMP C	TOTAL VOLUME VOLUME/CAPACITY m3
0	30	50587500
1	29.7	49575750
2	29.4	48564000
3	29.1	47552250
4	28.9	46540500
5	27.6	45528750
6	26.3	44517000
7	24.9	43505250
8	24.1	42493500
9	23.5	41481750
10	23.3	40470000
11	23.2	39458250
12	23.1	38446500
13	23	37434750
14	22.9	36423000
15	22.8	35411250
16	22.7	34399500
17	22.6	33387750
18	22.5	32376000
19	22.4	31364250
20	22.3	30352500
21	22.2	39340750
22	22.1	28329000
23	22	27317250
24	21.9	26305500
25	21.8	25293750

DIFFUSER DESIGN INFORMATION

TIME TO DESTRATIFY (DAYS)	5
dd, INTERNAL DIA OF DIFFUSER (mm)	35
ds, INTERNAL DIA OF SUPPLY LINE (mm)	45
LENGTH OF SUPPLY LINE (m)	500
LAKE VOLUME ABOVE THE DIFFUSER (m3)	10117500

ENERGY CALCULATIONS

STABILITY (J)	1.9e+08
R, SOLAR HEAT ENERGY INPUT (J)	25293750
E, TOTAL THEORETICAL ENERGY (J)	2.1e+08

MISCELLANEOUS CALCULATIONS

TIME TO DESTRATIFY (SEC)	432000
1+(D/10.4)	1.962

DESIGN CALCULATIONS

Q, REQUIRED AIR FLOW (l/s)	144.5
(CFM)	306.2

FIRST ESTIMATE

L, LENGTH OF DIFFUSER (m)	89.1
CALCULATION ESTIMATE (m)	89

*NOTE - SHADED AREAS DESIGNATE DATA TO BE ENTERED BY THE USER

Figure 2. Input/output information contained in worksheet A of the spreadsheet program

of the spreadsheet. Figure 2 shows the input and output information the user can expect to see as part of the spreadsheet.

The spreadsheet is set up to perform the necessary calculations to generate a first estimate of diffuser length. It then uses this number to step through a series of iterations between pressures, airflow capacity, and pipe length to converge on the solution of final pressure and diffuser length. The solution is usually arrived at within the allotted six iterations to within ±0.5 meter for the diffuser length and ±1.0 pound per square inch (psi) for the pressure calculations. If the calculations have not converged to within satisfactory tolerances, the final answer can be substituted back into the process for another six iterations.

The spreadsheet performs approximately 800 calculations for each iteration. In the graphical approach of Davis (1980) this number of calculations is significantly reduced but the solution is subject to the interpolation of the graph by the investigator and may take many trials until the user becomes familiar with the graph and can estimate accurate solutions. In place of the graph, the spreadsheet accesses a 30 by 10 table containing the graphical information, and it makes interpolations within the table to arrive at an accurate and consistent solution of the airflow through a single hole.

Advantages

The main advantage of using a spreadsheet to make the design calculations is the ease with which variables and formulas can be changed to observe the effects on the final system configuration.. A variety of temperature profiles can be used to determine system requirements for several different scenarios and the depth of the diffuser can be changed to simulate its different positioning in the lake. Time required to destratify the lake can be modified since it plays a major role in system size by affecting the delivery rate at which the system must operate. System requirements can be calculated and recalculated with very little effort to arrive at the best design for the conditions presented.

Although the design procedures could be incorporated into a more traditional computer program, the program would have to be recompiled each time for even minor formula or data changes. A spreadsheet offers more flexibility (as far as variable or formula changes) and real-time/rapid solutions. In addition, a spreadsheet usually offers built-in graphical ability which can be very useful for visualizing data and result trends. Spreadsheets also require no computer language programming skills so that anyone with a knowledge of how spreadsheets operate can use them and make changes to the data or formulas if necessary. Another advantage is software availability. Most offices have easy access to some form of spreadsheet software while comparatively few have the compilers necessary to run FORTRAN programs.

Limitations

Currently, the spreadsheet uses eight worksheets, linked to one another, to perform all the necessary calculations. However, the spreadsheet could be incorporated in a single worksheet by using separate areas. The advantage of using multiple worksheets is that it is easier to organize the calculations into a logical sequence and a single worksheet can be dedicated to input/output information while the rest are dedicated to the actual calculations. The disadvantage is that the spreadsheet occupies about 300,000 kilobytes of memory.

Davis' design does not take into account the lake geometry. Thus, the destratification process may be inhibited or its effectiveness reduced in a lake with relatively close physical boundaries, that is, long narrow lakes, lakes with many separate arms, sinuous lakes, or lakes with major underwater ridges. Although Davis does not mention this, on large lakes it may be more feasible to spread the system out over a greater area (using separate sections of diffusers) to achieve total destratification and to use natural constriction points in the reservoir as boundaries for the operating area of the subsystems.

The spreadsheet does have upper and lower limits of operation which are dependent on the depth to the diffuser, length of the diffuser, lake volume, and degree of stratification. However, since each lake scenario is unique, no definite general limits can be set. From experimentation, it seems that the larger the lake (total volume) and the stronger the stratification, the sooner the spreadsheet will fail to converge. Usually this is because the depth to the diffuser is too great and the pressures have exceeded the limits of the airflow table, resulting in an error. One way to get around the problem is to reduce the pressure within the system through specification of a shallower diffuser depth, increased internal diameter of the diffuser or supply line, or reduction in the length of the supply line.

Obtaining this Program

This program will run on any personal computer using Lotus 1-2-3, version 3.0. A copy of this program may be obtained by sending a request specifying the format required for a 5-1/4-inch or 3-1/2-inch floppy diskette to the US Army Engineer Waterways Experiment Station, ATTN: CEWES-HS-R, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199.

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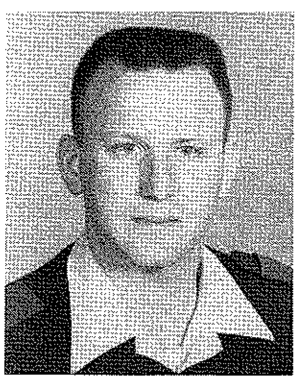

CPT Edward Meyer is currently assigned to the Environmental Laboratory, US Army Engineer Waterways Experiment Station (WES). He has a Bachelor's degree in Civil and Environmental Engineering from Clarkson University, New York, and a Master's degree in Civil Engineering (Hydraulic Engineering specialty) from Washington State University. CPT Meyer has worked for the past two years as a research engineer in the WES Hydraulics Laboratory on problems concerning water quality as they relate to aeration and destratification techniques. The past two summers have been spent designing, installing, and monitoring a pneumatic destratification system at East Sidney Lake.

Water Operations Technical Support Program (WOTS)

The WOTS Program was initiated in FY 85 to provide rapid technical assistance for field problems associated with water quality management in the US Army Corps of Engineers (USACE). The program is an Operations and Maintenance (O&M) funded program. Assistance is limited to USACE activities associated with operating projects, problems existing during the planning or engineering phases of renovations, or alterations to operating projects.

To request assistance, a letter to the Manager of the WOTS Program at the following address is required:

Commander and Director
US Army Engineer Waterways Experiment Station
ATTN: Mr. J. L. Decell, CEWES-EP-L
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

In the request you should name the project and state the nature of the problem and the type of assistance required. If you have been in contact with a technical person at the US Army Engineer Waterways Experiment Station (WES) who has knowledge of your problem, you may request that individual by name. The request should identify a point of contact in your organization and a telephone number. Upon receipt of your letter, the request will be directed to the proper technical staff member at WES for response.

Assistance under WOTS is provided at no cost to the user and is limited to 7 man-days, including travel. The results of the assistance provided will be formally transmitted to your organization by the Manager, WOTS. In cases where assistance is needed very rapidly, telephone requests are honored, but must be followed up by a letter. When the results are needed rapidly, advance copies are forwarded by FAX and followed up with a formal response.

In addition to this direct assistance to the FOA's, WOTS activities also include technology transfer, such as workshops, and the publication and distribution of the WOTS information exchange bulletin. Technology maintenance is also a WOTS function; it assures that the direct assistance provided is state of the art.

One way to improve reservoir quality is to prevent or reduce thermal destratification through some form of destratification system which continually mixes epilimnetic and hypolimnetic waters. Davis (1980) provides guidelines for the design, installation, and operation of a linear bubble column diffuser. This issue discusses the conversion of Davis' required calculations to a spreadsheet operation, saving time and effort.

WATER QUALITY

RESEARCH PROGRAM

This bulletin is published in accordance with AR 25-30. It has been prepared and distributed as one of the information dissemination functions of the Waterways Experiment Station. It is principally intended to be a forum whereby information pertaining to and resulting from WQRP can be rapidly and widely disseminated to Corps District and Division offices as well as other Federal agencies, state agencies, universities, research institutes, corporations, and individuals. Contributions of any type are solicited from all sources and will be considered for publication as long as they are relevant to the objectives of WQRP, i.e., to provide new or improved technology to solve selected environmental quality problems associated with Civil Works activities of the Corps of Engineers in a manner compatible with authorized project purposes. This bulletin will be issued on an irregular basis as dictated by the quantity and importance of information to be disseminated. Communications are welcomed and should be adressed to the Environmental Laboratory, ATTN: J. L. Decell, U.S. Army Engineer Waterways Experiment Station, 3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199, or call AC 601/634-3494.

LARRY B. FULTON, EN
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Commander and Director