2 WATER QUALITY

2.1 Water Quality Profiles

Given

Various categories of water sources.

Required

State what you believe may be reasonable estimates for water quality profiles (constituents and concentrations and any important time variations) for several source waters that may be put to some use (for any purpose as listed in the second problem), such as:

(a) mountain streams in the Rocky Mountains or in the High Sierras

(b) lower reaches of rivers, such as the South Platte, the Missouri, the Ohio, the Sacramento, the Iowa, the Cedar

(c) lakes such as Lake Superior, Lake Erie, Lake Tahoe

(d) raw wastewaters to municipal treatment plants

(e) treated wastewaters from municipal treatment plants

(f) tertiary treated wastewasters from municipal treatment plants

(g) raw wastewaters from industries such as electronics, metal plating, meat packing, brewery, poultry processing, electric energy generation, etc.

Develop case examples for situations that you select.

Solution

(a) Mountain Streams. The mountain streams of the Rocky Mountains and of the High Sierra Nevada Mountains have, except during the snowmelt runoff season from about May 1 to July 1, low turbidity, e.g., <0.1 NTU, low TDS, e.g., <50 mg/L; low alkalinity, e.g., <30 mg/L; low TOC, e.g., <5 mg/L; low coliforms, e.g., <10 colonies/100 mL; low total heterotrophic plate count, e.g., <1000 colonies/mL; winter temperatures have been measured at 0.0˚C. During the spring runoff the turbidity is much higher, e.g., 30-50 mg/L; TDS is lower yet, e.g., 30 mg/L; TOC is higher, e.g., 20-50 mg/L. The treatment train must be designed to handle both the summer, fall, winter conditions, as well as spring runoff conditions. The Cache La Poudre River, that flows through Fort Collins in northern Colorado and into the South Platte River at Greeley, fits the water quality profile described. Some waters in the northeast USA fits the profile described. Even some waters used in the vicinity of Atlanta, e.g., Gannet County, GA fits the profile, in part.

(b) Lower Reaches of Rivers, e.g., South Platte, the Missouri, the Ohio, the Sacramento, the Iowa, the Cedar. Each river is different, of course, but the lower reaches of rivers have a larger variety of contaminants and higher concentrations, as contrasted with mountain streams. Those mentioned have received treated effluents from municipalities and industries, agricultural runoff, etc. Further, they different with respect to ecological niches provided.

(c) Lakes such as Lake Superior, Lake Erie, Lake Tahoe. Lake Superior and Lake Tahoe are “oligotrophic” lakes, while Lake Erie is famous as a “eutrophic” lake.

(d) Raw Wastewaters to Municipal Treatment Plants. Raw wastewater has high BOD and suspended solids, e.g., 200-300 mg/L for each, high ammonia, phosphates, etc.

(e) Treated Wastewaters from Municipal Treatment Plants. BOD and suspended solids must meet the 30/30 standard, except lower levels may be required, depending on the context.

(f) Tertiary Treated Wastewasters from Municipal Treatment Plants. In general, BOD and suspended solids are about 5/5 mg/L.

(g) Raw Wastewaters from Industries such as Electronics, Metal Plating, Meat Packing, Brewery, Poultry Processing, Electric Energy Generation, etc. Meat packing a poultry processing may have BOD levels of several hundred mg/L. Brewery wastes may also have high BOD levels and is subject to sudden changes as releases occur from batches, e.g., "steeping". Electronics industries may have metals and perhaps organic compounds, depending upon the in-house recovery. Effluents from electric energy generation plants are likely to have higher temperatures than found in ambient waters.

Discussion

The situations cited illustrate the diversity of water quality that occur either in ambient waters, or waste-waters of various kinds, or treated waters of various kinds. If you have access to records from any organization that deals with water quality you can characterize the waters for which the records are available. These records will be perhaps continuous in some cases, e.g., turbidity; or from a daily grab sample, e.g., alkalinity; or perhaps quarterly or semi-annually, e.g., selected organic compounds; or possibly at irregular intervals, e.g., cartridge filter sampling. If you have records available over an annual cycle, a plot may be helpful. In some cases, e.g., raw municipal waste water, variation over the diurnal cycle may be useful. The responses provided are just indicative of the situations described.

2.2 Water Quality Criteria

Given/ Required

State what you believe may be reasonable expectations for water (constituents and concentrations and any important time variations) for purposes such as,
(a) irrigation of citrus, vegetables such as lettuce, sugar beets, etc.
(b) farm uses such as livestock, poultry, etc.
(c) industries such as sugar beet refining, steel manufacturing, manufacture of electronic chips, electric energy generation, poultry processing, dairies, etc.
(d) drinking water such as in New York City, Seattle, Denver, New Orleans, Baghdad, Zurich, Milano, Istanbul, Palermo, etc.
(e) recreation such as swimming pools,
(f) protection of salt water environments such as the Mediterranean, Caribbean, San Francisco Bay,
(g) fisheries such as the Blue River near Dillon, Echo Lake in the High Sierras, Lake Michigan, the South Platte near Greeley, San Francisco Bay, the Ohio River, etc.
Develop case examples for situations that you select.

Solution

An early book that provided general guidance to many of the foregoing questions was *Water Quality Criteria*, by Jack E. McKee, a professor at the California Institute of Technology, and commissioned by the Division of Water Resources, State of California and published in 1952. For many years, this book was the primary reference on the issues of water quality. In 1963 a second edition of the book was published by the California Water Quality Control Board, which was expanded by Harold Wolfe, a then doctoral student at UCLA and who became second author. Other references that have been added, and may be more generally available include: *Quality Criteria for Water*, US Environmental Protection Agency, Washington, DC, July, 1976 (sometimes called the EPA Red Book) and *Quality Criteria for Water 1986*, EPA 440/5-86-001, US Environmental Protection Agency, Washington, DC, May 1, 1986 (sometimes called the EPA Yellow Book). The Yellow Book has added entries on organic compounds. [Jack McKee was one of the three initial partners in the firm known as Camp, Dresser, and McKee or CDM.]

The format of these references is in terms of water quality constituents, arranged alphabetically, so one approach would be to scan the pages of one of the volumes mentioned. The Yellow Book would be the best since it has the latest entries. For some uses, a more extensive search may be necessary; for example, water quality for farm uses such as livestock and poultry uses, specialized searches may be necessary. Internet searches are likely to yield results.

Looking at drinking water, the criteria are really standards (in most cases). These are drinking water standards promulgated as regulations (to be adopted by the States) by USEPA and that have been evolving since 1974 and apply to all American cities. Certain cities that use surface water sources without filtration have exemption from the requirement that all surface waters be filtered, i.e., the "filtration rule" (first promulgated in 1989 in the *Federal Register*). New York City is a case in point, as is Portland, Oregon.

For countries that are members of the European Union (EU), certain "directives" are promulgated to be adopted by member countries. Such directives include the EU drinking water standards.

A weak link in providing drinking water is in the distribution system and control of cross-connections, dead-ends, maintenance of disinfectant, etc. Regulations are required first and then a cadre of trained inspectors must be in-place, along with vigilance in enforcement. A plumbing code is an essential element. Adequate pressure in the distribution network, to reduce the risk of negative hydraulic gradients, is another element. Culture is another element in the mix and may influence whether inspection is rigorous and whether enforcement is subject to being compromised.

The World Health Organization (WHO) also promulgates drinking water standards, which are less stringent than those of developed countries so that developing countries can find them attainable, but yet stringent enough such that there is low risk to public health.

State Health Department regulations may provide regulations for swimming pools. In addition the health departments (which may be called departments of environmental quality) may provide guidance for beaches, and regulations for river water quality to protect fisheries.

From the foregoing, we may conclude that standards for drinking water quality are “normative”, i.e., dependent upon the social norms of the community. There is nothing absolute about standards. The health risks may vary with the standards established. For some constituents, the difference in standards from one place to another will have little consequence. For others, the health risks may vary accordingly and may be immediate or long-term. Micro-organisms pose immediate risk, if present, whereas some chlorinated hydrocarbons are considered carcinogenic, which could take years or decades to be manifested. Various countries may view each of these risks with different degrees of aversion, depending on the health or ecological consequences, along with economic priority. In addition to health risks, there are nuisance effects such as hardness, staining, palatability, etc. All of these may be tolerated to various degrees depending again on the community and its economic priority.

In some countries water is considered a "free" good to the people. The problem is that financing of a system is not adequate for the needed capital investment or the ensuing maintenance. In many cases, rural communities have no piped water and so water quality standards may be a moot issue.

2.3 Source Water Quality and Treatment for Potable Water

Given/ Required

Discuss some examples from the literature with respect to water quality profiles of source waters and the degree of treatment needed to meet certain uses that you may select. If you have access to records of treatment plants, then these provide first-hand references and are more “real-world.”

Solution

First, the mix of possible combinations of “m” source waters and “n” uses is quite large, e.g., the size of a hypothetical matrix, m•n in size. Practically, the number of combinations is much less. The main point is, however, that this gives some idea of how to frame the problem. Thus, the treatment train design depends upon the selection made. At one end of the spectrum of water quality profiles are the mountain snow-melt waters and at the other end one may find sea water. Uses may vary from the requirement for essentially molecular water for the electronics industry to a relatively low quality water for transport of sugar beets within a plant.

Looking at the records of any water treatment plant will provide water quality data for both the source water and the product water and will provide an idea of the transformations involved. From these one may associate these transformations with the unit processes that comprise the treatment train.

2.4 Water Quality Criteria/ Standards

Given/ Required

Look up criteria and standards for uses that you may select. Pick two categories of uses. Document your sources.

Solution

General Statement. About any water use we select has much more complex water quality standards than in say 1960. Some of the basic notions of water quality criteria were well established by 1960 and were associated, to a large extent, with water-borne diseases. But since then, the issue has become much more complex. First, we know a great deal more about what's in the water, i.e., the constituents that comprise water quality and their concentrations. Second, we know more about the effects of certain constituents. Third, for uses with enforceable standards, we as a country have been willing to formulate regulations with enforcement. For those uses with non-enforceable standards or criteria, those having interest have probably revisited the premises of the criteria and either confirmed or revised them, as appropriate.

Selection. Out of hundreds of possible uses, select any two arbitrarily. Suppose we pick drinking water for one category and irrigation water for sugar beets for the other.

Drinking Water. USEPA drinking water standards fall into two groups, primary and secondary. Primary drinking water standards relate to health and are two parts: (1) non-enforceable health goals, i.e., MCLG's, and (2) enforceable regulations, i.e., MCL's. [MCL means maximum contaminant level.] Secondary standard relate to esthetics and are not enforceable. In 1989, the USEPA primary drinking water regulations were in several groups: (1) volatile organic compounds, (2) inorganic chemicals, (3) synthetic organic compounds, (4) radionuclides, and (5) microbiological parameters. The specific contaminant total is 62 for all of the foregoing categories. To illustrate a few of the standards, in the volatile organics category, the trichloroethylene standard is MCLG=0 mg/L and MCL=0.005 mg/L. Within the inorganics category, MCLG(mercury)=0.002 mg/L and MCL(mercury)=0.002 mg/L; and MCLG(nitrate)=10 mg/L, MCL(nitrate)=10 mg/L. Skipping to microbiological parameters, MCLG(*Giardia*)=0; MCL(*Giardia*)=filtration and disinfection. The same applies to viruses. [The reference used for this discussion was Chapter 1 Rationale for Water Quality Standards and Goals, by J. A. Cotruvo and C. D. Vogt, in *Water Quality and Treatment*, Fourth Edition, 1990, McGraw-Hill, New York, edited byFrederick W. Pontius. A fifth edition was published in 1999.]

Sugar Beets. I picked sugar beets because its not too complex with respect to water quality criteria. Some of the general water quality parameters for irrigation include: total dissolved solids (TDS) and sodium absorption ratio (SAR). Higher levels of TDS has an osmotic effect on crops resulting in more difficulty in water uptake; generally TDS≤1000 mg/L are satisfactory for irrigation but higher concentrations, e.g., 1400 mg/L, have been used in practice. The higher the salinity, the higher the water use advisable. This is because the salinity may be concentrated in the root zone, and so with higher salinities, more flushing through the root zone is required. Sodium may have a toxic effect on some plants but in general sodium causes clay soils to swell; therefore the proportion of exchangeable sodium should be low. The SAR is defined, $SAR=Na/[0.5(Ca+Mg)]^{0.5}$, with all values in milliquivalents per liter.

Other crops may have particular requirements, depending on the species. For example, boron is limited to ≤0.5 mg/L for citrus. If treated municipal waste-water is used for irrigation, there are limitations on its use. California has developed standards that define the limitation s. Colorado addressed the problem in the late 1990's.

2.5 Organic Carbon Over Annual Cycle

Given/ Required

Discuss levels of TOC, and color, as they vary over an annual cycle in ambient waters that you may select.

Solution

Table 2.5.1 shows TOC and alkalinity data as obtained by the City of Bellingham for their water treatment operation. For the raw water, 1.7≤TOC(raw)≤3.1 mg/L; dissolved organic carbon, DOC, was only slightly lower, e.g., 3.0≤DOC(raw)≤1.7 mg/L. Although not specified as a part of the problem, the treated TOC and DOC concentrations are reduced 0.3-0.5 fraction. Alkalinity levels are seen to be quite low, e.g., with average only about 20 mg/L as $CaCO_3$. Soda ash, i.e., Na_2CO_3, is added which increases the alkalinity slightly.

Table 2.5.1 Organic carbon and alkalinity (Lake Whatcom, Bellingham, WA)

Date	TOC Raw GH (mg/L)	TOC Treated (mg/L)	DOC Raw GH (mg/L)	DOC Treated (mg/L)	Raw Water Alkalinity (mg/L $CaCO_3$)	Treated Alkalinity (mg/L $CaCO_3$)
01/02/2002	2.8	1.1	2.5	1.0	19.5	26.5
02/05/2002	1.8	1.0	1.7	1.0	19.2	24.5
03/04/2002	1.8	1.0	1.7	1.0	21.5	24.6
04/09/2002	1.8	1.0	1.9	1.1	20.0	26.0
05/01/2002	1.7	1.0	1.6	1.0	19.0	24.5
06/04/2002	2.0	1.1	1.8	1.1	19.5	24.0
07/02/2002	1.8	1.1	1.8	1.1	21.2	28.5
07/18/2002	1.8					
07/30/2002	1.8					
08/05/2002	3.1	1.9	3.0	1.8	19.5	26.0
08/13/2002	2.0					
09/03/2002	2.4	1.4	2.0	1.3	20.1	27.0
09/10/2002	2.3					
10/01/2002	2.1	1.3	2.0	1.4	19.5	23.0
10/25/2002	2.1					
11/04/2002	2.2	1.3	2.3	1.4	20.0	25.5
11/19/2002	2.1					
12/03/2002	2.1	1.6	2.0	1.3	20.0	23.5
12/17/2002	1.9					
Average	**2.1**	**1.2**			**19.9**	**25.3**

All tests run per: TOC- SM 5310C
where:
Raw (gatehouse) is untreated Lake Whatcom water
Treated is fully treated water entering the distribution system
Data provided by Peg Monaghan Wendling, City of Bellingham; used with permission

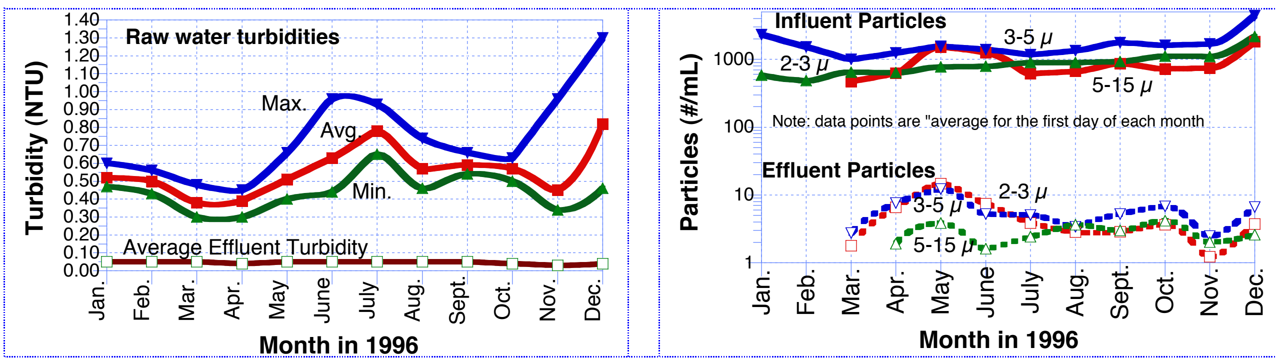
2.6 Particles and Turbidity Over Annual Cycle

Given/ Required

Discuss levels of particles and turbidity as they vary over an annual cycle in ambient waters that you may select.

Solution

Figure prob2.6 (a) and Figure prob2.6 (b) show turbidities and particles as obtained by the Bellingham, WA WTP over an annual cycle. The water source was Lake Whatcom, a reservoir several km in length located just a few km above the city. The water is snowmelt from the Cascades. As seen the turbidities of the lake water is mostly <1 NTU and often <0.5 NTU. For comparison, the filtered water turbidity is seen as always <0.1 NTU. Particle data are shown in Figure 2. 6 (b), which shows 3-5 μm particle counts generally about 1000 #/mL. Effluent particles are generally <10 #/mL for all sizes. The turbidity levels and particle counts of Lake Whatcom water are among the lowest found for any surface waters. Note also that the variations over the annual cycle does not show marked trends as found in most rivers. Its not likely that the changes seen in April and October are due to overturns since the winter temperatures are probably not below freezing (this is not confirmed by having seen temperature data for winter months).



(a) Turbidity **(b) Particles**

Figure prob2.6 Raw intake water from Lake Whatcom and filtered water over an annual cycle at Bellingham – turbidity and particles (Figure used with permission, Department of Public Works, City of Bellingham, WA)

Note: Figure prob2.6 (a) and Figure prob2.6 (b) are Figures 6.1 and 6.2 in a report: Hendricks, D. W., et al. Biological Surrogates for Filtration Performance Evaluation, AWWA Research Foundation and American Water Works Association, Denver, 2000. Data for the plots were from data provided by B. Evans, personal communication (1996). Mr. Evans was supervisor of the Bellingham Water Treatment Plant.

2.7 Water Quality Monitoring

Given/ Required

Provide some examples of water quality monitoring with respect to:

(a) regulatory surveillance
(b) process control
(c) data base development

Solution

(a) Regulatory Surveillance.

All plants must have documentation that their performance is as intended. There is always an overseer that has legal or administrative authority over the operation of a plant. At the State level, this is the regulatory agency to which potable water treatment plants report Data reported include all regulated contaminants and at intervals specified. Sampling intervals are stated in the regulations. In the case of the "filtration rule", the operation of the plant must be documented. For waste water treatment plants (municipal and industrial), the plant effluent must comply with the NPDES permit (in the USA). For industrial waste water treatment plants that discharge to municipal sewers, their discharges must meet the requirements of the local ordinance; usually an operator within the plant is assigned to oversee the system.

(b) Process Control.

As noted, monitoring for process control may be done separately from surveillance. The flows that provide an assessment of the respective processes are monitored. Thus turbidity and/or particle counting of plant effluent (in drinking water) give an assessment as to whether the filtration process is performing satisfactorily; if not, its likely that the coagulant dosage should be adjusted. In activated sludge wastewater treatment, there are a number of measurement needed for process control. Most of these have to do with ascertaining the condition of the sludge. In membranes, its usually the pressure loss across the membrane that must be monitored. In addition, there should be a system in place to detect pin-point leaks. Each unit process has its own unique requirements for process control.

(c) Data Base Development.

The idea of data base development is pertinent to the use of a source water. Any given water should be "profiled" with respect to time variation, e.g., diurnal and annual, and any trends over years. There should also be a spatial description, e.g., along the length of a river or over the area and depth of a lake. Sampling stations should be established and used without change. In the case of drinking water treatment, such a profile will help anticipate changes in water quality over seasons and to detect any trends that could occur during the life of the plant. Profiling the occurrence of *Giardia* cysts and/or *Cryptosporidium* oocysts is useful background knowledge. For discharge of wastewaters, knowledge of the receiving water quality is necessary both to minimize effects on the resource and to provide data in the event of legal action.