SECTION 5:
ACTIVITIES AND WASTE LOADS

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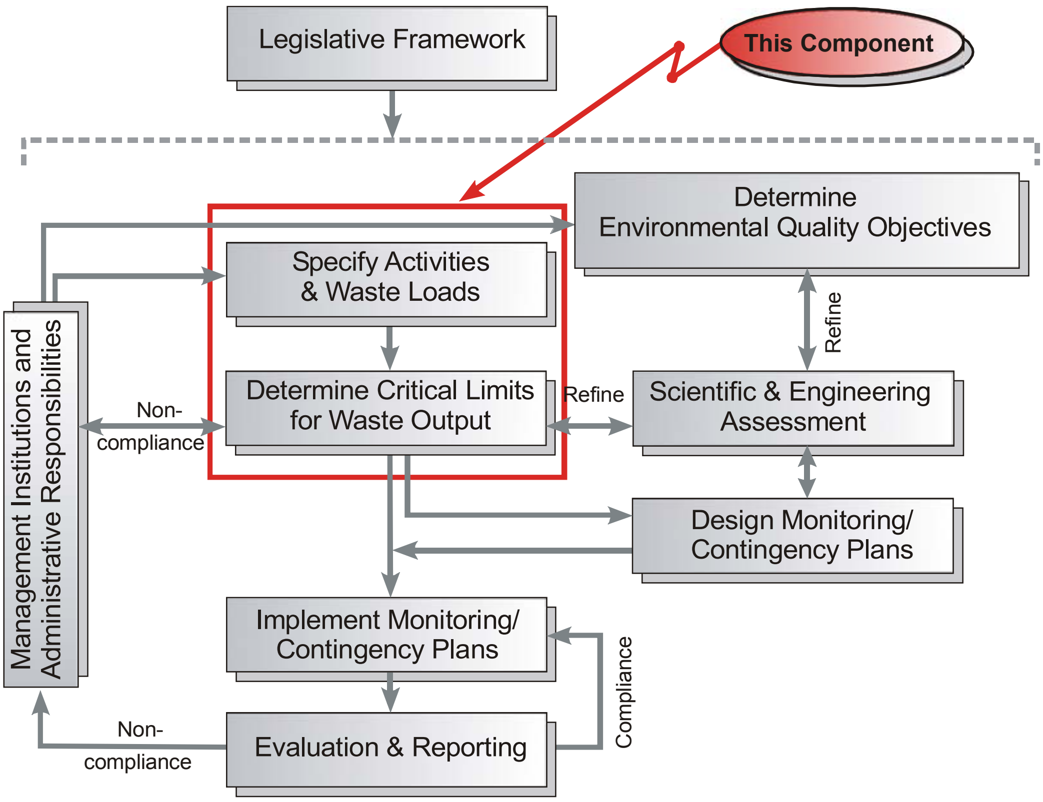

PURPOSE:

The purpose of this component is to quantify waste loads, not only from the wastewater discharges under investigation, but also other waste loads discharged into the area originating from anthropogenic (human) sources. The quantification of waste loads includes:

- ***Flow patterns, including temporal variation***
- ***Identification of constituents present in wastewater***
- ***Concentrations of constituents, as well as any temporal variation thereof.***

Waste sources to the marine environment can be categorised into four sub-categories, namely:

- *Point sources of land-derived wastewater*, including municipal and industrial wastewater
- *Diffuse sources of land-derived wastewater*, including urban stormwater run-off
- *Shipping and harbour activities*, including pollution from oil and garbage
- *Dumping at sea*, including the dumping of waste matter and dredge spoil.

Although this operational policy addresses land-derived wastewater inputs to the marine environment, it is important also to take into account activities and waste loads from other sources (for example shipping and dredging activities) to ensure that any cumulative and/or synergistic effects are considered.

An example of a map illustrating activities, of which the waste inputs can potentially have a negative impact on the marine environment in a specific area, is provided in Figure 5.1

Information typically needed to define wastewater characteristics include:

- Description of treatment processes
- Density, viscosity and temperature of the wastewater stream (average, maximum, minimum – specify if diurnal/seasonal variations occur
- Flow rates (average, maximum, minimum and diurnal/seasonal variations) for present and future scenarios
- Composition of the wastewater - in terms of all relevant constituents (average, maximum, minimum and diurnal/seasonal variations) for present and future scenarios.

An overview of the characteristics of various types of waste sources that could or have been disposed of to the marine environment is provided below.

5.1 MUNICIPAL WASTEWATER

Municipal wastewater refers to domestic wastewater (sewage) or a mixture of domestic wastewater and industrial wastewater (also referred to as trade effluent) and/or urban stormwater run-off.

The domestic wastewater component of municipal wastewater is mainly composed of water (> 99.9%) and solid wastes, primarily composed of organic material, which will eventually decay or decompose. The wastewater also contains some inorganic matter and heavy metals as well as grit/sand and debris such as cellophane, wood, plastic, etc.

Municipal wastewater also contains many bacteria, of which some may be pathogenic or disease-causing. The non-pathogenic bacteria are important for the decomposition of the organic waste load in the wastewater stream and form the basis of the wastewater biological treatment process. A group of microorganisms, known as faecal coliforms, is present in large numbers and serves as convenient indicator for the presence of pathogens in the waste stream and, ultimately, in the environment.

An indication of the strength of sewage is related to the total suspended solids load (SS) and biochemical oxygen demand (BOD). A typical composition of raw sewage under dry weather conditions, according to WRc (1990), is provided in Table 5.1.

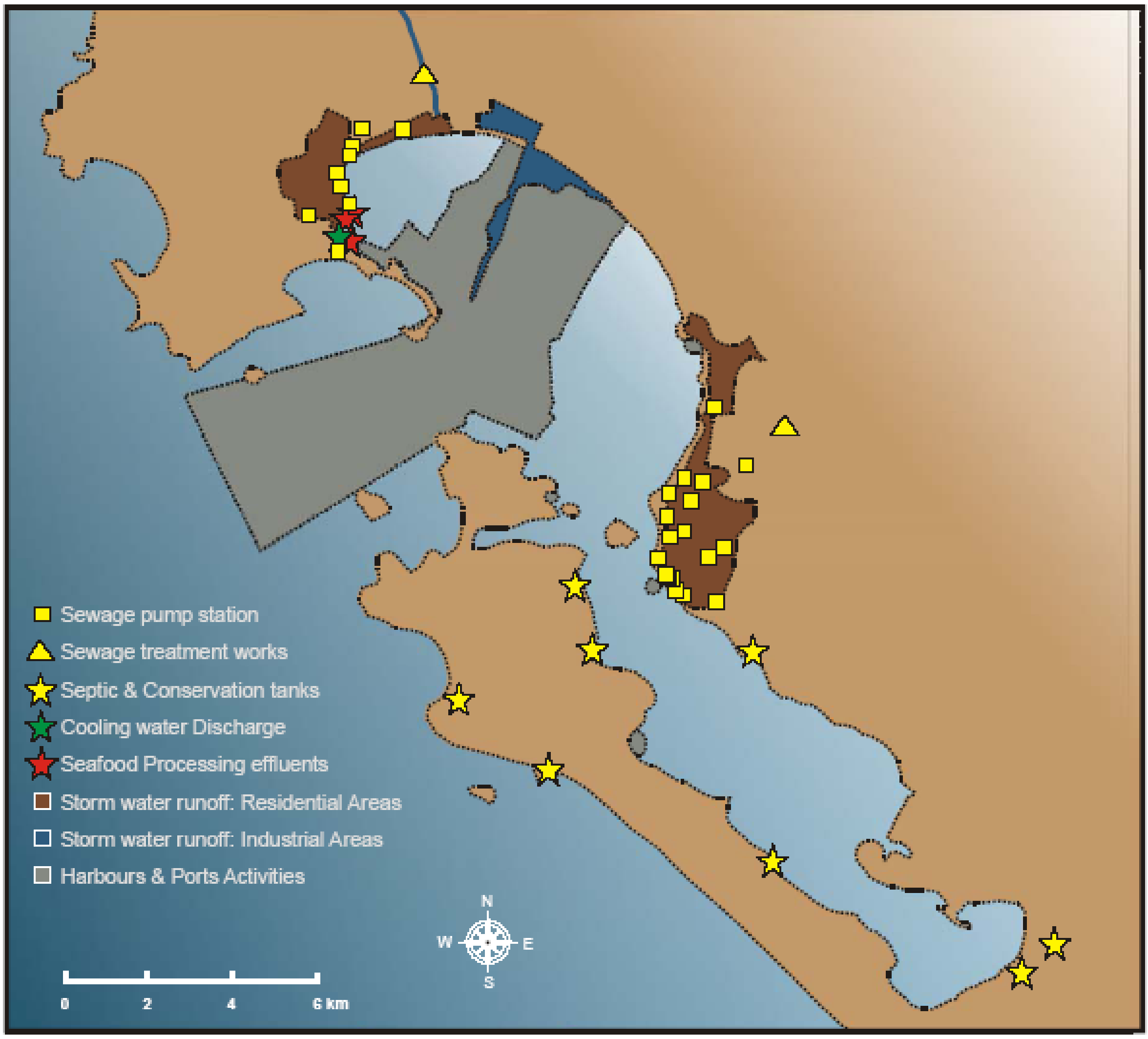

FIGURE 5.1: Example of a map illustrating activities that may affect water quality (adapted from Taljaard & Monteiro, 2002)

TABLE 5.1: Typical composition of raw sewage under dry weather conditions (WRc, 1990)

CONSTITUENT	*CONCENTRATION*	
	WRC(1990)	*SOUTH AFRICA**
Suspended solids	*250 – 400 mg/ℓ*	*300 - 330 mg/ℓ*
BOD	*300 – 500 mg/ℓ*	
Ammonia-nitrogen	*20 – 50 mg/ℓ*	*25 mg/ℓ*
Total phosphorus	*15 – 25 mg/ℓ*	*10-15 mg/ℓ*
Fats	*100 – 200 mg/ℓ*	
Chromium	*0,1 – 0,5 mg/ℓ*	
Copper	*0,2 – 0,5 mg/ℓ*	
Lead	*0,08 – 0,4 mg/ℓ*	
Zinc	*0,4 – 0,7 mg/ℓ*	
Faecal coliform	*2 – 30 x 10^6 per 100 ml*	

** Average values for the Green Point and Camps Bay offshore outfalls (Cape Town)*

The volume of municipal wastewater flow varies during the day with peaks in the morning, noon and late afternoon. A typical diurnal flow pattern is illustrated in Figure 5.2. However, each area will have a characteristic flow pattern, depending on the socio-economic factors as well as the physical layout of the sewerage system(s) with regard to retention times.

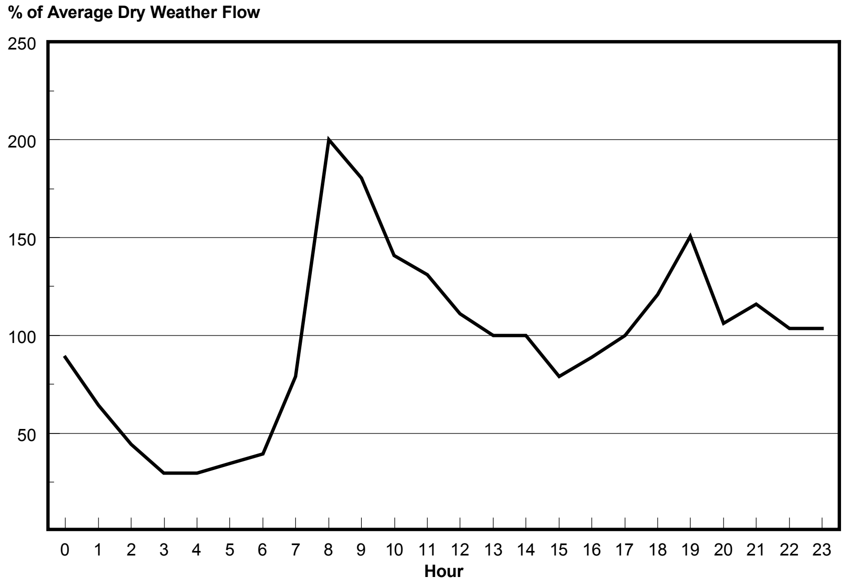

FIGURE 5.2: Typical diurnal flow pattern of municipal wastewater

For municipal wastewater discharges, it is also very important to take seasonal variation in the flow patterns into account, particularly for small coastal holiday resorts where such variation can be very large. For example, infiltration (due to damaged pipes) during the wet season or during a rainstorm will increase the flow. This must be taken into account in the assessment of treatment and disposal options of the wastewater.

Future flow scenarios should be based on the future water demand of a community with regard to future population and development trends.

Treatment of municipal wastewater (sewage) can be broadly categorised into:

- Preliminary treatment
- Primary treatment
- Secondary treatment
- Tertiary treatment
- Disinfection.

Each of these treatments is discussed in further detail in Sections 5.1.1 to 5.1.5 below.

The typical treatment process for domestic sewage is schematically illustrated in Figure 5.3.

5.1.1 Preliminary treatment

Preliminary treatment involves the removal of coarse solids and objects such as pieces of wood, paper, rags and plastic that are often present in raw wastewater. This treatment facilitates the operation and maintenance of the next treatment phase and improves the aesthetic quality of the wastewater. Preliminary treatment includes coarse and fine screening, and grit removal (maceration of large objects can also be introduced if required). Instruments (flow meters) to record the sewage flow are necessary for the management of the effluent after preliminary treatment.

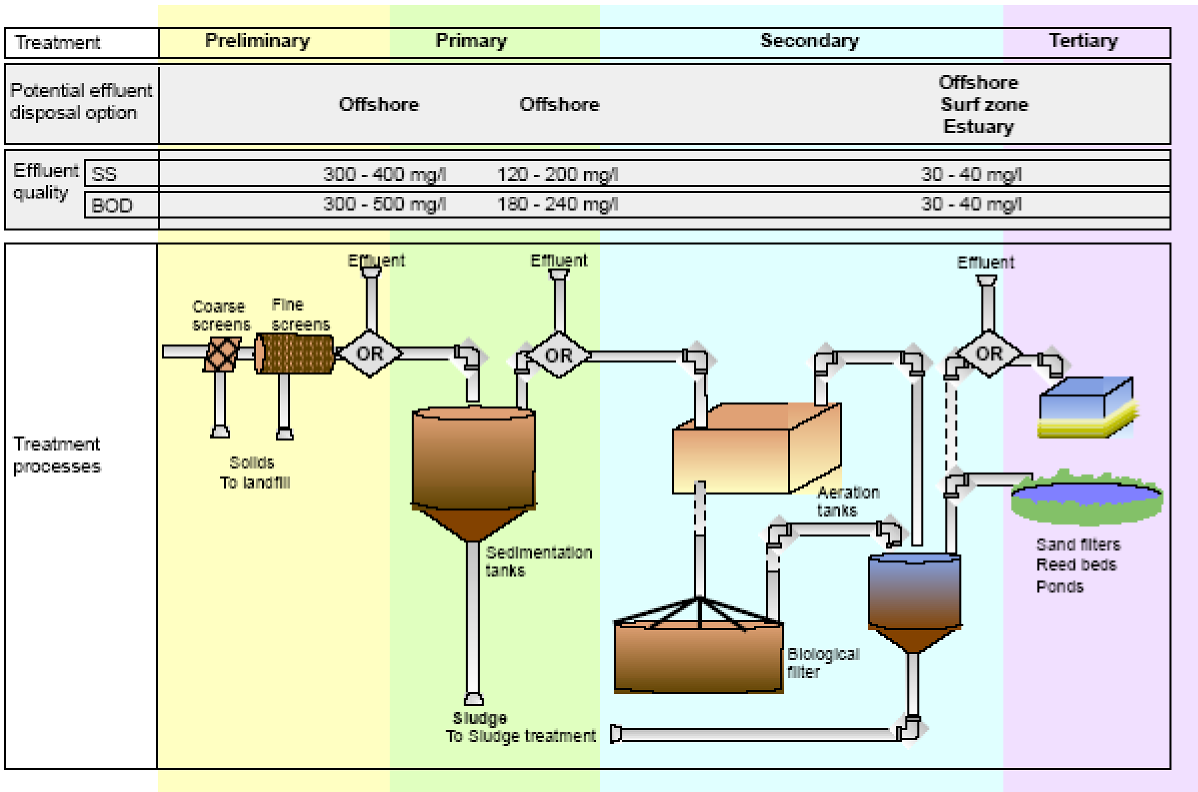

FIGURE 5.3: A schematic illustration of the different treatment processes for municipal wastewater (sewage)

5.1.2 Primary treatment

The objective of primary treatment is the removal of settleable organic and inorganic solids by sedimentation, and the removal of materials that will float (scum) by skimming. Approximately 25% to 50% of the BOD in the incoming wastewater, 50% to 70% of the SS, and 65% of the oil and grease are removed during primary treatment. Some organic nitrogen, organic phosphorus, and heavy metals associated with solids are also removed during primary sedimentation but colloidal and dissolved constituents are not affected. The effluent from primary sedimentation units is also referred to as primary effluent (FAO, 1992).

5.1.3 Secondary treatment

During secondary treatment, micro-organisms and oxygen are utilised to stabilise the sewage after primary treatment. During secondary treatment 85% to 95% of the suspended solids and the BOD load can be removed. Secondary treatment processes include:

i. Percolating filters (Trickling filters or rotating biological filters)

A trickling filter or biofilter consists of a basin or tower filled with support media such as stones, plastic shapes, or wooden slats. Wastewater is applied intermittently, or sometimes continuously, over the media. Micro-organisms become attached to the media and form a biological layer or fixed film. Organic matter in the wastewater diffuses into the film, where it is metabolised. Oxygen is normally supplied to the film by the natural flow of air either up or down through the media, depending on the relative temperatures of the wastewater and ambient air. The thickness of the biofilm increases as new organisms grow. Periodically, portions of the film 'slough off' the media. The sloughed material is separated from the liquid in a secondary clarifier and discharged to sludge processing.

Clarified liquid from the secondary clarifier is the secondary effluent and a portion is often recycled to the biofilter to improve the hydraulic distribution of the wastewater over the filter (FAO, 1992).

ii. Rotating biological contactors

Rotating biological contactors are fixed-film reactors similar to biofilters in that organisms are attached to support media. The support media are slowly rotating discs that are partially submerged in flowing wastewater in the reactor. Oxygen is supplied to the attached biofilm from the air when the film is out of the water and from the liquid when submerged, because oxygen is transferred to the wastewater by surface turbulence created by the discs' rotation. Sloughed pieces of biofilm are removed in the same manner described for biofilters.

iii. Aeration tanks

In the activated sludge process, the dispersed-growth reactor is an aeration tank or basin containing a suspension of the wastewater and micro-organisms, the mixed liquor. The contents of the aeration tank are mixed vigorously by aeration devices that supply oxygen to the biological suspension. Aeration devices commonly used include submerged diffusers that release compressed air and mechanical surface aerators that introduce air by agitating the liquid surface. The hydraulic retention time in the aeration tanks usually ranges from 3 to 8 hours but can be higher with high BOD wastewaters. Following the aeration step, the micro-organisms are separated from the liquid by sedimentation and the clarified liquid is termed secondary effluent. A portion of the biological sludge is recycled to the aeration basin to maintain a high mixed-liquor suspended solids level. The remainder is removed from the process and sent for sludge processing to maintain a relatively constant concentration of micro-organisms in the system. Several variations of the basic activated sludge process, such as extended aeration and oxidation ditches, are in common use and operate on the same principles (FAO, 1992).

5.1.4 Tertiary treatment

Tertiary treatment is used for further removal of specific constituents either not permitted to be discharged or that need to be reduced to meet environmental quality objectives. This includes filtration (sand filters, reed beds, etc.), phosphorus removal, ammonia stripping or other special treatment.

5.1.5 Disinfection

EPA Victoria (2002) provides guidelines for the disinfection of treated sewage effluent and group the methods as:

- *Chemical*, e.g. chlorination and ozonation
- *Physical*, e.g. ultraviolet radiation and microfiltration
- *Biological*, e.g. detention ponds.

What is most important is that the quality of the effluent will determine the effectiveness of any disinfection method. According to EPA Victoria (2002), the required pre-treatment to ensure that disinfection of the effluent is effective is secondary treatment.

The three most used disinfection methods are chlorination, UV radiation, and detention ponds.

Chlorine can be applied in gaseous form or as hypochlorite salts. The disadvantage is that free and combined chloride residues are toxic to aquatic life.

There is a potential for toxic organo-chlorinated derivatives to be formed, which tend to be persistent and bio-accumulate. However, experience from operational treatment works has shown that the ability to form these compounds is low. Dechlorination techniques remove all or part of the total combined chloride residues.

UV radiation is the exposure of a film of wastewater to ultra violet lamps, the efficiency of which depends on the quality of the effluent at the time of exposure. The main advantage of UV-radiation is that no consequent adverse effect on the environment has been observed.

Natural disinfection occurs when an effluent is stored in detention ponds for a sufficient length of time. The effectiveness depends on factors which influence the penetration of sunlight, such as the depth of the ponds and the turbidity and concentration of suspended solids in the wastewater.

The effectiveness of chlorination and UV radiation depends on the quality of the effluent and EPA Victoria (2002) recommends that concentrations of suspended solids be less than 20 mg/ℓ and 10 mg/ℓ for chlorination and radiation respectively. Gunnerson (1988) suggests a suspended solids concentration of 15 mg/ℓ for effective chlorination.

Where wastewater is discharged directly into areas used, for example, for the collection of seafood for human consumption or for recreation (e.g. surf zone or estuary discharges), EPA Victoria (2002) recommends the following disinfection methods:

BENEFICIAL USE AREA	***SUGGESTED BEST PRACTICE TREATMENT***	***SUGGESTED BEST PRACTICE DISINFECTION***	***ACCEPTABLE DISINFECTION (required site specific assessment)***
Shellfish harvesting	*Tertiary treatment*	*UV, micro-filtration or ozone*	*Chlorination/dechlorination*
Direct contact recreation	*Secondary treatment*	*UV, micro-filtration or ozone*	*Chlorination/dechlorination*
Other seafood harvesting	*Secondary treatment*	*UV, ozone or detention lagoons*	*Chlorination/dechlorination*

A summary of the comparison of different disinfection methods is provided in Table 5.2 (EPA Victoria, 2002).

TABLE 5.2: A summary of the comparison of different disinfection methods (EPA Victoria, 2002)

CONSIDERATION	*CHLORINE*	*OZONE*	*UV*	*MICRO-FILTRATION*	*DETENTION PONDS*
Effectiveness against					
Bacteria	*High*	*High*	*High*	*High*	*Medium to high*
Viruses	*Low to medium*	*High*	*High*	*Medium to high*	*High if >14 days*
Pathogens	*Medium to low*	*High*	*Not fully assessed*	*High*	*High if >30 days*
Practicality					
Process control	*Well-developed*	*Developing*	*Developing*	*Developing*	*Well-developed*
Complexity	*Simple to moderate*	*Complex*	*Simple to moderate*	*Simple to moderate*	*Simple*
Maintenance/cleaning	*Low to moderate*	*Moderate to intensive*	*Intensive*	*Intensive*	*Low to moderate*
Reliability	*High*	*High*	*Medium*	*Medium*	*Medium to high*
Costs					
Operation	*Medium*	*Medium*	*Medium*	*High*	*Low*
Capital (small to medium plant)	*Medium*	*High*	*Low to medium*	*High*	*Low to medium*
Capital (medium to large plant)	*Low to medium*	*High*	*High*	*High*	*Medium to high*
Adverse effects					
Safety risks: Transportation	*Yes*	*No*	*No*	*No*	*No*
Safety risks: on-site	*Substantial*	*Moderate*	*Minimal*	*Minimal*	*Minimal*
Fish toxicity	*Toxic (can be reduced by de-chlorination)*	*Unlikely*	*No*	*No*	*Potential toxicity from algae*
Formation of toxic by-products	*Potential*	*Unknown*	*Unknown*	*None*	*Potential toxic algal by-products*
Disposal of cleaning products	*No*	*No*	*Yes*	*Yes*	*No*
High energy consumption	*No*	*No*	*Yes*	*Yes*	*No*

5.2 INDUSTRIAL WASTEWATER

Numerous land-based industries discharge their wastewater to the marine environment. The pollutants associated with industrial waste discharges are largely dependent on the type of industry. Examples of industries known to have discharged or that are discharging wastewater to the sea (particularly in South Africa) as well as the major pollutants associated with such discharges are briefly discussed below.

5.2.1 Fertilizer factories

In South Africa, the fertilizer industry produces mainly nitrogenous and phosphatic fertilizers.

Wastewater pollutants from the factories producing nitrogenous fertilizers are typically nitrogen nutrients (nitrate, ammonia and urea) (Begg *et al.*, 1980; Van Eeden, 1982).

Phosphatic plants, on the other hand, produce acidic (i.e. low pH) wastewater that could contain high levels of:

- phosphates
- fluoride (where fluorideapatite is used in feedstock)
- gypsum (i.e. calcium sulphate)
- heavy metals (derived from the raw materials).

(Sources: Arnold and Wolfram, 1975; UNEP, 1982; Lord & Geldenhuys, 1986; WRC, 1988)

5.2.2 Pulp and paper mills

The wastewater composition of pulp and paper mills depends on the process that is used to produce the pulp or paper, which is typically the:

- Kraft or sulphate process
- Soda process
- Sulphite process
- Groundwood pulp manufacture.

(Sources: Southgate, 1948, Rudolfs, 1953; Billings & Dehaas, 1971)

In the Kraft process, wood is digested with a mixture of sodium salts such as hydroxide, sulphate and sulphide. Since a large fraction of the waste is re-used, wastewater from such a factory mainly originates from the washing of the pulp. Wastewaters from such plants can typically be contaminated by:

- Suspended solids, of which 70-90% are settleable solids
- Biodegradable organic matter
- Reducing compounds, e.g. sulphides and mercaptans.

(Sources: Southgate, 1948; Rudolfs, 1953; Billings & Dehaas, 1971; Gurnham, 1955):

The soda pulping process is similar to the Kraft process except that the soda process may use smaller quantities of sulphides, resulting in the wastewater containing smaller amounts of reducing compounds than, for example, effluent from the Kraft process (Rudolfs, 1953).

In the sulphite process the wood is treated with a calcium sulphite solution. During this process materials are not recovered from the spent liquid (also know as 'black liquor') as is done, for example, during the Kraft process. As a result, the waste contains as much as 50% of the wood processed. One of the major waste products is lignin, which is present as lignosulphonic acid or calcium salts. The wastewater from a plant using the sulphite process contains:

- Low pH, i.e. it is usually acidic
- High suspended solids
- High biodegradable organic matter
- The 'black liquor' causes discolouring of the receiving waters
- The presence of lignins results in surface foaming.

(Sources: Fijen, 1988; Southgate, 1948; Rudolfs, 1953; Billings & Dehaas, 1971; Gurnham, 1955; Murray, 1987)

The wastewater from groundwood pulp manufacture uses zinc hydrosulphite as a bleaching agent. The wastewater from such a plant includes:

- Suspended solids
- Biodegradable organic matter
- Heavy metals (e.g. zinc).

(Source: Billing & Dehaas, 1971)

Chlorine is usually used in the bleaching processes of pulp. Free chlorine as well as chlorinated organic compounds (e.g. chlorinated phenolic compounds) could, therefore, be present in wastewater from the bleaching plant (Murray, 1987).

5.2.3 Chemical and explosives factories

There are numerous types of chemical factories. Wastewater produced by such industries is consequently very diverse and the composition is largely dependent on the chemicals that are produced (Imhoff *et al*., 1971; Spencer, 1971). Depending on the processes involved, pollutants in such wastewater may include:

- Suspended solids
- Biodegradable organic matter
- Reducing agents such as sulphides
- Nutrients
- High acidity
- Toxic inorganic compounds (e.g. cyanide and fluorides)
- Toxic organic compounds (e.g. heavy metals and hydrocarbons).

(Sources: Southgate, 1948; Rudolfs, 1953; Van Eeden, 1982; Gurnham, 1955; Spencer, 1971)

The above list of pollutants is far from complete and wastewater from these types of factories should be analysed individually to identify any other potentially harmful pollutants.

5.2.4 Oil refineries

A large variety of pollutants may be present in the wastewaters of oil or petroleum refineries. Pollutants can originate from a large number of sources in the plant. Pollutants generally can be grouped as follows:

- Oils (e.g. petroleum hydrocarbons, volatile organic compounds, poly-aromatic hydrocarbons) which could be present as free oil floating on the surface or as an oil emulsion which is suspended in the water. Although free oils can usually be separated from wastewater by gravity or by means of differential oil-water separators, emulsions are usually not that easily removed.

- Condensate waters, which originate from distillation processes, contain high organic loads and reducing chemicals. They can also contain ammonia, heavy metals, cyanides and phenols.

- Acid wastes, which originate from processes in which sulphuric acid is used as a treating agent. Not only are these wastewaters acidic but they also contain high organic loads.

- Caustic wastes which originate from washing of certain oils to remove acidic materials naturally occurring in crude oil. These wastes are very alkaline (i.e. high pH) with a high organic content. They may also contain substances such as mercaptans, sulphides and phenols.

- Cooling water which typically is very hot.

(Sources: Rudolfs, 1953; UNEP, 1982)

The above list of pollutants contained in oil refinery wastewater is far from complete and, as with chemical factories, wastewater should be analysed individually to identify any other potentially harmful pollutants.

5.2.5 Sugar mills

The major processes in the production of sugar from sugar cane include:

- extraction of juices
- clarification of juices
- production of sugar crystals from juices.

(Source: Murray, 1987)

Lime and sulphur dioxide are usually used in the clarification processes, while activated carbon is used in the bleaching process of the final product. Pollutants that may be present is the wastewater from the sugar industry include:

- suspended solids
- biodegradable organic matter
- high temperatures (e.g. cooling water).

5.2.6 Fish factories

Wastewater originating from the processing of fish into fishmeal, oils and canned products can be broadly divided into:

- Blood water which refers to all the liquid separated from fish prior to the cooking process
- Stick water which is the waste that arises from the dewatering processes after cooking and during the pressing of the fish
- Oil polisher wastewater.

Pollutants in all of the above wastewater typically consist of:

- Suspended solids
- Biodegradable organic matter
- Nutrients, such as nitrogen.

(Source: Binnie & Partners, 1986)

5.2.7 Textile factories

Fibres used in the textile industry can be divided into two main categories: natural fibres (e.g. wool, hair, silk, cotton, flax, sisal, etc.) and synthetic fibres (e.g. rayon, nylon, etc.). Processing mainly involves removing the impurities and, subsequently, imparting various qualities such as dyeing and printing (Southgate, 1948; Rudolfs, 1953, Murray, 1987; Schlesinger *et al*., 1971).

Pollutants in wastewater from textile factories vary greatly and depend on the chemicals and treatment processes used. Pollutants that are likely to be present include:

- High acidicty/alkalinity
- Suspended solids
- Biodegradable organic matter
- Colour originating from dye processes
- Heavy metals, e.g. chromium and mercury
- Toxic organic compounds, e.g. phenols
- High temperatures (originating from cooling water).

(Sources: UNEP, 1982; Murray, 1987; Schlesinger *et al*., 1971)

5.2.8 Food canning factories

Food canning (e.g. fruit, vegetables and meat) consists of a series of processes including washing, peeling and blanching, all of which produce wastewater. Major pollutants in these wastewaters include:

- Suspended solids
- Biodegradable organic matter
- High alkalinity (originating from the peeling process in which caustic soda is used)
- Discolouration (e.g. from the canning of beetroot).

(Sources: UNEP, 1982; Southgate, 1948; Rudolfs, 1953; Glide, 1971; Cruickshank, 1965; Thatcher & Clark, 1968)

5.2.9 Aluminium smelter

The major harmful pollutant in the wastewater from an aluminium smelter is fluoride (UNEP, 1982, Lord & Geldenhuys, 1986; Murray, 1987).

5.2.10 Power stations (including nuclear power stations)

Both fossil fuel and nuclear power stations use large amounts of cooling water. If such waters are not re-cycled but discharged into the marine environment, thermal pollution can result (i.e. high water temperature), especially if discharged in sheltered areas such as estuaries and harbours (UNEP, 1982). Discharges from nuclear power stations may also contain traces of radio-active materials.

5.2.11 Return flow: Oceanariums

Wastewater or return flow of seawater from oceanariums is likely to contain higher levels of suspended solids, degradable organic matter and possibly ammonia, compared to the intake waters. These items are the result of excretion from animals or remaining excess food particles.

5.2.12 Return flow: Coastal mining

Wastewater or return flow seawater used in coastal mining activities, e.g. the diamond mining industries along the South African west coast, usually contains high levels of suspended and settleable matter.

5.3 STORMWATER RUN-OFF

Stormwater run-off is one of the major non-point sources of pollution. It is, however, very difficult to characterise stormwater run-off because of widely varying contaminant concentrations (Wanielista *et al*, 1977). This, together with large fluctuations in run-off volume and the large number of discharge points, has limited the treatment of such wastewater, which often contains toxic and refractory compounds (Meyer, 1985). The pollutants present in stormwater run-off include plant material, debris, plastics, oxygen demanding substances, suspended solids, nutrients, heavy metals, pathogenic bacteria and viruses, and toxic organic compounds (e.g. pesticides and petroleum hydrocarbons) (Bradford, 1977; Helsel *et al*, 1979; Hunter *et al*, 1979; Wigington *et al*, 1983; Brown *et al*, 1985; Green *et al*, 1986; Schmidt & Spencer, 1986).

Stormwater run-off can be divided into two broad categories namely (Hoffman, 1986):

- urban run-off (residential including formal and informal developments, industrial and commercial)
- rural run-off (e.g. rural settlements, agricultural and forestry areas)

The quality and quantity of stormwater run-off is determined to a large extent by catchment characteristics, rainfall characteristics and antecedent moisture conditions.

Stormwater run-off from agricultural catchments (more of a problem to inland water resources) was found to contain a high suspended solids load, high iron and manganese concentrations as well as high nutrient and pesticide concentrations, while copper, lead, zinc and petroleum hydrocarbons were predominant in run-off from urban catchments. The levels of these compounds increased with an increasing volume of vehicle traffic (Helsel *et al*, 1979; Hoffman, 1986; Duda, 1982; Moore *et al*, 1988). Concern about the rapid development of informal townships along the South African coastline is increasing. In most of these areas, a low level of sanitary services is provided with the result that the pollution of stormwater run-off, which usually drains directly into the surf zone, is more serious than in formally developed areas (Miles, 1984).

The first flush effect, which is evident as a peak of highest pollutant concentrations at the beginning of a storm event, is the result of accumulated materials being washed from the catchment surface. This effect seems to increase in frequency and intensity as the degree of urbanisation increases (Brown *et al*, 1979; Simpson, 1986). In general, highly urbanised catchments produce the greatest concentration of pollutants in stormwater run-off and rural catchments the least (Green *et al*, 1986).

Pollutants in stormwater run-off, therefore, are numerous and may include:

- Suspended solids
- Biodegradable organic matter
- Nutrients
- Heavy metals
- Toxic organic compounds (e.g. petroleum hydrocarbons)
- Pathogenic organisms (e.g. bacteria and viruses)
- Plastics and other litter.

Concern about the pollution effect of stormwater run-off in South Africa has increased dramatically over the past years. However, the data available on the quantity, and especially the quality, of this run-off are very limited. An overview of pollutant inputs from stormwater run-off, originating from different source areas, is provided in Pegram & Görgens (2001).

5.4 OTHER WASTE SOURCES

Although they are not specifically addressed as part of this operational policy, it is important to realise that shipping and harbour activities also contribute to the waste load entering the marine environment and that they cannot be ignored when assessing cumulative impacts. However, quantifying waste inputs from these activities is often extremely difficult owing to the unpredictable and sporadic nature of such events. Therefore, in situations in which such activities occur in a particular area, and which may have synergistic effects with land-derived wastewater discharges, a scenario-based approach is typically used.

5.4.1 Oil spills

Major sources of oil pollution originating from shipping activities include (Taljaard & Rossouw, 1999):

- operational discharges associated with day-to-day shipping activities at sea
- accidental spillages during transfer of oil in ports or at offshore moorings
- continuous diffuse spillages (owing to illegal dumping, bad operational practices, etc.)
- large oil spills as a result of a collision or severe structural damage to oil tankers or other vessels while at sea.

The input from operational and accidental spillages is typically diffuse and sporadic, which makes realistic quantification extremely difficult. Major oil spills, in contrast, occur on a different scale, being massive instantaneous events of which the impact is largely dependent on the magnitude and location of the spill and the type of oil spilled.

Chemical constituents associated with oil pollution consist mainly of petroleum hydrocarbons (including poly-aromatic hydrocarbons) and trace metal (Neff, 1979; Swann *et al*, 1984).

The type and concentration of trace metals and hydrocarbons in oils depend on the fuel product and crude oil source. In crude oils, vanadium, nickel and lead are typically the most common trace metals.

In addition to the harmful chemicals released into the sea during an oil spillage, the oil slick also causes physical damage by creating aesthetically unpleasant conditions, clogging water intake systems and smothering benthic marine fauna and flora (Taljaard & Rossouw, 1999).

5.4.2 Ballast water

Ships take on ballast water at sea to increase their stability. Up to 125 000 tonnes per vessel are taken from the coastal waters of the world. As South Africa is a net exporter of raw materials, such as coal and mineral ores, it receives a large amount of ballast water from overseas sources. It is estimated that the annual discharge of ballast water into South African harbours is in the order of 20 million tonnes, compared with about 66 million tonnes in Australia. The risk associated with ballast water discharges from ships is mainly the introduction of exotic organisms, which occurs when ballast water taken from one part of the ocean is discharged into another. In this way the natural ecological balance is upset, resulting in a variety of secondary problems. There is increasing concern, both nationally and internationally, that a wide variety of marine plants and animals (including pathogens) has been transported in the ballast water of ships and introduced into foreign countries.

5.4.3 Harbour activities

Activities in harbour that could result in marine pollution are numerous, including:

- Dry dock activities
- Cleaning and maintenance of vessels within harbours (e.g. dust from sand blasting), as well as emptying of toilets into harbour areas
- Dumping of blood water into harbours, as well as off-cuts and offal from fish cleaning operations being washed down into stormwater drains and eventually ending up in the harbours
- Poor waste disposal practices during the scraping and cleaning of ships, which eventually results in chemical pollution of harbour waters, e.g. by antifouling paints
- Litter which ends up in harbour basins as a result of wind, stormwater discharges or by being directly discarded from ships
- Oil originating from an accidental spill from a vessel in harbour.

Harbour water is particularly prone to pollution because harbours are sheltered basins often with poor water circulation. Pollutants entering harbours, therefore, tend to accumulate. Because the sources of pollution entering harbours are diffuse and often intermittent, it is very difficult to quantify such contaminant loading, in contrast to sewage or industrial point discharges.

Pollutants associated with sources in harbours are diverse. Depending on the source these can include:

- Suspended solids
- Biodegradable organic matter
- Nutrients
- Heavy metals
- Toxic organic compounds (e.g. petroleum hydrocarbons, antifouling paint)
- Pathogenic organisms (e.g. bacteria and viruses)
- Exotic organisms
- Plastics and other litter.

Regular monitoring of the key contaminants in the water and sediments best assesses pollution input to harbours.

5.4.4 Dumping of dredge spoil

Sediment removed during regular maintenance dredging, for example, to maintain the depth of shipping channels in harbours, is often dumped at sea. Contaminants associated with the dredged material results from the activities associated with the dredged area. Common pollutants associated with all dredged spoil, based on its inherent character, are suspended and settleable solids. Harbour sediments are often heavily contaminated with toxic chemicals such as trace metals and hydrocarbons (McGlashen, 1989; Henry *et al*, 1989; Kleinbloesem & Van der Weijde, 1983). When spoil is dumped at sea these trace metals may be released, under suitable chemical conditions, to the receiving marine environment. In contrast, dredged material from ecologically productive areas such as estuaries may contain high concentrations of biodegradable organic matter and nutrients (Badenhorst, 1986; McGlashen, 1989). Deep dredging in harbours can also yield sediments that are naturally high in trace metals of geological origin. For example, in South Africa the concentration of chrome and arsenic is often elevated in such sediments.

5.4.5 Dumping of sludge

Sludge is a concentrated source of pollutants and as a result many countries have placed a ban on the dumping of sludge at sea. The pollutants present in sludge depend on the source. Sewage sludge, for example is a major source of:

- suspended and settleable solids
- biodegradable organic matter
- heavy metals, including chromium, copper, lead, tin and zinc
- toxic compounds, such as pesticides
- pathogenic organisms.

(Sources: West & Hatcher, 1980; Reed, 1975; Waldichuk, 1977; Hatcher *et al*, 1981; O'Connor & Rachlin, 1982; Babinchak, *et al*, 1977; Hadeed, 1976; Lear *et al*, 1881)

5.4.6 Dumping of other waste

Dumping of other forms of waste includes ammunition, and containered pharmaceuticals and chemicals. Pollutants associated with such dumping are strongly dependent on the type of waste dumped. In areas where dumping of waste is known to have occurred, it is necessary to identify the type of waste and to determine the associated pollutants on an individual basis.

5.5 TOXICITY TESTING

It is recognised that point source discharges, such as municipal and industrial wastewater, and diffuse sources, such as urban stormwater run-off, can be complex mixtures that may contain unknown compounds which may act together to increase or ameliorate the toxic effects to the receiving marine environment (RSA DWAF, 2003b). Rather than attempting to identify all the chemicals in a sample or where the toxic effects of specific chemicals are not known, toxicity tests (bioassays) using living organisms provide a useful means of determining the potential toxicity of wastewater to the marine life. In the case of complex mixtures, toxicity testing of the waste stream (also referred to as the Whole Effluent Toxicity [WET] test) is therefore very important (ANZECC, 2000a; US-EPA, 2002b).

5.5.1 Types of 'whole effluent toxicity' tests

Acute (or short-term) toxicity tests typically measure the survival of a specific organism over a prescribed period. Chronic tests determine toxicity over significant portions of an organism's lifespan (ranging from weeks to years) or use sensitive early life stages.

The US-EPA (2002b) has identified three categories of toxicity tests:

- Static non-renewal: where test organisms are exposed to the same test solution for the duration of the test
- Static renewal: where test organisms are exposed to a fresh solution of the same concentration of sample every 24 hours or other prescribed interval, either by transferring the test organisms from one test chamber to another, or by replacing all or a portion of solution in the test chambers
- Flow-through: where either the test sample is pumped continuously from the sampling point directly to the dilutor system or, where grab or composite samples are collected periodically, placed in a tank adjacent to the test laboratory, and pumped continuously from the tank to the dilutor system.

The type of toxicity test and test species are selected to suit particular case studies, depending on the type of wastewater and the receiving marine environment.

EXAMPLES…

An example of the use of a short-term toxicity test to set a target for the required dilution was for the extension of an offshore marine outfall from a paper mill. While the required dilution for individual chemical constituents within the near-field was less than 500, a set of urchin gamete toxicity tests set a target dilution of 1450 (Dinnel 1984; Airey 1989; Connell, Airey & Rathbone, 1991).

Another example of the use of these tests to assess the toxicity of a specific contaminant was for an offshore wastewater discharge ocean outfall from a phosphate fertilizer factory. In this case the key component in the wastewater was fluoride, for which there was no target value available. The urchin gamete test proved relatively insensitive to fluoride but life-cycle tests using an amphipod, cultured in various concentrations of fluoride in seawater, showed impaired reproduction at levels of fluoride above 5mg/ℓ. Thus the pipelines was designed to ensure that fluoride levels did not exceed this level beyond the initial mixing zone, taking into account ambient seawater concentration (1.2-1.5mg/ℓ) (Connell & Airey 1981)

The decision to collect grab or composite wastewater samples depends on the knowledge of variability in wastewater composition. Where the variability is expected to be low, composite samples are usually collected over a 24-hour period. However, where instantaneous elevations ('spikes') of toxicity are expected, the maximum toxicity can only be determined by scheduled grab sampling. In such instances, 24-hour composite samples will mask the toxic 'spikes'.

The type of dilution water used in toxicity tests depends on the objectives of the study:

- If the objective of the test is to estimate the absolute acute toxicity of the wastewater, then synthetic (standard) dilution water needs to be used. This type of dilution water will typically be used in monitoring changes in the toxicity of wastewater over time.

- If the objective of the test is to estimate the acute toxicity of the wastewater on entering the receiving water, the dilution water to be used in the toxicity test needs to be obtained from a sample (grab) at the discharge location. For an existing outfall, the sample must be taken 'outside' the plume or the influence thereof (e.g. upstream of the diffuser).

If the test organisms have been cultured in water that is different to that of the test dilution water, a second set of controls, using culture water, should be included in the test.

The US-EPA (2002b) recommends that wastewater toxicity tests consist of a control and five or more concentrations of wastewater (i.e. a range of wastewater dilutions). These tests are used to estimate:

- LC_{50}, i.e. the wastewater concentration which is lethal to 50% of the test organisms in the time period prescribed by the test, or

- No-Observed-Adverse-Effect Concentration (NOAEC), i.e. the highest wastewater concentration at which survival is not significantly different from the control, and/or

- Minimum Acceptable Toxicant Dilution (MATD), which lies between a dilution with a response which is not significantly different from a control test (NOAEC) and the highest observed effect dilution.

Note that, where changes in, for example, pH, temperature, salinity, total residual chlorine, unionised ammonium and dissolved oxygen concentrations may occur in the test solutions during the test period and which may interfere with the toxicity results, such changes need to be monitored throughout the test period.

5.5.2 Data analysis

i. LC_{50} values

The LC_{50} value can be determined by the Probit, Graphical, Spearman-Karber or trimmed Spearman-Karber method, of which the latter three methods also provide 95% confidence intervals for the LC_{50} estimates. These well-proven methods are discussed in more detail in US-EPA (2002b) and can be applied by scientists proficient in basic statistics. However, where there are anomalies in the data or an alternative method is applied, a statistician should be consulted. Basic guidance for the selection of the appropriate method for LC_{50} determination, related to the number of mortalities, is provided in Figure 5.4 (US-EPA, 2002b).

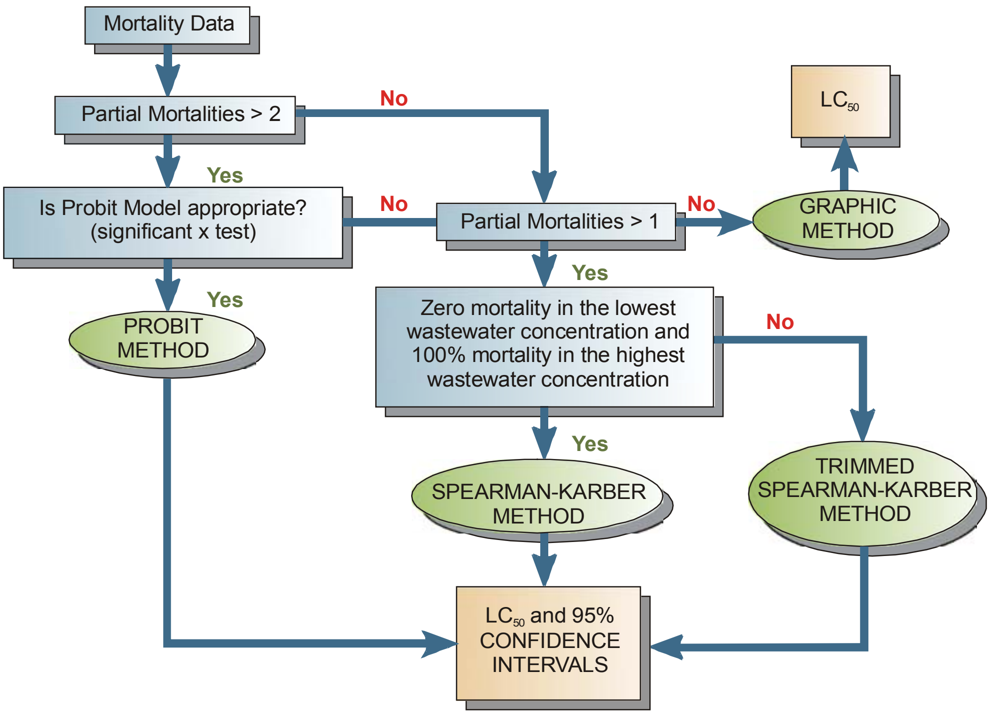

FIGURE 5.4: Guidelines on selection of the appropriate method for the determination of LC_{50} values (US-EPA, 2002b)

ii. NOAEC/MATD

Determination of the No-Observed-Adverse-Effect Concentration (NOAEC) and/or Minimum Acceptable Toxicant Dilution (MATD) is accomplished using hypothesis testing. The concept of hypothesis testing is based on the ability to distinguish statistically significant differences between a control treatment and other treatments (wastewater concentrations), where the null hypothesis (i.e. the wastewater is not toxic) yields no difference between a control treatment and a test treatment. The null hypothesis is rejected (i.e. the wastewater is toxic) if for a selected nominal error rate, there is a significant difference between the control treatment and the test treatment (an error rate of 0.05 is associated with a 95% confidence level).

A range of methods can be applied to determine NOAEC/MATD including Dunnett's test, T-test with Bonferroni adjustment, Steel's many-one rank test, and Wilcoxon rank sum test with Bonferroni adjustment. These methods are discussed in more detail in US-EPA (2002b) and can be applied by scientists proficient in basic statistics.

However, where there are anomalies in data or an alternative method is applied, a statistician should be consulted. Basic guidance for the selection of the appropriate method for NOAEC determination is provided in Figure 5.5 (US-EPA, 2002b).

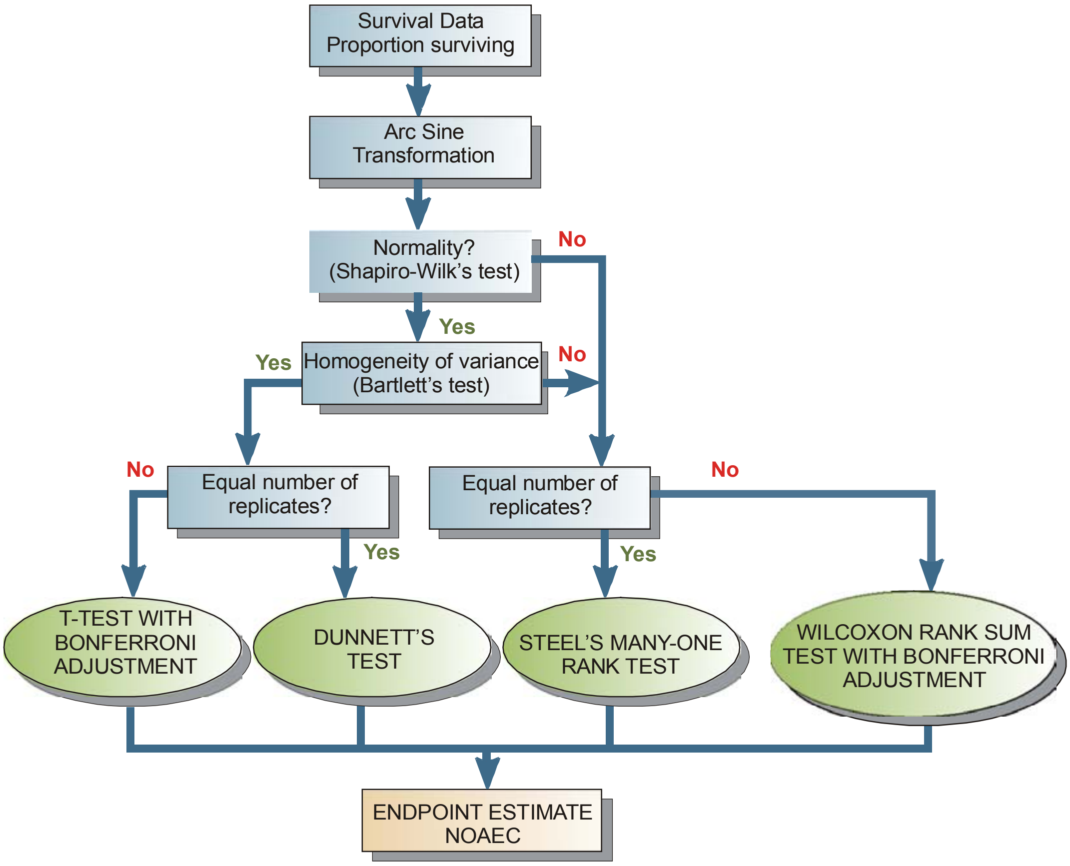

FIGURE 5.5: Guidelines on selection of the appropriate method for the determination of the NOAEC (US-EPA, 2002b)

5.5.3 Reporting

It is essential for the effective evaluation of long-term variations in wastewater toxicity that all relevant information be recorded, including:

- Details of the **wastewater sample**, including treatment operations, composition and flow volumes at the time of grab or 24-hour composite sampling
- Details of the **dilution water** (i.e. the water that is used in the experiment to dilute the wastewater), including source, pre-treatment, physical and chemical characteristics
- Description of the **test and quality controls**, including the test method, test conditions and test organisms (species, age, life stage, physical characteristics, source) and reference toxicants
- Description of the **data analysis**, including, raw toxicity data (tabular and graphical format), physical and chemical data (wastewater and dilution water), end-points and statistical methods to calculate end-points.