

## PREFACE

This book chronicles the development of advanced analytic laboratory capabilities at the Bloomington, Illinois water treatment plant over a 12-year period, 1997–2008. It details the application of these advanced analytical techniques to the evaluation of water treatment plant performance. Finally, it illustrates how the knowledge gained from these scientific evaluations can be used to improve the operations of the water treatment plant processes.

Initiated in 1997 as a cooperative effort between H<sub>2</sub>O'C Engineering and the Bloomington (Illinois) Water Department operating and laboratory staff, a progressive series of water quality studies and plant process evaluations were conducted on-site at the Bloomington water treatment plant. This was part of an overall effort to effect cost savings, improve operational efficiencies, meet evolving regulatory requirements, update emergency procedures, and document operational procedures and experiences for the benefit of future generations of plant operators. Much of the material presented in this volume was derived from discussions with Bloomington's operators. The continual enhancement of Bloomington's water treatment laboratory capabilities and the presentation of highly focused in-house operator training programs have been by-products of this ongoing series of plant process evaluations.

A number of special in-house studies were undertaken, on a pilot scale and using Bloomington's lake water sources, to evaluate alternative treatment procedures for controlling tastes and odors. At significant cost, substantial amounts of data were obtained on the seasonal occurrence of compounds known to be associated with tastes and odors. Further, in an effort to define causative agents, numerous micrographs of microorganisms, from lake to tap water, were archived throughout a specific taste-and-odor episode.

The age, history, and unusual configuration of the Bloomington plant also allowed for a unique comparative evaluation of three generations of upflow, slurry blanket contact, and lime softener/clarifiers, manufactured successively by Dorr-Oliver, Infilco, and CB&I ClariCone.

Since the sand filters at Bloomington have been capped with granular activated carbon (GAC) for odor reduction, a series of special studies were conducted to determine means for

improving the performance of the GAC in supporting microbial growth and reducing odor-causing compounds, such as geosmin and 2-methyl isoborneol (MIB). From the results, the seasonal timing of replacement of the GAC caps was modified. Finally, in-house pilot programs were initiated to assess the effectiveness of alternate odor control techniques, such as ozonation and ultraviolet light catalyzed peroxide oxidation.

## **CHAPTER 1 (MICROSCOPIC PARTICLE ANALYSIS)**

After developing the necessary capabilities and defining the methodologies, epifluorescence (ultraviolet light) microscopy was used for the enumeration of *total bacterial cell counts*. This sensitive parameter was then used to evaluate the particle removal performances of coagulation and lime softening in Bloomington's three generations of upflow lime softener/clarifiers. In addition, cell counts were made following recarbonation, filtration, and disinfection. Thereafter, comparisons of microscopic techniques were made with turbidity and electronic particle counter measurements to assess filter backwash effectiveness and establish a more scientific basis for setting criteria for filter *return-to-service* following backwash. Finally, micrographs were taken to illustrate the appearance of the particles commonly found in Bloomington lake water sources and at various stages of treatment and distribution.

To facilitate the extended use of the microscopic procedure, Appendix A provides detailed procedures and instructions for conducting the *total bacterial cell count by epifluorescence microscopy*.

## **CHAPTER 2 (PLANT PROCESS EVALUATIONS)**

More comprehensive studies were undertaken to assess the benefit of installing filter return-to-service *flow ramping* following backwash. Comparisons of filter effluent particle content were made using turbidity, direct microscopic enumeration, and electronic particle counts. While each measure is sensitive to different component parts of the spectrum of particles present in the filtered water, it was concluded that online monitoring of turbidity remains the most convenient and practical means for optimizing the backwash and flow ramping protocol for each individual filter.

## **CHAPTER 3 (LIME SOFTENING)**

Studies conducted during the winter of 2000–2001 assessed the performance of Bloomington's lime softening process and determined the overall plant performance with respect to reduction of total organic matter (TOC). In addition, seasonal data on softening and the comparative removals of magnesium hydroxide and calcium carbonate were reviewed and compared with the results of jar test softening studies conducted over a wide range of pH. The significant effect of temperature on magnesium solubility and, therefore, coagulation by magnesium hydroxide is discussed with respect to its implication for operation during periods of cold weather.

## CHAPTER 4 (ACIDIFICATION PROTOCOL)

Extensive in-house experimentation demonstrated that acidification of Bloomington softened water samples to pH 2.0 removed the finished water turbidity created by calcium carbonate but had no observable effect on the contribution to turbidity made by biotic particles. Therefore, filtered water sample acidification to dissolve inorganic precipitates increases the meaningfulness of turbidity as a microbiological surrogate. Based on these results, alternate turbidity exceedance levels were proposed and alternate operational procedures were established for routine filter performance evaluations.

## CHAPTER 5 (FILTER OPERATIONS)

Based on extensive interviews with plant operators, an illustrated manual was prepared detailing filter operation, backwash procedures, performance monitoring, and filter maintenance.

Separately, as part of a *filter surveillance program*, the degree of filter bed expansion during backwash was measured using a shop-constructed pan flute device. The device and results are illustrated.

The removals of organic compounds on Bloomington's GAC-capped filters were quantified on both virgin and aged media to observe adsorption and microbiological uptake of dissolved organic carbon. Micrographs of the microbial growth on both GAC and sand media were archived. Operationally, the annual GAC and sand replacement procedures are illustrated.

The *Filter Operations Manual* details Bloomington's current filter washing procedures. Filtered water turbidities, both unacidified and acidified, are plotted for effluents during a complete filtration cycle. In addition, measurements of dissolved oxygen were used to assess the extent of bacterial respiration as well as their removal from filter media during backwash. From these studies, a novel procedure is advanced for evaluating biological activity on filter media.

Systematic efforts were undertaken to assess the cleaning of the filtration media as first one pump and then a second is started to progressively increase the degree of bed expansion. Observing insufficient expansion in older filters, recommendations are given for comparative testing of a replacement underdrain system with auxiliary air scour in a rehabilitated test filter.

## CHAPTER 6 (GRIT REMOVAL)

The proprietary ClariCone, manufactured by CB&I, is an upflow, slurry blanket contact softener/clarifier that integrates the introduction of lime slurry, coagulation of precipitates within a slurry blanket, and settling to occur in an inverted cone-shaped basin.

The procedure for *gritting* (the process of removing the heaviest settled material from the lower cylinder of the softening unit) was evaluated by solids sampling and underwater video. In addition, the effect of the gritting process on the stability of the lime softening slurry blanket was evaluated. From these various evaluations, a revised gritting protocol was recommended.

To facilitate understanding of its operation, upward flow velocities in the inverted cone softener/clarifier were calculated and illustrated as a function of hydraulic loading and depth.

## **CHAPTER 7 (LIME SOFTENER PERFORMANCE ENHANCEMENTS)**

The evaluation of a modified grit removal procedure was undertaken to minimize the disturbance of the lime softener *slurry blanket* during gritting and, thereby, mitigate problems created by *lime overfeed*.

Slurry blanket particle size profiles were obtained as a function of depth, both before and after gritting. As a result, the lime feed points to Bloomington's four inverted cone softeners were significantly modified to achieve more effective utilization of lime, minimize slurry blanket upset, and avoid transient lime overfeeds.

## **CHAPTER 8 (LIME SOFTENER OPERATIONAL ENHANCEMENTS)**

The inverted cone softener receives its inflow through two pipes entering a cylindrical *can* tangentially at the base of the unit. The tangential inflows are intended to create a spiral flow pattern as the water rises within the cone. The distribution of the inflows between the two inlet pipes, one large and one small, is adjusted using two butterfly valves. This allows for control of the input kinetic energy required to promote an optimal spiral flow pattern. Too little energy input causes the spiral motion to *stall* so that the suspended matter in the blanket rises vertically. Such short-circuiting results in reduced residence time in the lime softening slurry blanket and causes surface upwellings or *boils* on the blanket surface.

To assist in operational control of the inflow valves, this evaluation explored the adjustment of flows to the inlet pipes for the establishment of an optimal blanket *swirl* (optimum hydraulic energy input). In addition, the studies aimed at determining the appropriate heights of the slurry blanket and the required setting of the height of the concentrator cone.

A discussion of the operation and maintenance of the complex slaked lime slurry delivery system is included in this chapter.

## **CHAPTER 9 (GRANULAR ACTIVATED CARBON)**

Although taste-and-odor control was the primary goal when GAC caps were initially installed on Bloomington's 18 filters, other benefits realized included the supplemental reductions of TOC, pesticides, and herbicides (e.g., atrazine). This current reevaluation of the performance of the GAC included an assessment of the costs, required frequency of GAC replacement, warranties, and service contract conditions.

## **CHAPTER 10 (PLANT OPERATIONS MANUAL)**

Photo- and micrograph-illustrated descriptions of Bloomington's water sources, watershed protection measures, treatment system (e.g., lime equipment and feed facilities, softening operations, recarbonation facilities, lime sludge disposal practice, filter operations,

backwashing protocols, GAC replacement, primary and secondary disinfection, system control and data acquisition (SCADA) systems, laboratory and shop facilities, emergency power generator, and other backup systems) were derived from extensive interviews with plant operating and maintenance personnel, and plant design data. Constantly under revision, this document is being developed to serve as an introduction to plant configuration, nomenclature, and operation for newly recruited plant personnel.

The following series of brief, illustrated *guideline documents* (included in Appendix C) were also prepared to supplement the *Plant Operations Manual*.

### **Guideline Documents**

1. Operator-on-Duty: Responsibilities
2. Operator's Laboratory: From Analysis to Database
3. Operator-on-Duty: *Making the Rounds*
4. The Lime Delivery System: From Dry Storage to Slakers to ClariCones
5. Recarbonation: From Liquid CO<sub>2</sub> to Gas to Solution
6. Filtration: Description and Operation

## **CHAPTER 11 (TASTE-AND-ODOR CONTROL)**

Owing to a seasonal increase in nitrate levels in Lake Bloomington from agricultural drainage, on December 2, 2004, the influent to Bloomington's treatment plant was adjusted to a blend of 60% Lake Bloomington and 40% Evergreen Lake water. While effectively reducing nitrate levels, musty-earthly odors from Evergreen Lake water were detected in the plant's finished water within a day.

System assessments included an evaluation of nutrient input sources; microscopic examination and quantification of organisms through the plant; monitoring of geosmin, MIB, TOC, H<sub>2</sub>S and tannin/lignin; and observation of lake stratification conditions, including temperature and oxygen profiles.

Preliminary assessments of responses to treatment alternatives (powdered activated carbon, GAC caps, aeration, potassium permanganate, chlorine dioxide, hydrogen peroxide, Fenton's reagent, ozone, aerobic biodegradation on GAC) were undertaken as an operational guide to the most effective and practical methods for taste-and-odor control.

A series of microscopic surveys of particle abundance provided micrographs of organisms from lake to tap water on numerous dates throughout the duration of the taste-and-odor episode.

## **CHAPTER 12 (GAC ADSORPTION AND MICROBIAL DEGRADATION)**

A major objective of this testing program was to determine the effectiveness of organism growth on aged (used or in-service) GAC in providing biologically mediated removal of odorous compounds after the initial adsorptive capacity of the virgin GAC was exhausted. In addition to odor surrogate (geosmin) removal, a temperature-dependent dissolved oxygen depletion on microbially colonized GAC was observed.

Monitoring of geosmin and MIB as a function of lake water depth revealed that these compounds were most abundant just above the lake benthos.

*Aeration* and *ozonation* were compared with respect to geosmin odor removal. While effective, ozonation was found, instead, to impart an ozonous odor.

A special series of tests was made using a feed of hydrogen peroxide to plant filtered water followed by *ultraviolet irradiation* to catalyze the oxidation of geosmin. Preliminary results indicated that high peroxide dosages and extended UV contact times would be required for effective geosmin removal.

## PROCESS EVALUATIONS AND OPERATIONS

Water supply, treatment, and distribution systems constantly evolve to meet increasing demands and address more stringent drinking water quality criteria. Continuing development of additional, new water sources often change water quality input parameters. However, improved analytical techniques provide better means for optimizing water treatment processes and achieving economies through improved operations.

Overall, external changes and developments create challenges to those methods previously employed for system operations. The authors hope that the scientific and technical methodologies illustrated in this case study will provide specific examples of how a progressive water utility can work to meet these challenges. In the spirit of contributing to these efforts to improve water treatment practice, questions, comments, and suggestions may be sent to [john@h2oc.com](mailto:john@h2oc.com).

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