Problem 1.

The results of an analysis of water from the Thames River, London, are given below.

<table>
<thead>
<tr>
<th>Chemical Species</th>
<th>milligrams/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silica [Si(OH)₄]</td>
<td>14</td>
</tr>
<tr>
<td>Calcium (Ca⁺²)</td>
<td>94</td>
</tr>
<tr>
<td>Magnesium (Mg⁺²)</td>
<td>6.1</td>
</tr>
<tr>
<td>Phosphate (PO₄⁻³)</td>
<td>1.0</td>
</tr>
<tr>
<td>Bicarbonate (HCO₃⁻)</td>
<td>156 [as CaCO₃(s)]</td>
</tr>
<tr>
<td>Chloride (Cl⁻)</td>
<td>52</td>
</tr>
<tr>
<td>Iron [assume present as colloidal Fe(OH)₃(s)]</td>
<td>1.8</td>
</tr>
<tr>
<td>Chromium (assume present as CrO₂⁻⁴)</td>
<td>0.01</td>
</tr>
<tr>
<td>Copper (Cu⁺²)</td>
<td>0.05</td>
</tr>
<tr>
<td>Suspended solids</td>
<td>43.0</td>
</tr>
</tbody>
</table>

a) What is the hardness of this water (in mg/L as CaCO₃)?  **Ans. 260 mg/L as CaCO₃(s)**

b) If the pH = 7.4, what is the concentration of OH⁻ in moles/L?

c) If this water were used for drinking without dilution, what constituents could pose a health hazard (as indicated by a violation of the primary standards for drinking water)? What constituents could represent aesthetic or economic concerns (as indicated by a violation of the secondary standards for drinking water)?

d) What is the total alkalinity [in units of equivalents/L and in units of mg/L as CaCO₃(s)]?  

Note that the contribution of CO₃⁻² to total alkalinity is expected to be insignificant for pH values < 8.3. You can check this since the equilibrium constant for the reaction HCO₃⁻ ↔ H⁺ + CO₃⁻² is K₂ = 10⁻¹⁰.³, i.e.,

\[
10^{-10.3} = \frac{[CO_3^{2-}][H^+]}{[HCO_3^-]}, \text{ where } [\text{ ]} \text{ indicates the concentration of the indicated substance in units of moles/L.}
\]

In the water analysis HCO₃⁻ is reported in units of mg/L as CaCO₃(s). Before you can use this to calculate total alkalinity, you must convert to units of mole HCO₃⁻/L. To do this, divide mg/L as CaCO₃(s) by the molecular weight of CaCO₃ to obtain moles CaCO₃/L. Then multiply by \( \frac{1 \text{ mole CO}_3^{2-}}{1 \text{ mole CaCO}_3} \) and then by \( \frac{2 \text{ equivalents}}{1 \text{ mole CO}_3^{2-}} \) to obtain a concentration in eq/L. One mole of CO₃⁻² can react with two moles H⁺ in an acid/base reaction (to produce H₂CO₃), so that’s why there are 2 eq/mole. Since, in the context of a particular type of reaction, one equivalent of any substance is equal to one equivalent of anything else, you can now multiply by \( \frac{1 \text{ equivalent HCO}_3}{1 \text{ equivalent CO}_3^{2-}} \) and since one HCO₃⁻ can react with one H⁺ in an acid/base reaction, you can multiply by \( \frac{1 \text{ mole HCO}_3}{1 \text{ equivalent CO}_3} \) to get the desired units of mole HCO₃⁻ per liter for your calculation of total alkalinity.

**Ans. 3.1x10⁻³ eq/L**
e) Total alkalinity is measured by titration with a strong acid to a predefined endpoint (approximately pH = 4.5) at which point weak base species such as $\text{HCO}_3^-$, $\text{CO}_3^{2-}$ and $\text{OH}^-$ will have reacted essentially completely with the added acid. This measurement process is termed a “titration”. How many milliliters of 0.02 N $\text{H}_2\text{SO}_4$ would be required to measure the total alkalinity of a 100 mL sample of Thames River water? **Ans. 15.6 mL**

[Note: a 1 N solution has a concentration of 1 equivalent/L and remember that one equivalent always reacts with one equivalent in the context of a particular type of reaction.]

**Problem 2. Analysis of Solids Data**

a) The following test results were obtained for a wastewater sample taken at the headworks (i.e., input) to a wastewater treatment plant. All of the tests were performed using a sample size of 50 mL. Determine the concentration (mg/L) of total solids, total volatile solids, suspended solids, and volatile suspended solids.

Tare mass of evaporating dish = 53.5433 g.

Mass of evaporating dish plus residue remaining after evaporation of sample at 105°C = 53.5793 g.

Mass of evaporating dish plus residue remaining after ignition of dried sample at 550°C = 53.5772 g.

Tare mass of Whatman glass fiber, grade C (GF/C) filter = 1.5433 g.

Mass of filter plus residue on Whatman GF/C filter after filtering sample and drying at 105°C = 1.5553 g.

Mass of filter plus residue on Whatman GF/C filter after ignition at 550°C = 1.5531 g.

**Partial Ans. VSS = 44 mg/L**

b) Explain why inorganic compounds such as $\text{MgCO}_3(s)$, that are unstable when exposed to heat, can introduce an error in the measurement of volatile solids.

**Problem 3.** How is the chemical oxygen demand (COD) of a water measured? How does COD differ from biochemical oxygen demand (BOD)?

**Problem 4.** Six weekly effluent samples were analyzed for bacterial content using the 5-tube lactose-fermentation technique. The results are given on the following page. Determine the coliform concentration, expressed as MPN/100 mL, for each sample using the MPN tables given in appendix G of *Water Quality* by Tchobanoglous and Schroeder. [Pay special attention to the instructions given in appendix G for interpretation of data].
### Problem 5.

Pick one physical or chemical water quality parameter discussed in class (other than total alkalinity, volatile solids, COD and BOD which are covered in homework problems above) and describe how it is analytically measured. Discuss one possible limitation of the measurement, such as a source of error, an analytical limitation or subjective feature of the analysis.

### Problem 6.

Ethical decisions often do not present clear right or wrong choices. The attached discussion of “Decisions Based on an Ethical Analysis” is taken from Introduction to Environmental Engineering by P.A. Vesilind (PWS Publishing Co., NY; 1997). The discussion illustrates how thorny ethical frameworks can be when we try to apply them to decisions that affect the environment.

Consider the following hypothetical case taken from Vesilind’s text. A wastewater treatment plant for a city discharges its treated plant effluent into a stream, but the treatment is inadequate. You are in charge of the city’s public works, and you hire a consulting engineer to assess the problem and to offer solutions. She estimates that expanding the capacity of the treatment plant to achieve the required effluent quality will be an expensive proposition. She figures that the city can meet the downstream water-quality standard by building a large holding basin for the plant effluent (discharge) and holding back the treated wastewater during dry weather (low river flow) and discharging only during high stream flows (rainy weather). The amount of organic pollution being discharged would remain the same, of course, but now the stream standards would be met, the river water quality would be acceptable for aquatic life, and the city would be off the hook.

Of course your consulting engineer did some calculations before making her recommendation. You have checked her calculation of the annual cost of the two alternatives and, on the basis of economics alone, the engineer’s recommendation is correct.
since the holding basin would save the city approximately $275,000 per year. Would you recommend this solution to the city council? Provide a ½ to 1 page (maximum) (single spaced) analysis of the ethical basis for your decision. Please type your answer to this question.

[Note: the intent of this problem is to have you think about your values and the ethical system you use to make decisions and how they might be applied to an environmental problem. Your instructor is not in the business of promoting one particular personal ethical framework over another; however Civil and Environmental Engineers are expected to make professional decisions that conform to the fundamental principles of the ABET Code of Ethics of Engineers. A copy of this code is attached. Your essay will be graded upon the basis of its being clear, articulate and proposing a solution that is consistent with the ethical system you describe.]