

# 4. Water Chemistry

## 4.1 *Chemistry of Natural Waters*

### 4.1.1 INTRODUCTION

Water quality is a generic term and is usually determined by the levels of various indicator substances. These indicators are generally selected on the basis of the type of waterbody in question (eg. stream, estuary, groundwater, potable water) and the water use (eg. the quality of water required for drinking is higher than that required for recreation).

Impacts on surface and groundwater water quality can occur during exploration, construction and operation of mines, as well as at abandoned and rehabilitated minesites. Uncontrolled drainage from mines can contribute potentially harmful materials to local waterways and may degrade the water's suitability for domestic, agricultural or industrial uses, or be harmful to the ecology of the receiving environment. Government authorities are placing tighter controls on site discharges and many sites throughout Australia now operate under a zero discharge policy.

It is important to understand the characteristics associated with the various types of water sources and discharges likely to be encountered.

While the quality of the source or discharge at any given site is dependent on the geochemistry, mineralogy and geographical location of the operation, there are general characteristics associated with the water that may be encountered in Australia. This section includes a general overview of some of the common physicochemical parameters and includes for each:

- definition and alternate names;

- units in which the parameter is commonly measured and reported;
- sources (what activity can contribute to the levels of these parameters); and
- environmental significance of the parameter being determined.

However, before discussing individual physico-chemical parameters, several terms and concepts common to most aquatic and geochemical parameters will be introduced.

### 4.1.2 DISSOLVED VERSUS PARTICULATE AND TOTAL CONSTITUENTS

#### *Definition*

The distinction between dissolved, particulate and total constituents is one of the most important definitions used in water quality assessment. An element can move between the dissolved and particulate phase depending on physico-chemical conditions such as temperature, pH or the presence of some other element or compound. This is often referred to as "partitioning". Discharge licences generally relate levels of a certain element to either the dissolved, particulate or total concentration. The following example depicts the relationship between the three phases.

Consider a one litre bottle of a water sample collected for the analysis of cadmium. The sample contains both dissolved and particulate forms of cadmium. The *dissolved* cadmium concentration is the cadmium in the sample after it has been filtered through a 0.45µm pore size filter. The *particulate* cadmium in the sample is what remains bound to the material on the filter.

**Total** concentration can be determined either directly or by calculation from the dissolved and particulate results. It is not simply a summation of the two concentrations as the suspended solids concentration has to be taken into account. For example, the dissolved cadmium concentration was found to be 3 µg/L, the particulate concentration of cadmium was determined as 250 µg/g (or mg/kg), and the suspended sediment concentration was 6540 mg/L (0.650 g/L).

Therefore the total cadmium concentration is:

$$0.650(\text{g/L}) \times 250 (\mu\text{g/g}) + 3 (\mu\text{g/L}) = 154.5 \mu\text{g total Cd/L.}$$

Alternatively, the total cadmium concentration may be measured directly by digesting (using acid) and analysing a sub-sample of the original one litre sample.

The definition of “dissolved” using a 0.45 µm filter is purely operational and has no direct biological rationale. Precise definitions may be found in APHA (1994).

The classifications of total, particulate and dissolved concentration are used widely when setting discharge permits and water quality criteria. Generally, dissolved criteria are more often used for the protection of aquatic ecosystems. This is because most toxicity data show that it is the dissolved phase of pollutants which is bioavailable to aquatic organisms and thus potentially toxic. Total concentration criteria are generally used for recreation, livestock and human health water quality criteria, given that separation of the particulate load prior to either swimming or drinking raw water is unlikely to occur. In addition, the acidic nature of the human gut means that many pollutants can remobilise into the dissolved phase and therefore become more bioavailable.

#### 4.1.3 DIFFERENCE BETWEEN ORGANIC ACID AND CARBONATE WATER SYSTEMS

The main aquatic geochemical processes throughout most of Australia's inland fresh waters are dominated by one of two general geochemical systems. In the context of this handbook, these will be termed:

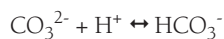
- carbonate water (water in which the carbonic acid equilibrium plays the dominant role in governing water chemistry); and
- organic acid water (water with natural high levels of dissolved organic matter).

Waters in which the primary control is the carbonic acid system have pH values ranging from 6 to 8.5 and electrical conductivities up to many thousands of mS/cm. Organic acid systems generally have a pH less than 6 and much lower electrical conductivity.

##### *Carbonate Waters*

The carbonate, or carbonic acid, system describes water in which carbonate species in solution control or influence aquatic geochemical processes. The principal components of the carbonate system include carbon dioxide (CO<sub>2</sub>), carbonic acid (H<sub>2</sub>CO<sub>3</sub>), bicarbonate (HCO<sub>3</sub><sup>-</sup>) and carbonate (CO<sub>3</sub><sup>2-</sup>). The reactions involving these species are very important in surface waters, groundwaters and in the atmosphere. Carbonic acid in water can be derived from several sources, the most important of which are:

1. the weathering of carbonate rocks via:



and

2. uptake of CO<sub>2</sub> from the atmosphere via:

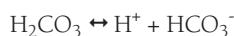
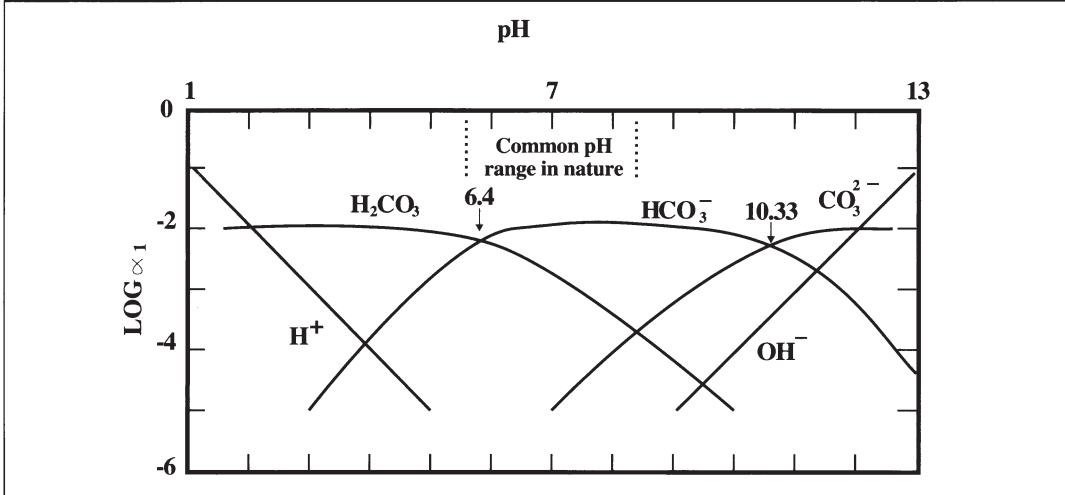


FIGURE 4.1: Species of the Carbonate System as a Function of pH



The species of the carbonate system that is present depends on the pH of the solution (see Figure 4.1). Below pH 6.4, carbonic acid ( $\text{H}_2\text{CO}_3$ ) is the dominant species in solution whereas above pH 6.4 bicarbonate ( $\text{HCO}_3^-$ ) is the dominant species. The greater the total concentration of the carbonate species, i.e.  $\text{HCO}_3^-$  plus  $\text{CO}_3^{2-}$ , the greater the buffering capacity of the water, i.e. the greater the ability of the water to resist change from either acidic or basic inputs. The amount of carbonate produced from reaction 2 is far less important than that derived from the weathering process of rocks. Generally, carbonate system rivers have a higher conductivity, due not to the presence of bicarbonate but rather the co-cations in solutions which are also weathered as a part of the same process that liberates the bicarbonate.

#### Organic Acid Waters

The particular organic acids which control the second major system of aquatic geochemical processes occurring in Australian freshwater rivers and streams are derived from what is loosely termed humic and fulvic material or dissolved organic matter (DOM). DOM is derived from the breakdown products of organic matter and comprises a wide range of complex molecules.

Almost all surface partitioning and adsorption processes involving natural sediments are mediated to some degree by organic matter of this type. Rivers draining regions where little or no carbonate is present, and where bedrock is resistant to weathering, tend to have a low pH and low conductivity. Soils developed in these areas are frequently organic-rich because the bedrock is resistant to breakdown and therefore contributes little mineral to the soil. As water percolates and circulates through the organic rich soil, cations that are present in solution (Ca, Mg, Na, K) are exchanged for  $\text{H}^+$  in the soil organic matter.

As the  $\text{H}^+$  accumulates in solution, the pH decreases. As the pH decreases, organic compounds are leached from the surface litter, into solution. Organic acids are also synthesised by soil organisms and excreted by plant roots.

These waters also originate from areas of high rainfall where peat deposits are common, eg. the western highlands of Tasmania.

#### 4.1.4 LOAD VERSUS CONCENTRATION

In determining water quality, the distinction between load and concentration must often be made. Concentration of the element compound

is emphasised in systems where a threshold or regulatory level is desirable in the receiving water, eg. maintaining total suspended solid values below 100 mg/L, or dissolved oxygen above 9.5 mg/L. Concentration is usually expressed in terms of mass per unit volume, ie.  $\mu\text{g/L}$ ,  $\text{mg/L}$ ,  $\text{g/L}$  or %.

There are other situations where total load or flux (ie. the total amount - mass or volume - of substance per unit time) may be of more concern, eg. nutrient loading into lakes and rivers to avoid algal blooms or the spread of nuisance weeds and phytoplankton. Loadings are usually expressed in terms of mass per unit time ( $\text{g/day}$ ,  $\text{tonnes/year}$ ), mass per unit area ( $\text{kg/ha}$ ), or mass per unit area per unit time ( $\text{kg/ha/year}$ ).

#### 4.1.5 pH

##### *Definition and Alternative Names*

pH is an indicator of the intensity of the acidic or basic character of a solution (APHA 1994).

##### *Units of Measurement*

pH is a dimensionless parameter and is represented on a logarithmic scale of 1 to 14. A pH value of 1 indicates a highly acidic solution, 7 is neutral and 14 is strongly basic, or alkaline. The technical definition is:

$$\text{pH} = -1/\log_{10}[\text{H}_3\text{O}^+].$$

##### *Sources and Environmental Significance*

One of the greatest causes or contributors to the production of acidic water is from sulphide oxidation of iron sulphide minerals such as pyrite ( $\text{FeS}_2$ ) in the presence of oxygen (air) and water. The oxidation reactions are bacterially mediated, primarily by *Thiobacillus ferrooxidans*. Acid generating conditions can occur in damp mine workings, in exposed waste rock dumps, tailings dams and in washeries. Fact Sheet No.7 discusses acid drainage in greater detail.

As the water moves through the acidic material, oxidation of reactive sulphides occurs, generating acidity which initially can be neutralised by alkalinity in the groundwater. If more acid is

generated than the initial alkalinity of the water, the alkalinity will be consumed and acid water will result. If sufficient oxygen is present, the amount of acidity generated is determined by the amount of reactive sulphides in the material. In the absence of mining, acid waters are uncommon because dissolved oxygen in the groundwater is insufficient to produce acidity greater than the alkalinity of the groundwater. During mining, gaseous oxygen is introduced as the rock is broken up, and water movement through the system is accelerated.

The bacteria that catalyse the acidity producing reactions thrive only under acid conditions so that, once acidity is initiated, acid production becomes more rapid and the problem increases rapidly.

A phenomenon only recently identified in Australia is natural acidification of water as a result of acid sulphate soils. These waters have developed in tidal swamps, wetlands and estuarine environments along coastal regions where iron rich silts and muds have mixed with accumulated organic matter. Bacteria thrive in these anaerobic conditions, creating pyrite. When these soils are exposed to air, as occurs with disturbance due to coastal development, sulphuric acid is produced due to oxidation of the pyrite. Potential acid sulphate soils occur in most coastal regions from north of Sydney to Onslow in Western Australia. Any mining development which potentially affects such soils could also result in acid drainage.

In most natural streams where acid drainage is not present, pH levels range between 5.5 and 8.5. Extremes to these levels are usually the results of high loads of natural organic acids (DOM) or high carbonate concentrations. Another effect of mixing acid water with receiving waters high in carbonate is the formation of  $\text{CO}_2$  which affects the respiration of aquatic biota. When pH values fall below 4, most aquatic biota will be severely stressed.

In contrast to the low pH water produced by acid rock drainage, many mineral processing facilities

require water with an elevated pH (9 to 11) which is normally achieved through the addition of lime. Problems of scaling in pipes and ecosystem stress brought about by high pH waters are no less serious than the problems associated with low pH waters.

### **Treatment Options**

Several approaches can be adopted to raise or lower pH including:

- addition of an alkali or acid;
- activated carbon or ultra-violet irradiation to remove DOM; and
- bubbling with CO<sub>2</sub> to manipulate the carbonic acid equilibrium.

### **4.1.6 ALKALINITY**

#### **Definition and Alternative Names**

Alkalinity refers to the acid neutralising capacity (pH buffering) of water, ie. its ability to reduce changes in pH brought about by the addition of an acid. The higher the alkalinity, the more acid is required to reduce the pH. Alkalinity is generally due to the presence of inorganic anions including carbonate (CO<sub>3</sub><sup>2-</sup>), bicarbonate (HCO<sub>3</sub><sup>-</sup>) and hydroxide (OH<sup>-</sup>); however alkalinity may also result from the presence of borates (B<sub>4</sub>O<sub>7</sub><sup>2-</sup>), phosphates (PO<sub>4</sub><sup>3-</sup>) and silicates (SiO<sub>2</sub><sup>2-</sup>).

#### **Units of Measurement**

Alkalinity is expressed in the units of:

mg of calcium carbonate per litre  
of water (mg CaCO<sub>3</sub>/L).

The reported results for alkalinity are influenced by the method of the determination and depend on the pH end-point used in the analysis. Analytical methods are documented in APHA (1994).

#### **Sources and Environmental Significance**

The main sources of alkalinity are the soluble salts of the anions listed in Section 4.1.13.

Alkalinity is known to influence several aquatic geochemical processes including:

- pH and effects from acid drainage;
- dissolved metal solubility and bioavailability (toxicity) to aquatic organisms;
- foaming, scaling and metallurgical problems; and
- dissolution of bicarbonate and carbonate, causing liberation of CO<sub>2</sub> and corrosion.

### **4.1.7 HARDNESS**

#### **Definition and Alternative Names**

Hardness is commonly associated with a water's ability to lather or foam soap. The harder the water the more difficult it is to lather the soap. The principal components of hard water are calcium and magnesium ions (Ca<sup>2+</sup> and Mg<sup>2+</sup>).

Total hardness is defined as the numerical sum of the calcium and magnesium concentrations, expressed as calcium carbonate. When hardness is numerically greater than the sum of carbonate and bicarbonate alkalinity, that amount of hardness equivalent to the total alkalinity is called "carbonate hardness"; the amount of hardness in excess of this is called "non-carbonate hardness". When hardness is numerically equal to or less than the sum of the carbonate and bicarbonate alkalinity, all hardness is carbonate hardness and non-carbonate hardness is normally absent.

#### **Units of Measurement**

Hardness is reported in the same units as alkalinity, ie. mg (CaCO<sub>3</sub>)/L.

There are two methods for determining hardness. The first is by calculation from the Ca<sup>2+</sup> and Mg<sup>2+</sup> concentration in solution, the other is by titration.

Hardness may range from zero to several hundred mg/L, depending on the source and any prior pre-treatment of the water.

#### **Sources and Environmental Significance**

Hardness usually occurs through dissolution of minerals containing calcium, magnesium, and silica compounds, typically calcium and magnesium carbonates, sulphates, chlorides or

nitrates. Because of the inverse solubility of these compounds with temperature, at high concentrations they precipitate out of solution in, for example, boilers and hot water pipes. There are no reported human toxicological consequences of elevated hardness; however, high hardness waters are generally unpalatable.

**Treatment Options**

Treatment options for water with high hardness comprise mainly precipitation of the Ca<sup>2+</sup> and Mg<sup>2+</sup> ions using a mixture of lime (Ca(OH)<sub>2</sub>) and soda ash (Na<sub>2</sub>CO<sub>3</sub>). In this process, the Ca<sup>2+</sup> and Mg<sup>2+</sup> ions precipitate as CaCO<sub>3</sub> and Mg(OH)<sub>2</sub>. As this process occurs at high pH, subsequent pH adjustment may be required. This can easily be achieved by the addition of either H<sub>2</sub>SO<sub>4</sub> or by the bubbling of CO<sub>2</sub> through the softened solution.

**4.1.8 CONDUCTIVITY**

**Definition and Alternative Names**

"Conductivity" is a measure of the ability of water to conduct an electric current. Factors affecting conductivity include temperature and the type, concentration and valency of ions present (eg. Na<sup>+</sup>, Ca<sup>2+</sup>, Cl<sup>-</sup> and SO<sub>4</sub><sup>2-</sup>).

The higher the concentration of conducting solutes, such as salts, the higher the conductivity (see Table 4.1).

TABLE 4.1 Typical Conductivity Range of Waters	
Water	Conductivity Range (mS/m)
Freshly distilled	0.5 - 2
Potable waters	50 - 1 500
Seawater	40 000 - 50 000
Groundwater	up to 50 000

**Units of Measurement**

Conductivity is usually determined by measuring the resistance where:

$$\text{Conductivity} = \frac{1}{\text{Resistance.}}$$

The SI<sup>1</sup> unit for conductivity is mS/m (milliSiemens per metre); however µS/cm is still in common use, and many conductivity instruments use the units µmhos/cm, where 1 mS/m = 10 µmhos/cm.

**Sources and Environmental Significance**

Conductivity is used to monitor several different processes, some of which include:

- determination of amounts of ionic reagent needed in certain precipitation and neutralisation reactions; and
- estimation of total dissolved solids (TDS) in mg/L and salinity in a sample by multiplying the conductivity in mS/m by an empirical factor. For TDS this factor may vary from 0.55 to 0.90 depending on the soluble components of the water and the temperature of the measurement. In the absence of a site-specific relationship, a factor of 0.68 is commonly assumed. Similarly, an estimate (in milliequivalents per litre) of either anions or cations can be derived from the conductivity measurement.

**4.1.9 SALINITY**

**Definition and Alternative Names**

Salinity is an indirect measurement of the total amount of soluble salts in solution. These salts include sodium chloride as well as various calcium and magnesium salts of chlorides, sulphate and nitrates.

**Units of Measurement**

Salinity is generally expressed as parts per thousand (ppt or ‰).

<sup>1</sup> Système Internationale = International System of Units

The only direct method of measuring absolute salinity is to analyse the individual chemical components. Given the time and costs associated with individual analyses, indirect methods such as conductivity are normally favoured.

Conductivity measurements can be made in the field or laboratory with a meter and probe which has temperature compensation. Total dissolved solids is also an approximate measure of salinity

### ***Sources and Environmental Significance***

Dry land salinity is a major problem in certain areas of Australia, caused primarily by the widespread clearing of native vegetation. Replacement of deep-rooted perennial native vegetation with shallow rooted annual pastures which use much less water, allows the water table to rise, bringing dissolved salts to the surface where they are concentrated by evaporation. Similarly, the storage of acid and saline mine water in dams can pollute high quality groundwater reserves. Hypersaline groundwater, with salinities well in excess of seawater, is used as process water in the goldfields of Western Australia. Release of this water into the environment can cause death of vegetation and land degradation.

Criteria for salinity pertaining to various livestock, irrigation and domestic uses can be found in ANZECC (1992) and DME (nd).

#### **4.1.10 SOLIDS**

Total solids, as the name suggests, is a measure of all the substances associated with a water sample, other than the water itself. It can be further refined into its constituent parts, total dissolved solids (TDS) and total suspended solids (TSS), ie.

$$TS = TDS + TSS.$$

### ***Definition and Alternative Names***

Another name for total solids is total residue.

TDS or filterable residue is that portion of a sample (other than water) which passes through a filter of pre-defined pore size. This will obviously depend on the pore size of the filter used. For this reason,

industry has standardised on a range of filters from various manufacturers all with a similar nominal pore size of around 1.2µm. In Australia, perhaps the most widely used is the Whatman glass-fibre filter GF/C. After the water sample is filtered through the GF/C filter, the filtrate is evaporated to dryness at 180°C and weighed; the TDS is calculated from this result.

It is important not to confuse dissolved solids, which are filtered through the GF/C type filters, with the dissolved component of metals. Dissolved metals refers to that portion of the total metals in a sample which pass through, or are not retained on, a 0.45µm filter membrane.

TSS may also be referred to as non-filterable residue (NFR) or suspended particulate matter (SPM).

This parameter measures the amount of solids suspended in a water sample which can be separated from the water and dissolved solids phase by filtration through a filter of fixed pore size.

TSS can be related to the turbidity of a water sample. With careful site-specific calibration, and where the sediment source is relatively constant and homogenous, turbidity can be used to calculate TSS (see: Section 4.1.11). However, extreme care must be taken in developing this relationship.

### ***Units of Measurement***

Total solids and its constituent parts are reported as mg/L. In samples with very high concentrations the units may be expressed as %.

### ***Sources and Environmental Significance***

The composition of total solids depends on the geology, land use, geochemistry and the environment of the catchment. Dissolved solids in water may result from the dissolution of materials exposed during mining, or from the addition of soluble chemicals during the processing of ores. High levels of TDS are often not suitable for potable water, mainly due to inferior taste. In addition, waters high in TDS are rarely suited for industrial applications.

Suspended solids can result from erosion of unprotected ground surfaces, from wash water, or from stormwater mobilising solids deposited on the ground surface as a result of mining or processing activities. The TSS in water can affect the operation of biological and physical wastewater treatment processes. Samples high in TSS are also aesthetically unsatisfactory and affect the partitioning and distribution of various contaminants in the aquatic system. Suspended solids reduce light penetration through the water column, affecting growth of aquatic flora and fauna as well as the aesthetic appeal of the water and its subsequent use for recreation. Under certain flow conditions, suspended material settles out and can smother benthic organisms and their habitats. Other problems with sedimentation include possible disruption to navigation. Since most pollutants can be carried by or adsorbed onto suspended solids, tight controls of TSS in a water management plan can also lower the flux or total load of pollutants entering watercourses. Adsorbed nutrients and organic matter are also a source of nutrients for algal blooms.

Solids remain in suspension only when there is enough force or energy (turbulence) in the water column to keep them in suspension. Rivers with lower gradients and lower energy enable suspended sediments to settle out and become benthic sediment or bed load. The effect of increased sediment loads to a river system are numerous. High suspended sediment loads can affect the gills of fish leading to irritation and lesions. When suspended sediment settles, it can increase river bed elevation or aggradation which, as well as affecting aquatic organisms, may also lead to increased overbank flows and flooding. Sedimentation in water storage can reduce the life of a dam, or increase the costs of dredging as well as decreasing the quality of the retained water.

### **Treatment Options**

Prevention of dust generation through control of processes and stockpiles, and erosion of

land through controls on clearing and prompt revegetation, are ways of reducing solids loadings to water. Sediment retention through the placement of sediment traps will lead to a reduction in the amount of sediment reaching natural watercourses. Sediment traps upstream of a storage dam are an effective means of prolonging the life of a relatively small dam. Treatment of water containing suspended sediments prior to use in a plant or for domestic potable water may require settling, screening, filtering or dosing with a flocculant.

#### **4.1.11 TURBIDITY**

##### ***Definition and Alternative Names***

"Turbidity" is an optical measurement of the sample's inherent ability to scatter light. Turbidity measurements can be affected by the particle size of the suspended matter, its mineral content and its respective abilities to scatter and absorb light. In addition, fine colloidal material can have a major effect on increasing the turbidity (light scattering) of a sample but only have a minor effect or increase in the concentration of total suspended solids.

Optical right angled back-scatter nephelometers are generally used for low level turbidity measurements while forward scattering devices, which are more sensitive to the presence of larger particles, are generally used for in-stream analysis systems. Care must be taken in using optical devices, especially in tropical regions where algae and slime growth can rapidly affect the calibration of these instruments. Similarly, in waters with high suspended solids, abrasion of the optical surface can affect calibration of the instrument.

##### ***Units of Measurement***

The units of turbidity are generally reported in nephelometric turbidity units (NTU). It is possible to produce a calibration curve or regression curve of turbidity versus TSS at a given site; however, this must be repeated for each site, because of the likely changes in the characteristics of suspended solids between different geological regions.

Flow rates can also affect particle size distribution and hence the relationship between turbidity and TSS.

### ***Sources and Environmental Significance***

By world standards, Australian watercourses are quite turbid as a result of intense rainfall and flood events, and the erodibility of agricultural and arid soils. The aquatic ecosystems of many Australian watercourses have adapted to higher turbidity levels than existed prior to white settlement, but most probably at a cost of lower species numbers and diversity.

Turbid waters normally require some form of treatment prior to their use as industrial or potable water. Treatment processes used to remove turbidity can include filtration, coagulation and settling.

#### **4.1.12 OXYGEN DEMAND**

(DISSOLVED OXYGEN, BOD AND COD)

Dissolved oxygen is a key water quality parameter required to sustain a healthy aquatic ecosystem. The presence of excess organic materials such as sewage sludge can significantly add to the oxygen demand of a system, consuming dissolved oxygen from the water as they decompose.

### **Dissolved Oxygen**

#### ***Definition and Alternative Names***

Dissolved oxygen refers to the oxygen molecules that are dissolved in water.

#### ***Units of Measurement***

Dissolved oxygen is usually expressed in parts per million or mg/L. For some natural systems, % saturation is also commonly used.

#### ***Sources and Environmental Significance***

For the protection of aquatic ecosystems, ANZECC (1992) recommends that dissolved oxygen should not normally be permitted to fall below 6 mg/L or 80-90% saturation, this being determined over at least one diurnal cycle.

Reduction in dissolved oxygen within natural aquatic systems can result from inputs of organic material to the system (eg. sewage, some mineral processing effluents) and also from algal blooms. Dissolved oxygen concentrations usually decrease with increasing water temperature.

### **Biochemical Oxygen Demand (BOD)**

#### ***Definition and Alternative Names***

The BOD test is an empirical test in which standardised laboratory procedures are used to determine the relative oxygen demand of wastewaters, effluents and polluted waters. It is often referred to as the BOD<sub>5</sub> test, referring to the biochemical oxygen demand over a five day incubation period.

#### ***Units of Measurement***

The units of BOD<sub>5</sub> are expressed in mg/L along with the incubation time.

#### ***Sources and Environmental Significance***

The BOD test measures the oxygen consumed by biochemical degradation of organic material (carbonaceous demand) and the oxygen used to oxidise inorganic material such as sulphides and ferrous iron. It may also measure the oxygen used to oxidise reduced forms of nitrogen (nitrogenous demand), unless their oxidation is prevented by an inhibitor.

If BOD<sub>5</sub> in effluent is high, then oxygen dependent organisms in the receiving waters may become stressed.

### **Chemical Oxygen Demand (COD)**

#### ***Definition and Alternative Names***

The COD test is used as a measure of the oxygen equivalent of the organic matter concentration of a sample that is susceptible to oxidation by a strong chemical oxidant. For samples from a given location COD can be empirically related to BOD, organic carbon or organic matter.

### *Units of Measurement*

Results are expressed in units of mg O<sub>2</sub>/L.

### *Sources and Environmental Significance*

COD is a useful, but not commonly used, parameter in mine water management. Its usefulness stems from its measurement of the total oxygen demand, unlike BOD which measures oxygen demand available to bacteria over a five day period. As a result, COD concentrations will normally always be higher than BOD concentrations from the same sample.

#### 4.1.13 ANIONS AND CATIONS

##### *Definition*

Anions are those elements with a negative charge (eg. Cl<sup>-</sup>, OH<sup>-</sup>, HCO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>2-</sup>, CO<sub>3</sub><sup>2-</sup>, PO<sub>4</sub><sup>3-</sup>) as opposed to cations which are positively charged (eg. Na<sup>+</sup>, K<sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>). This discussion will be restricted to the common inorganic anions and cations.

##### *Inorganic Anions*

Common anions associated with mine water quality management are chloride (Cl<sup>-</sup>), hydroxide (OH<sup>-</sup>), bicarbonate (HCO<sub>3</sub><sup>-</sup>), nitrate (NO<sub>3</sub><sup>-</sup>), sulphate (SO<sub>4</sub><sup>2-</sup>), carbonate (CO<sub>3</sub><sup>2-</sup>), and phosphate (PO<sub>4</sub><sup>3-</sup>).

##### *Units of Measurement*

Anions are typically reported in the units mg/L. Values in natural and wastewaters range from zero to several hundred mg/L.

##### *Sources and Environmental Significance*

The sources of these anions is dependent on geology as well as prior treatment and uses of the water. Sources of chloride are salts such as NaCl and CaCl<sub>2</sub> which are often present in high concentrations in groundwater. For example, the aquifers of the Hunter Valley of New South Wales contain high concentrations of salt as a result of deposition of sediments in a marine environment. The most common source of soluble SO<sub>4</sub><sup>2-</sup> from mine operations is from the oxidation of sulphide

minerals such as pyrite (FeS<sub>2</sub>). Phosphates (which are present in domestic and industrial detergents) and nitrates (from mine explosives and fertilisers used in mine rehabilitation) can also find their way to watercourses. If these nutrients occur in moderate to high concentrations they can readily stimulate the growth of algae and aquatic weeds.

##### *Inorganic Cations*

##### *Definition*

Cations are those elements with a positive charge, such as sodium (Na<sup>+</sup>), potassium (K<sup>+</sup>), calcium (Ca<sup>2+</sup>), and magnesium (Mg<sup>2+</sup>). These are among the most abundant natural elements in the environment.

##### *Units of Measurement*

Cations are typically reported in the units mg/L. Values in natural surface and groundwaters and wastewaters range between zero to several hundred mg/L.

##### *Sources and Environmental Significance*

The concentrations of these elements in natural waters depends on the geology and geochemistry of the host rock. Calcium concentrations in water from limestone areas are typically higher than for waters from non-calcareous areas.

High concentrations of these cations are typically found in groundwaters and increase their hardness. They also affect the permeability and fertility of soils and, for this reason, their concentrations are closely monitored in the agricultural sector.

Other sources of these cations include leachate from waste rock and tailings dams.

The ratio of the specific major cations relative to each other is also an important factor in considering the implication of their respective concentrations in either feed, process or discharge water.

#### 4.1.14 METALS (TRACE METALS, HEAVY METALS, METAL SPECIATION)

##### *Definition*

Two terms are commonly used when discussing metals in water and environmental management. These are:

- *Trace metals*, which commonly refers to:
  - metals at very low levels in the environment (trace analysis); or
  - trace elements which are either essential nutrients or serve some other necessary biochemical function. These include zinc, iron, copper, cobalt, sodium and potassium;
- and
- *Heavy metals*, which are generally thought to mean toxic metals. Strictly speaking the term refers to metals with an atomic weight greater than that of sodium (22.9).

##### *Units of Measurement*

The units are dependent on the metal and its concentration. Particulate metals are usually reported as  $\mu\text{g/g}$  or  $\text{mg/kg}$ . Dissolved metals are usually expressed in terms of  $\mu\text{g/L}$  or parts per billion. Other units in which metals are sometimes reported include mol, millimol or micromol per litre ( $\text{mol/L}$ ,  $\text{mmol/L}$ ,  $\mu\text{mol/L}$ ). These units relate to the number of molecules of the metal that are present and are not influenced by the actual weight of the elements of concern. This unit is most commonly used in toxicological assessment.

##### *Sources and Environmental Significance*

In natural systems, most metals are only sparingly soluble in water, with higher concentrations usually associated with the particulate phase. The amount of a metal released from its particulate phase into solution is a function of pH, particle geochemistry, aquatic geochemistry, hydrologic factors, temperature, etc. Mobilisation of metals is frequently a secondary effect of acid drainage.

The impact of a particular metal on water quality depends not only on the type and concentration of the metal, but also on its chemical form or speciation. The chemical speciation of a metal (eg. whether copper exists as  $\text{Cu}^{2+}$ ,  $\text{CuCO}_3$ ,  $\text{Cu}(\text{OH})_2$ , or Cu-dissolved organic matter complexes etc.) dictates how bioavailable it is and the extent to which it may enter the food chain, where it may accumulate to toxic levels. Generally, metals are most toxic in their soluble free ionic form (species) eg.  $\text{Cu}^{2+}$ ,  $\text{Ag}^+$  etc., compared to metals complexed with either inorganic or organic ligands (eg.  $\text{CuCO}_3$  or Cu-DOM) or in particulate form (associated with minerals). One exception is mercury which is more toxic in the methyl mercury ( $\text{CH}_3\text{Hg}$ ) species compared to the free ( $\text{Hg}^{2+}$ ) species.

Further information on individual metals and their environmental Significance can be obtained from the various ANZECC guideline documents.

#### 4.1.15 NUTRIENTS

##### *Definition and Alternative Names*

The term "nutrient" refers collectively to elements and compounds which are essential to sustaining adequate biological function. The most common nutrients which may affect the water management of a mining operation are nitrogen and phosphorus. There are various forms of nitrogen such as ammonia, nitrite, nitrate, and organic nitrogen. Phosphorus can be found in the form of orthophosphate, total phosphorus and organically bound phosphates. The form of the nutrient has an integral role in its function and fate in the aquatic environment. Biological productivity may be limited by the availability of either nitrogen or phosphorus, which are often referred to as the growth limiting nutrients. Silica has also been identified as a limiting nutrient in some aquatic systems.

##### *Units of Measurement*

The units of measurement for nutrients depend on the form of either phosphorus or nitrogen that is being measured. Typical expressions are

micrograms of total phosphorus or total nitrogen per litre ( $\mu\text{g TP/L}$  or  $\mu\text{g TN/L}$ ) and milligrams of ortho-phosphorus or nitrate nitrogen ( $\text{mg Ortho-P/L}$  or  $\text{mg NO}_3\text{-N/L}$ ).

### **Sources and Environmental Significance**

Sources of nutrients in mining operations include:

- sewage or septic wastewater;
- nitrogen based nutrients from explosives;
- phosphorus based nutrients from process chemicals and industrial detergents;
- fertilisers applied during rehabilitation works; and
- degradation products of cyanide.

Excessive concentrations of nutrients can promote and accelerate growth of aquatic plants and algae, including attached and floating macrophytes and dense suspensions of free-floating algae. These reduce light penetration and, upon decomposition, cause odours and loss of oxygen in the host ecosystem.

### **4.1.16 OILS, GREASES AND HYDROCARBONS**

#### **Definition and Alternative Names**

The parameter “oil and grease” refers to a range of chemicals which can be extracted from a water sample into the organic solvent trichlorotrifluoroethane. The types of compounds collectively analysed by this method are primarily fatty components from animal and vegetable sources and hydrocarbons from petroleum products. While trichlorotrifluoroethane is used to extract the group of compounds of interest, there are three subsequent analyses which can be conducted depending on the make-up of the water being examined and the likely constituents. Oil and grease determination can also be performed on sludge samples.

If required, total petroleum hydrocarbons (TPH) can be selectively analysed as a separate group by a modification of the oil and grease method.

#### **Units of Measurement**

Oil and grease in water samples is commonly expressed in  $\text{mg/L}$ . Oil and grease in solid sludge is expressed as % of dry solids.

Hydrocarbons are also expressed in this way.

#### **Sources and Environmental Significance**

If present in high amounts, oil and grease can reduce the efficiency of water treatment processes by interfering with anaerobic and aerobic biological processes. Large quantities of oil and grease discharged in wastewater can cause surface films and deposits and result in the staining of riverbanks and coast lines. They can also affect oxygen exchange, oxygen demand and palatability.

#### **Treatment Options**

Treatment options available for the reduction of synthetic organics (fuels, oils, grease etc.) include simple oil-water separators through to expensive dissolved air flotation systems.

### **4.1.17 ORGANICS, NATURAL ORGANIC MATTER, DISSOLVED ORGANIC CARBON**

#### **Definition and Alternative Names**

The term *organics* refers to a broad group of chemical parameters, some of which are used in the resource development and mineral processing industries.

In addition to manufactured organic compounds, there is a broad group of naturally occurring organic compounds which play an important role in aquatic biogeochemical processes. Collectively, these compounds are referred to as dissolved organic matter (DOM), natural organic matter (NOM), dissolved organic carbon (DOC), or humic substances (HS).

#### **Units of Measurement**

For the more general definition of synthetic organics, the units of measurement depend on the analysis being undertaken. Most commonly, they are reported in either  $\text{mg/L}$  or  $\mu\text{g/L}$ .

Naturally derived organic material is most commonly measured as DOC and expressed in units of mg C/L. DOC typically represents approximately 50% by mass of DOM.

#### **Sources and Environmental Significance**

Process reagents such as collectors, frothers and flocculants are all synthetic organic-based compounds. Usually, the amounts of organic compounds used for mineral processing are small and any residual concentrations decay rapidly.

DOM, NOM, DOC and HS refer to a generic group of compounds which are best described as the humic and tannin extracts of soil and plant materials which impart the characteristic tea colour of some natural waters. The organic compounds making up DOM are a group of weakly acidic molecules which, in high concentrations, are able to reduce the pH of the water.

#### **Treatment Options**

The removal of natural organic material can be performed in many ways and is dependent on the amount of DOC present and the amount of water requiring treatment. Common treatment options include adsorption onto activated carbon, UV oxidation and ozone oxidation.

### **4.1.18 COLOUR**

#### **Definition and Alternative Names**

The term *colour* can be divided into:

- *True colour*, ie. the colour of a sample from which turbidity has been removed; and
- *Apparent colour*, which includes the colour and turbidity of the total sample.

Apparent colour is measured on the sample prior to any treatment (except inversion of the sample to suspend all particulate matter) and true colour is measured after either filtration or centrifugation.

Normally, unless otherwise stated, the term *colour* refers to the measure of true colour.

#### **Units of Measurement**

Several methods exist for the analysis of colour, varying from the simple visual comparison, to techniques requiring sophisticated instruments and determination of the colour wavelength of the sample. The units of colour depend on the method of analysis but generally correspond to a “colour number” or code which is based on a visual comparison of the colour of the sample to that of a series of standards, usually made with a platinum cobalt solution. Alternatively, the colour can be measured by light transmittance through a special system of photoelectric cells and light filters. The final choice of measurement depends on the specific water quality to be determined. Regulatory authorities usually specify the parameters to be determined and the specific method of analysis.

#### **Sources and Environmental Significance**

Colour may result from a number of sources including metallic ions (iron and manganese), dissolved organic material (humus and peat material), plankton and weeds. Highly coloured industrial wastes can also contribute to the colour of water.

The environmental implications of colour depend on the element that is imparting the colour.

### **4.1.19 CYANIDE**

#### **Definition and Alternative Names**

Cyanide (CN) is used widely throughout the mining industry to dissolve and complex gold and silver to separate them from the ore. In terms of water quality management there are three main forms or species of CN:

- total CN - refers to all forms of CN and is usually determined by performing an exhaustive hot acid extraction whereby all the CN from both liquid and solid phases are dissolved and subsequently analysed as NaCN;
- weak acid dissociable CN (WAD CN) includes only those CN compounds that are liberated

under weakly acidic conditions, i.e. it does not include all the CN present in the sample; and

- free CN (CN<sup>-</sup>) and hydrogen cyanide (HCN) are the most bioavailable forms of CN, the abundance of which is strongly dependent on pH. The lower the pH the greater the proportion of the total CN that exists as HCN.

### *Units of Measurement*

The units in which CN is expressed depends on the form being analysed and from where it was collected. Samples from process waters containing CN will generally have total CN values in the mg/L range; however, after storage or treatment the values may realistically be in the very low µg/L range. Generally, for process waters using CN values are reported as:

- mg total CN/L;
- mg WAD CN/L; and
- g free CN/L.

### *Sources and Environmental Significance*

While CN can be formed naturally by nitrifying bacteria, the main source in the mining industry is waste streams from cyanidation processes. The mechanisms affecting the environmental fate of CN include:

- bacterial degradation - movement of CN through soils and sediments is thought to be restricted through biodegradation by soil organisms and adsorption to soil particle complexes;
- atmospheric diffusion - at neutral and acidic pH, CN in solution occurs predominantly as HCN gas which readily diffuses into the atmosphere;
- conversion to thiocyanate - free CN reacts with pyrite and pyrrhotite to form thiocyanate, which is relatively stable and non-toxic. Thiocyanate is also produced as a part of the natural detoxification and biodegradation of CN in biotic systems;

- complex formation with metals - CN forms complexes with metal ions which are common in mineral processing wastes. These complexes are usually resistant to biological uptake and are stable in the environment, although some may be readily broken down to their basic components, for example CuCN; and
- photochemical degradation - although complex ions such as ferro-CN and ferri-CN are thermodynamically stable, they can undergo photo-reduction to form free CN in the presence of UV light. In compacted and solid tailings dams, this is only a problem at the surface of the dam. Beneath the surface, away from the UV light, the CN remains as a stable metal-CN complexes. The conversion of CN complexes to free CN is affected by pH, temperature, pond geometry and the intensity of UV light incident on the pond. The concentration of total CN has been observed to drop from around 60 mg/L to less than 5 mg/L in just over 1.5 months (Smith & Mudder, 1991).

#### 4.1.20 ODOUR AND TASTE

##### *Definition and Alternative Names*

Both odour and taste are subjective tests which often depend on an individual's personal criterion to determine the acceptability of the water or otherwise. The tests are usually based on a comparison with tasteless and odourless water samples. Flavour is more objective, and can be used instead. Documented procedures for flavour are available.

##### *Units of Measurement*

Taste and odour are generally reported as dimensionless descriptive numbers which relate to threshold detection limits where the sample is compared to a standard with no, or some definable taste or odour characteristics. The measurements include threshold odour number, flavour threshold number, flavour rating assessment and flavour profile analysis number.

### *Sources and Environmental Significance*

Taste and odour may render the water unsuitable for human consumption and domestic use as well as tainting fish and other foods which inhabit the water. There is no single compound which causes odour. However, tests exist for the determination of several of the prime compounds which impart an odour in waters.

#### 4.1.21 RADIONUCLIDES

### *Definition and Alternative Names*

The mining and milling of ore containing uranium may result in water and wastewater that contains variable concentrations of radionuclides present in the ore. The water that is retained or discharged from an operation should, as a minimum, be analysed for radium-226, thorium-230, lead-210, uranium-238 and polonium-210.

### *Units of Measurement*

The commonly used unit of measurement for radionuclides is the becquerel (Bq). For water, the units are expressed as Bq/L and for soil and sediment the units are expressed as Bq/g.

### *Sources and Environmental Significance*

Radionuclides can be found in wastewater arising from the mining and milling of radioactive ores. Typical streams are:

- excess process water, which may be pumped to a tailings impoundment;
- runoff from the mine pit, ore stockpiles, waste dumps, borrow areas, haul roads and plant area;
- seepage from the mine pit, tailings dam and evaporation ponds; and
- water from water supply bores and dams which has flowed through mineralised material.

## 4.2 *Biological Aspects of Waters*

Mining and mineral processing operations rely on or influence the biological component of natural or artificial systems. These systems can include:

- biological processes beneficial to the operation, eg. anaerobic and aerobic treatment ponds, artificial wetlands;
- ecosystem protection, ie. limiting the physical and/or chemical parameters associated with mine discharges to levels suitable for ecosystem protection; and
- bio-monitoring, ie. using aquatic organisms to monitor the effects and effectiveness of water management practices.

ANZECC (1992) recommended four biological indicators to assess ecosystem condition or health. These indicators are based on the assumption that the extent to which the integrity of an ecosystem is being maintained can only be assessed when the characteristic biological communities of a region are known or, since this will rarely be the case in Australia, by comparison of the biological community at the site or sites of interest with unimpacted communities in similar habitats elsewhere in the region. Each of these indicators relies on a rigorous and statistically sound sampling scheme, which is able to distinguish between various population parameters between impacted and unimpacted sites. Of these biological indicators, two relate to biological community structure and two to community processes.

The biological indicators recommended are:

### **Species Richness**

Measures of specific richness indicate the number of species present in a sample of organisms of given size. They differ from diversity measures which also incorporate the concept of species evenness. A decrease in richness is generally considered as an indicator of ecosystem stress.

Since different components of an ecosystem may respond differently to stress, it is important that all the major biological groups (eg. macroinvertebrates, fish) be evaluated. The ANZECC guideline specifies that the species richness as measured by a standardised index should not be altered.

### Species Composition

ANZECC (1992) has proposed a guideline that, in any waterbody, impacts that result in Significant changes in species composition compared to those in similar, local unimpacted systems should not be permitted. It is possible, although probably unlikely, that ecosystems could maintain species richness while still changing markedly in species composition.

### Primary Production

Primary production forms the basis of most aquatic food chains. In any waterbody, net primary production should not vary from the levels encountered in similar local, unimpacted habitats, under similar light, temperature and nutrient loading regimes. Primary production is known to be sensitive to light (water clarity), temperature and nutrients, amongst other factors.

### Ecosystem Function

In any waterbody, changes that vary the relative importance of the detrital and grazing food chains should be minimised. Production to respiration ratios should not vary significantly from those of similar, local, unimpacted systems.

Some ecosystems, such as large standing waterbodies, have autochthonous primary production (produced within the waterbody) as their major energy source. Others, including forest streams and some wetland systems derive most of their energy from allochthonous detritus (produced from outside the waterbody and is transported to where it is used).

Aquatic systems should be managed such that the relative balance between these two

major energy pathways is maintained, and that natural detritus-driven aquatic systems are not converted to autochthonous primary production driven systems, and vice versa.

### Levels of Protection

Two categories of aquatic ecosystems are identified within the national ANZECC guidelines:

- *Pristine ecosystems* are not subject to human interference through discharges or activities within the catchment. For these ecosystems, now largely restricted to National Parks, it is appropriate for the existing water quality to be protected and preserved through strict management; and
- *Modified ecosystems* include all those systems subject to human interference. Some modified ecosystems have been permanently altered physically, for example through stream channelisation or port construction. Others have been changed through long-term chemical toxicity caused by contaminated sediment or by changed river flow regimes.

#### 4.2.1 MICRO-ORGANISMS

Micro-organisms play an important role in natural aquatic systems and in the treatment of wastewater. The greatest use of microbes in wastewater treatment is for the treatment of sewage using anaerobic and aerobic treatment systems. Other uses of micro-organisms relevant to the minerals industry are:

- treatment of cyanide waste streams generated from mining and mineral processing operations;
- treatment of hydrocarbon contamination arising from spillage or leaks from storage tanks or pipes; and
- remediation of high nutrient or sulphate wastewaters.

#### 4.2.2 ALGAL BLOOMS

Problem algal blooms are usually the result of a number of factors and not generally the result of a single person or a projects activities. A bloom is usually an indication of widespread problems or stress throughout the catchment, as in the case of blue-green algal blooms along the Murray-Darling system. While localised algal blooms can occur on a site, they usually do not pose any great problems and can frequently be controlled. Algal blooms are usually short-term occurrences leading to a population explosion and normally result from a combination of high light penetration and water temperatures, slow flowing or stagnant water and high concentrations of nitrogen and phosphorous. Oxygen depletion and the release of toxic constituents from blue-green algae are common problems that can develop when a bloom collapses and the algae decay.

#### 4.2.3 TOXICITY AND ECOSYSTEM HEALTH

In general, toxicity testing involves determining the effect of various compounds on test organisms under set conditions. The terms  $LD_{50}$  and  $LC_{50}$  are both acute measures of toxicity. However, toxicity can also be measured in terms of non-lethal, chronic parameters such as an organism's growth rate, fecundity changes and behavioural response changes.

An extensive listing of toxicological data has recently been compiled within the ANZECC guidelines, which list the types of compounds and the range of toxicity data available. In general, toxicity evaluation is time-consuming and very expensive.

##### Acute Toxicity

This term refers to a relatively short-term lethal or other effect, usually defined as occurring within four days for fish and macroinvertebrates and less for smaller organisms.

*Lethal dose*<sub>50</sub> ( $LD_{50}$ ) refers to the dose of a test compound, which kills 50% of the test population.

The time required to kill 50% of the population is then used as an index of toxicity. Standard  $LC_{50}$  and  $LD_{50}$  tests are performed over 96 hours. The 96 hour duration is operationally defined and has no biological or biochemical foundation. It was established so that a test could be completed within one working week. It refers to a specific dose of a test compound and is usually expressed as a concentration of the test compound per mass of test organism body weight. Such information is usually used to calculate and assign a safe exposure limit or of recommended dose per person per day.

*Lethal concentration*<sub>50</sub> ( $LC_{50}$ ) is similar to the lethal dose but refers to a concentration. Therefore, this figure is more widely used to test aquatic organisms such as fish and invertebrates. Often, toxicity data are related to a time of exposure, eg. a value of 50µg/L is not to be exceeded more than once over any 12 month period. While such limits do take into account accidental spillages, they are assigned on a purely arbitrary basis and the toxicological information in relation to this value being exceeded is not absolute in nature.

##### Chronic Toxicity

This term refers to long-term toxicity as opposed to sudden death resulting from a test compound. Chronic toxicity is much more difficult to diagnose and relates to longer term exposure to a specific compound. Continued chronic exposure can include adverse responses such as changes to spawning, metabolism or growth rates, or appetite, behavioural or reproductive changes. Because chronic effects are harder to identify, minimal work has been performed to date on the chronic effects of most pollutants, except in the case of human health (mercury for example). Chronic toxicity is often more subjective than a measurement of acute toxicity or  $LC_{50}$  or  $LD_{50}$ . However the chronic toxicity effects of pollutants are now becoming much more important to maintain long-term ecosystem health.

#### 4.2.4 FACTORS INFLUENCING BIOAVAILABILITY AND TOXICITY OF CONTAMINANTS

The following factors play a major role in determining the fate of any waste discharge to the aquatic environment.

- *Carbonate equilibria and effect on metals speciation* - The presence of carbonate enables the formation of inorganic carbonate-metal complexes, as well as buffering pH which can have a major effect on metal speciation.
- *pH effects on speciation* - The lower the pH (ie. the more acid the water), the higher the proportion of a dissolved metal which is bioavailable or in the free ionic or weakly complexed state. If there are significant quantities of particulate-bound metals in the waterbody, a reduction in pH can leach metals from the particles into solution and thus alter the distribution (partitioning) of the metal between the soluble and particulate phases.
- *Effects of organic matter on complexation and speciation* - Natural organic matter in aquatic systems can consist of large polyelectrolytic molecules with numerous binding sites of different polarities. Consequently, on a single molecule, numerous sites are available for binding metals and pesticides. The degree to which organic carbon partitions between the solid and solution phase also influences pollutant partitioning. High concentrations of dissolved organic carbon (DOC) can increase the solubility of metals and pesticides by stabilising and complexing these compounds into soluble aqueous complexes. If high suspended solids are present, DOC also binds strongly with sediment particles, and consequently detoxifies the adsorbed contaminant. DOC is critical in assessing the environmental fate of effluent containing metal and organic wastes.
- *Partitioning between dissolved and particulate species* - Bioavailability is dependent on whether a compound is associated with the

particulate phase compared to the aqueous phase, in addition to the pH and concentration of organic matter. The more the compound is associated with the particulate phase, the less bioavailable it will be. The partition coefficient is the term which defines the ratio of the amount of particulate bound pollutant to the amount in the aqueous phase.

#### 4.2.5 BIO-MONITORS, BIO-ACCUMULATION AND BIO-AMPLIFICATION

##### *Definitions*

*Bio-monitors* are organisms used to determine the extent of pollutant transport and the extent of biological uptake of a pollutant.

*Bio-accumulation* refers to the increase in a contaminant concentration within a particular organism or group of organisms, eg. liver of fish, egg shells of birds of prey.

*Bio-amplification* refers to the amplification of the bio-accumulated contaminant through the food web from one organism up the trophic order.

Organisms such as bivalves (mussels, oysters etc.) are sometimes used as bio-monitors because they filter large volumes of water and any associated metals and organic pollutants, thus bio-concentrating the actual levels of a pollutant within the water column. At this stage bio-monitors can only be used reliably as indicators of the presence of a pollutant. Further research is required before the significance of any relationships between bio-monitor and ecosystem health can be established.

Whether a compound will bio-accumulate depends on a number of physico-chemical parameters such as the class of compound (eg. metal, organic pesticide), its concentration, exposure frequency and duration. Bio-accumulation also depends on the target organism, the compound of concern and its fate within the target organism. Many organisms have the ability to regulate pollutant levels in certain

parts of their body. Therefore identification of key organs (kidney, liver, adipose or fat tissue) are important considerations when interpreting bio-accumulation data.

Bio-amplification is an extension of bioaccumulation where a contaminant which has been taken up by one particular organism or trophic level is passed on to higher order organisms - such as the case of mercury in fish which are then consumed by humans.

### 4.3 Nature of Waters

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This section outlines a number of additional concepts which are pertinent to the complete understanding of the properties of water.

#### 4.3.1 BENEFICIAL USE

Beneficial use refers to the designated uses of a waterbody. Examples of beneficial uses include:

- ecosystem protection;
- recreation - swimming, fishing, aesthetics;
- domestic and potable water;
- livestock watering;
- commercial fisheries; and
- irrigation.

Dischargers to waterbodies will generally be required to identify and meet a designated beneficial use.

This may include the designation of a mixing zone.

#### 4.3.2 ASSIMILATIVE CAPACITY

Assimilative capacity refers to a waterbody's ability to absorb or resist changes brought about by the addition of a particular parameter. An example is that of buffering capacity, where high alkalinity waters are able to assimilate additions of low pH water with no adverse changes.

#### 4.3.3 RECEIVING WATERS

The type of receiving water into which wastewater is discharged is an important factor in determining the effect and ultimate fate of discharged pollutants. For example, the fate of metals discharged into a freshwater lake will be different to that of an estuary or ocean. Physical characteristics such as temperature, flow, pH, salinity, dissolved oxygen and light penetration determine the behaviours of a specific pollutant in the aquatic environment. The capacity of the receiving environment to dilute and assimilate the effluent stream is also of primary importance. These considerations should be evaluated prior to an effluent stream being discharged to a receiving water. Effluent streams of significance emanating from mining operations include sewage treatment plants, stormwater discharges from haul roads, waste dumps, workshop discharges and machinery washdown discharges containing hydrocarbons, or surfactants.