Wastewater Reclamation at Lake Arrowhead, California: an overview. K. Madireddi, R.W. Babcock, Jr., B. Levine, T.L. Huo, E. Khan, Q.F. Ye, J.B. Neethling, I.H. Buffet, M.K. Stentstrom, **69**, 350.

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DISCUSSION

Of: **Wastewater reclamation at Lake Arrowhead, California: an overview.** K. Madireddi, R.W. Babcock, Jr., B. Levine, T.L. Huo, E. Khan, Q.F. Ye, J.B. Neethling, I.H. Suffet, M.K. Stenstrom, **69**, 350.

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This paper describes a pilot study of a kind that is likely to be highly important in the future. The study itself was carried out with great thoroughness and success, and the paper is a very clear description of what was done, why it was done, and the results.

Water reclamation is an increasingly important topic (Iranpour *et al.,* 1995). The most difficult form of water reclamation is potable reuse because the water must be thoroughly purified to remove toxins, wastes, and disease organisms. Even a project that achieves a high degree of purification can expect public controversy because the idea of drinking wastewater is revolting, and many people will point to past failures of waste disposal or purification systems as reasons to expect that the system will malfunction.

In an attempt to prevent such objections, the authors developed a collection of treatment processes to purify wastewater until every available measure of contamination indicated that it was more pure than the famously pure waters of Lake Arrowhead. They succeeded in all of their goals except for the removal of nitrate-nitrogen, and it is almost certain that this goal also would be achieved by a nitrification unit constructed for a full-scale plant.

It is clear that such a plant would be expensive to build and to operate, but the Lake Arrowhead community is experiencing some population growth, and obtaining water from outside the lake basin would be even more expensive. On the other hand, the withdrawal of lake water cannot increase, especially in periods of drought such as the one that lasted from 1985 to 1991.

The reuse is indirect, with detention of the reclaimed water for 8 to 9 years in Lake Papoose and Lake Arrowhead and for treatment in the Bernina water treatment plant.

We invite the authors' comments to the following items:

1. A few more words about estimated costs might have been helpful. High precision would not be necessary, but a rough estimate of the capital and operation and maintenance costs of a pipeline to the terminus of the California Water Project as compared to the same for the planned full-scale reclamation treatment plant would provide additional perspective.
2. We gather from their description of the selection of goals in Table 1 that if two or more agencies had differing standards for the same parameter of reclaimed water, they chose the most stringent. If so, mentioning this explicitly might have been desirable.
3. Hollow-fiber systems are used in Memcor microfiltration units, with the flow from outside to inside the fibers and an air backwashing system used every few minutes to remove collected solids (Iranpour *et al.,* 1998). This design operates successfully and achieves higher filtration surface area for the volume of these units than the spiral-wound design described on page 353 of the article. We presume that in ultrafiltration or nanofiltration, air backwashing cannot be done because of the smaller pore size. Is this correct?
4. At the high end of Figure 4b, the nitrate concentration at sample point Q3b is shown as exceeding the nitrate concentration in the influent a very small fraction of the time. Could this be an artifact of the log-linear fit, or was such a difference actually observed?
5. We assume that the log-linear fits in parts (b) of Figures 3 through 7, are based on more data than what appears in parts (a) of these figures, and that the monthly values in the (a) parts are averages. Is this correct?
6. In Table 2, as it appears that no tests were made for filtration of humics by any of the filtration units, it is not clear why this item was included.
7. The removal of refractory-organic compounds by a combination of ozonation, bacterial metabolism, and reverse osmosis (RO) is a valuable feature of this project (page 357). It is unlikely that refractory chemicals discharged to the lakes would break down even after several years of detention; thus, they would eventually return to the drinking water.
8. The low but nonzero concentration of total organic carbon detected in the product water (Figure 7) evidently provides enough nutrition for slow bacterial growth in the membrane effluent pipes, so that the need for a final disinfection step is clear. This raises the question of whether a full-scale plant would need provisions for occasional chemical cleaning of the effluent pipes.
9. Have the authors considered that ultraviolet (UV) irradiation might greatly reduce the need for ozone in partially oxidizing refractory-organic chemicals? Including a high-intensity, medium-pressure UV irradiation unit might produce similar decomposition of refractory chemicals at a lower cost than ozonation by itself. A medium-pressure UV unit produces light in a wide range of wavelengths that could break organic chemical bonds, providing increased opportunities for reactions with ozone. This has been investigated for paper industry wastewater by Mobius and Cordes-Tolle (1996). Oeller *et al.* (1996) may also be relevant. Because the energy cost of ozone production is very high, a process that combines ozonation and UV could have a lower operating cost. Probably it would also be less expensive to use UV instead of ozone in the final disinfec-

tion step. Additional information on the subject of UV disinfection and related cost estimates can be obtained from Loge, Darby, *et al.* (1996), Loge, Emerick *et al.* (1996) and Iranpour *et al.* (1995, 1996, 1997, and 1998).

10. In Table 5, it is somewhat surprising that the nanofiltration unit consistently removed larger fractions of *Giardia* and *Cryptosporidium* than did RO. The bacteriophage results match better with conventional expectations. Do the authors have any explanation for these differences? In addition, it might have been good to provide some indication of the number of samples used in at least some of these measurements, as was provided in Table 3.

Let us repeat once again that this is an excellent report about an excellent project; we strongly recommend the paper as among the best and most informative work in the field of water reclamation.

Acknowledgments

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Closure

K. Madireddi, R.W. Babcock, B. Levine, T.L. Huo, E. Khan, Q.F. Ye, J.B. Neethling, I.H. Suffet, M.K Stenstrom

The authors are thankful for the comments made in the Discussion. We agree that water reclamation is an increasingly important technology. Below are our comments on the questions raised:

1. We did not perform a detailed cost estimate for a scaled-up version of the plant, and we agree that a cost estimate would be useful; however, an estimate for this plant would be atypical of the cost of reclamation. The extremely high water quality would make the plant more expensive per unit of capacity than other facilities, such as those proposed for San Diego, California. There are also several factors that make such advanced reclamation economical for the Lake Arrowhead community, and that are not found elsewhere. The high elevation (approximately 1 800 m) makes pumping of imported water costly. Additionally, the ultimate disposal cost for the Lake Arrowhead wastewater effluents further increases the incentive for reclamation; the community will require new effluent pipelines as growth continues. Finally, in this area of California, new firm water supplies are generally unavailable. The Lake Arrowhead community is not part of the California Water Project and is therefore ineligible for water supply; water from the Colorado River is already overallocated in California.
2. We did choose the most stringent water-quality standard.
3. When we began our planning for this project, the hollow-fiber microfilters, such as those cited in the Discussion, were unproven, and we chose more conventional spiral-wound membranes. Microfilters would have allowed many more contaminants to reach the reverse-osmosis (RO) membranes, which would probably have resulted in greater fouling rates. We are aware of continuing studies at Water Factory 21 in Orange County, California, using microfiltration, and their findings will be useful in evaluating our results. The author of the Discussion is correct in assuming that conventional spiral-wound membranes cannot be air backwashed.

4, 5. The data are represented as monthly averages in Figures 4 and 5. The small increase that the Discussion notes is an artifact of the log-linear regression.

6. Humics should not have been included.
7. Over the average detention of 8 years, many organics will degrade in the lake, and the intense sunlight at the high elevation and lake clarity should accelerate this process. We chose the most conservative assumption that refractory organics will not be attenuated by processes in the lake.
8. The amount of reactive carbon in the effluent is lower than normally found in most drinking water distribution systems, which are not normally cleaned. The location of the final disinfection facility (at the plant or near Lake Papoose) will be evaluated if a full-scale facility is constructed.
9. We did not evaluate UV disinfection, although we considered it when planning the pilot studies. We agree that UV disinfection may offer some advantages and cost savings. Using both ozone and UV, however, would probably not be economically advantageous over ozone use alone. One of our concerns for choosing ozone was its improved efficiency for disinfecting *Giardia* and *Cryptosporidium.*

10. Please note that in the Challenge Testing section of the text, the reference to "Table 6" should read "Table 5." In Table 5, the columns UF, NF, and RO must be compared with caution because they were not challenged with the same quantities of organisms, which occurred for the following reasons. To properly sample each process, it was necessary to know its retention time, which was determined using sodium chloride as a tracer. Sodium chloride was spiked into feed tanks, and process effluents were sampled over time. The processes showed mixing characteristics close to "plug flow," and sampling times for subsequent challenge tests were chosen to correspond to the time of 95 to 100% sodium chloride breakthrough. At a later date, the procedures were repeated, except that feed tanks were spiked with organisms instead of sodium chloride. The actual number of organisms in each feed tank was determined to calculate removal efficiency. The different-sized feed tanks and dilutions resulted in the RO process being challenged with fewer organisms than the ultrafiltration (UF) or nanofiltration processes, which produced the lower log-removal rates. Three tests each were performed for UF, RO, and nanofiltration; one test was performed for each ozone process. The *Giardia* and *Cryptosporidium* removals were obtained by filtering 160- to 200-L composite samples. The bacteriophage results were based on triplicate samples.