1. a. What change was made to the MCL for arsenic in the early 2000’s? Why was this change delayed for a while, and why was it ultimately approved?

Right as President Clinton was ending his term in office (January 2001), EPA determined that the MCL for arsenic should be lowered from 50 µg/L (ppb) to 10 µg/L. When President Bush took office, he wanted to be sure that his new EPA Administrator would have the opportunity to review any last-minute decisions made by the outgoing administration. Therefore the new arsenic standard was delayed until May 2001, and then again until February 2002, so that the public could comment and so that the EPA could re-assess the new rule (including the science behind the rule and the costs and benefits associated with the proposed lower standard). Three expert panel reviews were conducted in 2001 to help EPA evaluate the proposed lower standard. In October 2001, the new EPA Administrator decided to let the proposed rule stand, affirming that the science was sound and that the more stringent standard would help protect public health.

b. What are some of the benefits of lowering the arsenic standard? What are some of the costs?

The benefits of lowering the arsenic MCL are dominated by the avoidance of certain cancers and non-cancer health effects. Several forms of cancer, including skin, liver, bladder, kidney, and lung cancers have been associated with arsenic exposure. Non-cancer health effects that would be avoided (and thus listed as benefits) include skin thickening, vascular and gastrointestinal effects, nervous system effects, developmental effects, and diabetes. EPA estimates these benefits to total between 59–86 deaths avoided each year, with a quantified annual benefit of $140 to $198 million. Other benefits include the reduction in risks for co-occurring contaminants that may be removed by installing new treatment technologies.

The costs of lowering the standard are substantial. The costs are dominated by the additional treatment that will be necessary to remove arsenic from contaminated drinking water supplies. Also included are costs relating to additional personnel needed to operate the new treatment facilities, additional training and oversight of these persons, and costs related to the increased production of materials and chemicals for treatment processes. EPA estimates these costs to be approximately $181 million each year.

c. Briefly explain why we are concerned about arsenic levels. What human health effects are associated with arsenic exposure?
We are concerned about arsenic because the estimated risks of cancer at the former MCL of 50 µg/L are quite high. High levels of arsenic in drinking waters in Bangladesh have led to very high levels of skin cancer, and similar situations have occurred in the past in Taiwan. Though we are not currently experiencing a crisis on the order of Bangladesh’s crisis, increased demand for water in western states will likely require the development of new sources of water.

d. Where does arsenic in drinking water come from?

Arsenic is a naturally occurring contaminant that is released to drinking water supplies primarily from the weathering of soils and minerals. Unfortunately, many of the same states that are likely to see growth in water demand also have high levels of arsenic in their groundwater supplies (e.g., in the Southwest). Thus more and more people would be exposed to arsenic at higher levels if a lower standard had not been adopted.
2.  a. Why is there no MCL for microorganisms such as *Giardia lamblia*, *Legionella*, and viruses?

   Laboratory tests to quantify these organisms are too expensive and difficult for routine water-quality monitoring. Therefore, they are regulated with a treatment technique (TT) rather than an MCL.

   b. What types of treatment are required to remove these microorganisms? What are the required levels of inactivation for *Giardia*, viruses, and *Legionella*?

   Filtration and disinfection are required to remove these pathogens. *Giardia* requires three-log (99.9%) removal, and viruses require four-log (99.99%) removal. There is no removal level specified for *Legionella*. The rationale is that if the standard is met for *Giardia* and viruses, then it is quite likely that *Legionella* will be effectively removed as well.

   c. Recently, EPA has been instituting a set of “enhanced surface water treatment rules” (ESWTR). What is the main objective or purpose of this set of rules?

   These rules started coming on-line after the *Cryptosporidium* outbreak in Milwaukee in the mid-1990s. Their main purpose is to protect against *Cryptosporidium*. There is also an effort to reduce the risk from disinfection by-products, but the main driver for these rules is protection against Crypto.
3. (15 pts) Read the following article:
I’ll try to get a PDF copy to distribute, but you should be able to access this article from a USF computer by going to http://pubs.acs.org and searching for it there. After reading the article, answer the following questions (in your own words, of course).

a. Summarize the approach and the specific steps used by EPA in setting a drinking water standard for trichloroethene (TCE).

The approach used by EPA in setting a drinking water standard for trichloroethylene (TCE) consists of the following basic steps:
1) Survey the occurrence of TCE in drinking water supplies and estimate the number of people exposed as a function of concentration;
2) Determine the individual exposure and the level of cancer risk imposed by varying concentrations in drinking water (i.e., develop dose-response curves);
3) Quantify the population risk by combining estimates of cancer risk with the estimates of the number of persons exposed; and
4) Estimate the total expected excess of cancer deaths due to TCE exposure, and set the standard based on maximum acceptable risk level. (e.g., $10^{-6}$ risk means that one person in a million will contract cancer as a result of a lifetime of exposure to this chemical in drinking water.)

b. In your opinion, is it reasonable to establish a MCL for this contaminant? In other words, is there need to regulate TCE specifically in public water supplies?

Opinions on whether it is reasonable to establish an MCL for TCE may vary. I agree with EPA that TCE should be regulated with an MCL. From my point of view, the relevant question is how we should act in the face of immense scientific uncertainty, and my opinion is that it is better to err on the side of stringency rather than leniency when it is a question of public health. (Of course, there is a practical limit to that – we can never make water perfectly “safe” – but establishment of an MCL for TCE has proven feasible without putting any significant financial burden on our water providers.)
4. (10 pts) Read the following short articles:
I will try to get PDF copies to distribute, but you can access these from a USF computer via the http://pubs.acs.org web site. You can also refer to the following EPA web site.
http://water.epa.gov/drink/contaminants/unregulated/perchlorate.cfm

Based on what you read, do you think it is appropriate for EPA to set an MCL for perchlorate at this point? Why or why not? Hint: answer question 5 after you answer question 4, because question 4 will help you understand what is involved in setting an MCL.

A reasonable case could be made that, since we don’t yet know how much perchlorate is ingested in food versus water, it is premature to set a drinking water MCL for perchlorate. However, my personal opinion is that EPA should not wait until that knowledge is gained. Enough data already exist to go through the four-step process outlined above, and thereby determine a “safe” level of perchlorate in drinking water. Personally, I do not believe that it is an acceptable argument to say “since people are eating contaminated food, it is therefore OK if they drink contaminated water too.” Instead, I suggest that safeguards be put in place so that both our water and our food be safe for ingestion. There are costs associated with that, to be sure, but my opinion is that it is worth it.
PROBLEM: Suspension of particles in water

Calculate the sphericity of the particles.

Area of an ellipse = \( \pi \frac{L_1 L_2}{4} \) where \( L_1, L_2 \) are lengths of major, minor axes

Volume of particle = \( \pi \frac{L_1 L_2 H}{4} \) where \( H = \) thickness = 1 nm = 0.001 \( \mu m \)

Given \( L_1 = 2 L_2 \) \( \Rightarrow \) \( V_{\text{particle}} = \frac{1}{4} \pi x \left( \frac{x}{2} \right) (0.001 \mu m) \) where \( x = \) size given in table

So what sphere has the same volume?

\( \frac{4}{3} \pi r^3 = \frac{1}{4} \pi x \left( \frac{x}{2} \right) (0.001 \mu m) \) \( \Rightarrow \) \( r^3 = \left( \frac{3}{16} \right) (x) (\frac{x}{2}) (0.001 \mu m) \)

\( r = \sqrt[3]{\frac{3x^2}{32} (0.001 \mu m)} = \) radius of the sphere with equal volume

Now think about surface area

Surface area of sphere = \( 4 \pi r^2 \)

Surface area of particle = area of top + area of bottom + area of sides

\[ = 2 \left[ \frac{4}{3} \pi x \left( \frac{x}{2} \right) \right] + H \times (\text{circumference of ellipse}) \]

\[ = 2 \left[ \frac{4}{3} \pi x \left( \frac{x}{2} \right) \right] + H \times \left[ \pi \frac{1}{2} \left( \frac{L_1}{2} - \frac{L_2}{2} \right)^2 \right] \]

\[ = \frac{4}{3} x (\frac{x}{2}) + (0.001 \mu m) \pi \frac{1}{2} (\frac{x}{2} + \frac{x}{4}) \]

\[ = \frac{1}{4} \pi x^2 + (0.001 \mu m) \left( \frac{3x^2}{8} \right) \]

Notice the second term will be negligible because \( x \approx 0.001 \mu m \) for all size classes

This surface area of particle \( \approx \frac{1}{4} \pi x^2 \)

Sphericity \( \psi = \frac{4 \pi r^2}{A_{\text{particle}}} = \frac{16r^2}{X^2} \) where \( r = \sqrt[3]{\frac{3x^2}{32} (0.001 \mu m)} \)

e.g., for biggest size range, 32-128 \( \mu m \):

\( x = \) geometric mean = \( \sqrt{(32 \mu m)(128 \mu m)} = 64 \mu m \)

particle volume = \( \frac{1}{4} \pi (64 \mu m)(32 \mu m)(0.001 \mu m) = 1.61 \mu m^3 \)

radius of equivalent sphere = \( r = 0.73 \mu m \)

surface area of particle = \( 3,220 \mu m^2 \)

surface area of equivalent sphere = \( 6.64 \mu m^2 \)

sphericity \( \psi = \frac{6.64 \mu m^2}{3,220 \mu m^2} = 0.002 \) -- not spherical at all!

See spreadsheet for calculations for all size classes.

Smallest class is "most spherical" but still not really spherical at all.
Estimate TSS.

For each size class, \( \frac{\text{mass}}{\text{vol}} = \frac{\text{particles}}{\text{vol}} \times \frac{\text{volume}}{\text{particle}} \times \frac{\text{mass}}{\text{volume}} \)

We are given \( \frac{\text{particles}}{\text{vol}} \) for each size class, also given density = 2.2 g/cm³.

We know the volume of the particle from part (a).

Thus we can calculate TSS for each size class.

Total TSS = sum of all size classes = 112 mg/L.

TSS is dominated by the smallest particles -- 78 mg/L.

Estimate surface area concentration

For each size class, \( \frac{\text{area}}{\text{vol water}} = \frac{\text{area}}{\text{vol water}} \times \frac{\text{area}}{\text{particle}} \)

The area per particle was found in part (a).

Add up individual size classes \( \Rightarrow 102 \text{ m}^2 \text{ particles/L} \)

This is also dominated by the smallest particles.

Just as an aside -- we can determine the surface area mass of the particles.

...It works out to \( 900 \text{ m}^2 \text{g} \) -- very high! So these flaky particles have lots of surface area because of their non-spherical shape.

How much removal to get 99% removal of TSS?

Reduce TSS from 112 mg/L \( \Rightarrow 1.12 \text{ mg/L} \).

To do that, we must remove 100% of size classes 2-5.

Size class 1 (the smallest) must reduce from \( 77.8 \text{ mg/L} \) \( \Rightarrow 1.12 \text{ mg/L} \).

Remove 98.5% of smallest size class and 100% of all larger classes.

How much alum required?

![Diagram of sphere and area covered by sphere]

Spheres have diameter 2.5 nm \( \Rightarrow \) radius 1.25 nm.

Area covered by 1 sphere is \( \pi r^2 = 4.9 \text{ nm}^2 \)

\( = 4.9 \times 10^{-18} \text{ m}^2 \)

Need to cover \( 0.5(102 \text{ m}^2/\text{L}) = 51 \text{ m}^2/\text{L} \)

Therefore need \( 1.0 \times 10^{14} \) spheres.
(2) continued

\[ 1.0 \times 10^{19} \text{ spheres} = 1.7 \times 10^{-5} \text{ moles of hydronium alum spheres} \]

But 1 mole of \([\text{Al}_6(\text{OH})_{18}]^{3+}\) requires 3 moles of alum \(\text{Al}_2(\text{SO}_4)_3\)

Therefore need \(5.2 \times 10^{-5}\) moles/L of alum.

Molecular weight of alum = 342 g/mol as \(\text{Al}_2(\text{SO}_4)_3\)

\[
\text{or } 594 \text{ g/mol as } \text{Al}_2(\text{SO}_4)_3 \cdot 14 \text{ H}_2\text{O}
\]

Here I will consider the hydrated form, \(\text{Al}_2(\text{SO}_4)_3 \cdot 14 \text{ H}_2\text{O} \ldots \text{OK if you used } \text{Al}_2(\text{SO}_4)_3\]

\(5.2 \times 10^{-5} \text{ mole/L} \times 594 \text{ g/mole} \times \frac{1000 \text{ mg}}{1 \text{ g}} = 31 \text{ mg/L alum needed}

(would be \(\approx 18 \text{ mg/L if you used } \text{Al}_2(\text{SO}_4)_3\) as molecular formula)

(3) How much alkalinity would be consumed?

1 mole alum addition is like 3 moles of \(\text{H}_2\text{SO}_4\) or 6 moles of \(\text{H}^+\)

\[ 5.2 \times 10^{-5} \text{ moles alum/L} \times \frac{6 \text{ eq}}{1 \text{ mol alum}} \times \frac{1 \text{ mol CaCO}_3}{2 \text{ eq}} \times \frac{100 \text{ g CaCO}_3}{1 \text{ mol CaCO}_3} \times \frac{1000 \text{ mg}}{1 \text{ g}} = 16 \text{ L as CaCO}_3
\]

(3) Estimate \(A\) and \(\beta\) for \(\frac{dN}{dx} = Ax^{-\beta}\)

For each size class, estimate \(\frac{dN}{dx} \approx \frac{\Delta N}{\Delta x}\) where \(\Delta N\) is the given concentration, and \(\Delta x\) is given by \(x_{\text{max}} - x_{\text{min}}\) for that size class.

Then graph \(\log(\frac{\Delta N}{\Delta x})\) vs. \(\log(x)\) for the five size classes.

See spreadsheet for calculations and graph.

From the graph, we find the slope of the line = \(-4.68\)

Therefore \(\beta = 4.68\)

The intercept of the line = \(\log(A) = 10.822\)

Therefore \(A = 6.6 \times 10^6 \text{ (particles/mL) } \times \mu m^{4.7} = 6.6 \times 10^6 \text{ particles/mL } \mu m^{3.7}\)

\[
\frac{dN}{dx} = (6.6 \times 10^6) x^{-4.7} \text{ for } x \text{ in } \mu m
\]

\(N\) in particles/mL
PROBLEM: How textbook problem 5-1(c).

2) Calculate the molar concentration of metal ion in the stock coagulant.

Given coagulant is 50% as Fe₂(SO₄)₃, and specific gravity 1.45

\[
1.45 \, \frac{\text{g}}{\text{cm}^3} \times \frac{1000 \, \text{cm}^3}{1 \, \text{L}} \times 0.5 = 725 \, \text{g/L as Fe₂(SO₄)₃}
\]

\[
725 \, \text{g/L} \times \frac{116.19 \, \text{g Fe}}{399.87 \, \text{g Fe₂(SO₄)₃}} = 208.5 \, \text{g/L of Fe} = 3.16 \, \text{mol/L of Fe in stock}
\]

3) Calculate coagulant feed rate.

\[
25 \, \text{mg Fe₂(SO₄)₃/L water} \times \frac{75,000,000 \, \text{L water}}{1 \, \text{d}} = \frac{1 \, \text{L stock coagulant}}{725 \, \text{g Fe₂(SO₄)₃}} \times \frac{1 \, \text{L stock coagulant}}{1000 \, \text{mg}} = 26,700 \, \text{L/d}
\]

\[
25 \times 12 \, \text{L/d} \times \frac{1 \, \text{d}}{1440 \, \text{min}} = 1.8 \, \text{L/min of stock coagulant}
\]

4) Calculate alkalinity consumed.

\[
25 \, \text{mg Fe₂(SO₄)₃/L water} \times \frac{1 \, \text{g}}{1000 \, \text{mg}} \times \frac{1 \, \text{mol Fe₂(SO₄)₃}}{400 \, \text{g Fe₂(SO₄)₃}} \times \frac{6 \, \text{eq Fe₂(SO₄)₃}}{1 \, \text{mol Fe₂(SO₄)₃}} \times \frac{1 \, \text{mol CaCO₃}}{2 \, \text{eq}}
\]

\[
= \frac{100 \, \text{g CaCO₃}}{1 \, \text{mol CaCO₃}} \times \frac{1000 \, \text{mg}}{1 \, \text{g}} = 19 \, \text{mg/L as CaCO₃} \text{ alkalinity consumed}
\]

(also Creideren 3rd edition 9-5)

5) Calculate sludge production.

\[
25 \, \text{mg Fe₂(SO₄)₃/L water} \times \frac{1 \, \text{mmol Fe₂(SO₄)₃}}{400 \, \text{mg Fe₂(SO₄)₃}} \times \frac{2 \, \text{mmol Fe(OH)₃}}{1 \, \text{mmol Fe₂(SO₄)₃}} \times \frac{107 \, \text{mg Fe(OH)₃}}{1 \, \text{mmol Fe(OH)₃}}
\]

\[
= \frac{75,000,000 \, \text{L water}}{1 \, \text{d}} \times \frac{1 \, \text{kg Fe(OH)₃}}{10^6 \, \text{mg Fe(OH)₃}} = 1000 \, \text{kg/d Fe(OH)₃ sludge}
\]

That's one ton every day! About the same as a Honda Civic car, every day. Solids handling is a major part of large centralized water-treatment facilities.

(also Creideren 3rd edition 9-5)
Demonstrate that 1 g of Fe₂(SO₄)₃ will produce approximately 0.5 g of Fe(OH)₃ as a precipitate, generate 0.66 g CO₂, and consume approximately 0.75 g of alkaliinity as CaO₂₃.

Stoichiometry: Fe₂(SO₄)₃ + 6 H₂O → 2 Fe(OH)₃ + 6 H⁺ + 3 SO₄²⁻

6 H⁺ + 6 HCO₃⁻ → 6 CO₂ + 3 H₂O

50 Fe₂(SO₄)₃ + 3 H₂O + 6 HCO₃⁻ → 2 Fe(OH)₃ + 6 CO₂ + 3 SO₄²⁻

Mol. wt. of Fe₂(SO₄)₃ = 400 g/mol
Mol. wt. of Fe(OH)₃ = 107 g/mol
Mol. wt. of CO₂ = 44 g/mol

1 g Fe₂(SO₄)₃ x \frac{1 \text{ mole Fe₂(SO₄)₃}}{400 \text{ g}} x \frac{2 \text{ moles Fe(OH)₃}}{1 \text{ mole Fe₂(SO₄)₃}} x \frac{107 \text{ g Fe(OH)₃}}{1 \text{ mol Fe(OH)₃}} = 0.535 g Fe(OH)₃

1 g Fe₂(SO₄)₃ x \frac{1 \text{ mol Fe₂(SO₄)₃}}{400 \text{ g Fe₂(SO₄)₃}} x \frac{6 \text{ moles CO₂}}{1 \text{ mole Fe₂(SO₄)₃}} x \frac{44 \text{ g CO₂}}{1 \text{ mol CO₂}} = 0.66 g CO₂

1 g Fe₂(SO₄)₃ x \frac{1 \text{ mol Fe₂(SO₄)₃}}{400 \text{ g Fe₂(SO₄)₃}} x \frac{6 \text{ eq produced}}{1 \text{ mol Fe₂(SO₄)₃}} x \frac{1 \text{ mol CaCO₃}}{2 \text{ eq}} x \frac{100 \text{ g CaCO₃}}{1 \text{ mol CaCO₃}} = 0.75 g CaCO₃