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Emission estimation technique manual for

Potable water treatment Version 2.0

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POTABLE WATER TREATMENT

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1 Introduction

The purpose of all emission estimation technique (EET) manuals is to assist Australian manufacturing, industrial and service facilities to report emissions of listed substances to the National Pollutant Inventory (NPI). This manual describes the procedures and recommended approaches for estimating emissions from facilities engaged in potable water treatment activities.

EET MANUAL		Potable water treatment
ANZSIC CODE	2006	2811

Note that the ANZSIC code is part of NPI reporting requirements. The *NPI Guide* contains an explanation of the ANZSIC code. (Prior to 2006, the appropriate ANZSIC code was 3701 – Water supply). This manual has been developed through a process of national consultation involving state and territory environmental authorities and key industry stakeholders.

NPI substances are those that when emitted at certain levels have potential to be harmful. Australian, state and territory governments have agreed, in response to international requirements to provide information to the community, that industries will report these emissions on an annual basis. NPI substances are set out in the *NPI Guide* and are listed in categories which have a threshold; i.e. once annual 'use' of substances or fuels is above the threshold their emissions and transfers must be reported.

1.1 The NPI reporting process

The process for NPI reporting can be seen in the following flow chart:



1.2 Structured approach to NPI reporting

The main tasks are consolidated below in phases to provide a suggested approach to NPI reporting.

Box 1. Suggested approach for NPI reporting

Process flow definition

- 1. Construct a system diagram for your treatment plant identifying:
 - a. water treatment system boundary
 - b. inflows (e.g. raw water and chemical additives)
 - c. substance storage
 - d. water treatment processes
 - e. outflows (e.g. leaks and discharges)
 - f. waste treatment and handling activities.

Data recording

- 2. Perform a desktop screening calculation (refer to Section 4.2) to identify relevant substances, thresholds and issues.
- 3. Record the quantities of materials containing NPI reportable substances:
 - a. purchased and brought onsite
 - b. brought onsite in raw water
 - c. discharged or transferred in wastewater
 - d. discharged or transferred in waste sludge
 - e. released as gases.
- 4. Record the quantity, and type of fuel burned.
- 5. Record the quantity of electrical energy used.
- 6. Document emission reduction activities (pollution control devices employed).

Reporting

- 7. Determine which substances need to be included in the report.
- 8. Estimate emissions for the relevant substances.
 - a. to air
 - b. to water
 - c. to land
- 9. Estimate transfers for the relevant substances and record the destination.
- 10. Record the estimation techniques used and any reasons for 'significant differences to previous report'.
- 11. Prepare and submit reports to NPI.

Quality assurance

12. Keep the above records, calculations and copies of reports. Contact your State's NPI Team for records' retention advice.

In addition to the above tasks, regularly check the NPI website for the latest reporting information, access to other EETs, and other sources of advice. For site-specific issues, contact your state's NPI team for advice.

Many of the tasks will require minor ongoing effort once the initial output is complete. For example the system diagram will only need to be updated to reflect process changes. Likewise, calculation and reporting tasks will be routine provided that there is a sound precedent in the previous year's NPI report and associated documentation. NPI reporting is very streamlined by international standards. Nonetheless, terms such as *categories*, *substances* and *transfers* have specific NPI definitions and the reporting process may appear daunting. A feature of the suggested approach is the desktop screening calculation (task 5). Some of the common issues for conventional potable water treatment are the use of chlorine and fluoride compounds. For some facilities, these will be the only relevant NPI substances. For example, if a facility uses more than 10 tonnes of chlorine or fluoride compounds, then it must report to the NPI. If no thresholds are exceeded (refer Section 4), then no report is required and the desktop screening calculation provides documentation of that result.

The suggested approach is intended to maximise the use of existing operational monitoring. Recording quantities of water and materials is a standard operation; the specific NPI aspect of data recording involves substances with potential risk to health or environment.

The *NPI Guide* provides the definitive description of the reporting process and this EET manual is intended to be used in conjunction with the *NPI Guide*.

1.3 Information required to produce an annual NPI report

In general, the types of data that will need to be collected and recorded for report preparation include:

- system and process flow data
- monitoring and inventory data:
 - a. volume of raw water flowing into the treatment plant (GL)
 - b. concentrations of substances in the raw water (mg/L)
 - c. quantities of chemical additives purchased and brought onsite (tonnes)
 - d. quantities, and type, of fuel burned onsite (tonnes for solid and liquid fuels, GJ for natural gas)
 - e. quantity of electrical energy used (MWh).

1.4 Additional reporting materials

This manual is written to reflect the common processes employed in potable water treatment. In some cases it will be necessary to refer to other EET manuals to ensure a complete report of the emissions for the facility can be made. Other applicable EET manuals may include, but are not limited to:

- Fossil fuel electric power generation
- Fuel and organic liquid storage
- Fugitive emissions,
- Inorganic chemicals manufacturing, and
- Sewage and wastewater treatment.

2 Process description

The essential objectives of potable water treatment are:

- removal of unwanted suspended and dissolved material
- disinfection to inactivate potentially harmful microbes, and
- stabilisation of water for distribution.

2.1 Potable water treatment processes

A variety of process options exist for treating water to a quality where it is acceptable for drinking. The components assembled to create a treatment plant and the sequence and details of treatment for each stage, can vary between plants and over time within the same plant.

Typical processes associated with potable water treatment are illustrated in Figure 1.



Figure 1: Processes associated with potable water treatment

Treatment can involve a combination, or all, of the following stages:

- raw water collection, abstraction, storage
- initial aeration; conditioning, disinfection
- pre-filtration coagulation, flocculation, sedimentation, adsorption
- filtration which might exclude particles ranging in size from millimetres to a sub-micrometre (molecular) level, and
- pre-distribution conditioning, disinfection and storage.

Aeration removes certain dissolved compounds from the water and this process may not be employed by facilities receiving high quality water. Likewise, fluoridation is a common process, but by no means universal. Sludge management systems are commonly applied to consolidate solids in the side streams from flocculation, sedimentation or filtration processes.

Some facilities may employ processes that are not in widespread use and these should be reviewed closely. Some raw water storages are prone to seasonal microbial 'blooms' and a range of processes and chemicals are used to manage these outbreaks and ensure potable water quality. A structured approach to NPI reporting will help avoid overlooking seasonal and non-routine processes.

A holistic and comprehensive approach is required to fully identify a facility's processes. This is important as subsequent NPI reporting steps rely on the process description.

Once the processes have been identified, consideration should be given to:

- inflows
- outflows, and
- the system boundary.

2.2 System diagrams

An example of a system diagram showing process flows is illustrated in Figure 2..



Figure 2: Generalised system diagram: typical potable water treatment

The key elements of the systems diagram include:

- system boundary
- inflows
- processes that may use materials or generate waste / losses, and
- outflows (emissions/transfers).

Note that a system boundary need not be a physical structure or based on a property boundary. You should consider raw water storage unit as part of the system if it falls under your operational control. For example, if you have the authority to add chemicals to the storage unit to control microbial populations, then that is a clear example of a process within your system. Conversely, if the responsibility for the operation and maintenance of distribution belongs to another party (e.g. a neighbouring council), then that distribution network is outside your system boundary.

Inflows are of particular relevance to the NPI because inflows can trigger the need to report. Chemicals and raw water are the main inflows for most facilities. A list of chemicals that have been approved for use by the National Health and Medical Research Council (NHMRC) is shown in Table 1. Chemicals containing NPI substances are highlighted in blue.

Treatment chemical	Formula	Approval date	Uses
		2005	
Aluminium chloronydrates	AICI(OH)5	2005	Coagulation
Aluminium sulfate (alum)	$AI_2(SO_4)_3$	1983	Coagulation
Ammonia	NH ₃ aq	1983	Disinfection
Ammonium sulfate	$(NH_4)_2SO_4$	1983	Disinfection
Calcium hydroxide (hydrated lime)	Ca(OH) ₂	1983	pH correction, softening, corrosion control
Calcium hypochlorite	Ca(OCl) ₂	1983	Disinfection/oxidation
Calcium oxide (quick lime)	CaO	1983	Coagulation aid, pH correction, softening corrosion control,
Carbon, powdered activated/granulated activated (PAC/GAC)	С	1983	Adsorption
Chlorine	Cl ₂	1983	Disinfection/oxidation
Chlorine dioxide	ClO ₂	2005	Disinfection/oxidation
Copper sulfate	CuSO ₄	1983	Algicide
Ferric chloride	FeCl ₃	1983	Coagulation
Ferric sulfates	$Fe(SO_4)_3$	1983	Coagulation
Hydroxylated ferric sulfate		2005	Coagulation
Hydrochloric acid	HCl	2005	pH correction
Hydrofluorosilicic acid (fluorosilicic acid)	H_2SiF_6	1983	Fluoridation
Hydrogen peroxide	H_2O_2	1983	Disinfection/oxidation
Ozone	O ₃	2005	Disinfection/oxidation
Polyacrylamides	$(C_3H_5NO)_n$	1977	Coagulation, flocculation and filter aid
Polyaluminium chlorides	Al _n (OH) _m CL _(3n-m)	1979	Coagulation
Polyaluminium silica sulfates	Na12(AlO2)(SiO2)12.xH2O	2005	Coagulation
Polydiallyldimethylammonium	n chlorides (polyDADMACs)	1982	Coagulation and aid

Table 1: Chemicals approved for potable water treatment

Treatment chemical	Formula	Approval date	Uses
Potassium permanganate	KMnO ₄	1983	Disinfection/oxidation
Sodium aluminates	NaAlO ₂	1983	Coagulation
Sodium bicarbonate	NaHCO ₃	1983	pH correction, softening, corrosion control
Sodium carbonate (soda ash)	Na ₂ CO ₃	1983	pH correction, softening, corrosion control
Sodium fluoride	NaF	1983	Fluoridation
Sodium fluorosilicate	Na ₂ SiF ₆	1984	Fluoridation
Sodium hexametaphosphate	(NaPO ₃) ₂	1983	Corrosion control
Sodium hydroxide (caustic soda)	NaOH	1983	pH correction, softening, corrosion control
Sodium hypochlorite	NaClO	1983	Disinfection/oxidation
Sodium silicate	Na ₂ SiO ₃	1983	Coagulation and flocculation aid, pH correction, corrosion control
Sodium tripolyphosphate	$Na_5P_3O_{10}$	2005	Corrosion control, softening
Sulphuric acid	H_2SO_4	1983	pH correction
Zinc orthophosphate	$Zn_3(PO_4)_2$	1987	Corrosion control

In addition to chemicals and raw water, inflows may include electricity and fuel. These inflows may trigger the need to report and facilities employing reverse osmosis or other energy intensive processes need to monitor electricity (or fuel for generating electricity). A generalised system diagram for desalination using reverse osmosis is shown in Figure 3.

The system diagram in Figure 3 for a reverse osmosis process is similar to that shown in Figure 2. Disinfection and fluoridation are equally important for both systems. Continuing the comparison between system diagrams, the inflows will probably be greater for the reverse osmosis processes as the system requires more energy and chemicals to treat the saline raw water source. The saline raw water source will probably contain higher concentrations of substances than a fresh raw water source. If the reverse osmosis facility exceeds the thresholds due to substances in the raw water, then the outflow destination will determine whether the reporting is for emissions (to water) or transfers (to containment).

The raw water quality and source will dictate the processes required. The inlet structure shown in Figure 3 relates to a seawater source. These may become encrusted with molluscs and other biota that thrive in the artificial 'current'. If shock exposure to biocides is required, then the biocide use data must be incorporated into the NPI considerations. If groundwater is the source, inlet structures are not used, but aeration may be an early treatment process.



Figure 3 Generalised system diagram: desalination using reverse osmosis

In summary, once you have identified facility inflows, determine how these inflows are processed. Developing a thorough system diagram and associated mass balance will then link your inflows and processes to your emissions and transfers.

2.3 Potable water treatment process descriptions

Treatment plants in Australia range in size from supplying less than 1 ML/day to supplying about 3,000 ML/day. The sources of water available range from fresh and saline surface water, to fresh and saline groundwater, and brackish to ocean seawater. Figures 1, 2 and 3 provide generalised information and typical configurations and sequences. Actual treatment system processes are varied and largely dictated by the demand quantity and source quality. This section provides descriptions of many of the key processes used in potable water treatment.

Appendix B describes over 30 potable water treatment processes and it is intended that you scan through the headings to locate the processes of particular relevance to your system.

NPI reporting is not focussed on processes. Inflows determine the scale of your facility's potential health or environmental impact and therefore inflow thresholds determine the requirement to report. Outflows include emissions and transfers and these are the essence of NPI reporting. Process understanding is nonetheless important for reasons including to:

- ensure that estimates are representative of your facility, and
- communicate the context of your emissions/transfers to those accessing the NPI database.

3 Emission sources

Emissions from potable water treatment are discussed below in terms of emissions to air, water and land.

3.1 Emissions to air

Air emissions may be categorised as point source or fugitive emissions.

Point source emissions

Point source emissions are directed and emitted through a single point source into the atmosphere such as through a vent or stack. Examples of point source emissions are:

- In the initial stages of treatment, hydrogen sulphide might be stripped from raw water by aeration. Non-routine or accidental releases to air may occur.
- Treatment plants in remote locations might generate their own power by burning fuel or waste. For determining emissions from burning fuel, refer to the NPI EET manual for fossil fuel electric power generation.

Air emission control technologies need to be considered where relevant and where emission factors from uncontrolled sources have been used in emission estimations.

Fugitive emissions

These are emissions not released through a vent or stack. Examples of fugitive emissions for potable water treatment include emissions from volatilisation from open water surfaces, spills and materials handling, or from equipment leaks, such as from valves and flanges. Estimating emissions using emission factors or engineering judgement is the usual method for determining losses from fugitive emission sources in potable water treatment plants.

Chlorine and ammonia are the most likely substances to be lost fugitively to air from water treatment. Water treatment processes vary considerably as discussed in Section 2 and some additional substances listed in Table 1 may be emitted in very small quantities. Releases from storage and handling of treatment chemicals could occur, but normally such flows would be negligible. For the majority of potable water treatment facilities fugitive emissions are most likely to emanate from disinfection stages in the treatment process.

3.2 Emissions to water

Emissions of substances to water can be categorised as discharges to:

- surface waters (lakes, rivers, dams, estuaries)
- coastal or marine waters
- stormwater runoff.

Treatment plants that process seawater using reverse osmosis generate brine that is discharged back into the sea. Substances in that brine discharge are emissions to water.

Treatment plants that process freshwater using conventional processes are unlikely to generate routine emissions to water. Burst water mains that discharge to stormwater would be considered to be an emission and, for example, the chlorine residual and fluoride quantities emitted during the event would be added to the total emissions to water.

Emissions of toxic substances to waterways may pose environmental hazards. Most facilities emitting NPI-listed substances are required by their state or territory environment agency to closely monitor and measure these emissions. These existing sampling data can be used to calculate annual emissions to the NPI.

Substances contained within an end product, such as water treated and distributed to the consumer for domestic and commercial use, are not emissions.

The discharge of substances to a sewer or evaporation pond represents a transfer.

3.3 Emissions to land

Emissions of substances to land include solid wastes, sludges, slurries, sediments, spills and leaks. Burst water mains that discharge to land would be considered to be an emission. Accidental spills may contribute to emissions to land.

Disposal of substances in a waste, such as alum sludge, to a landfill represents a transfer. The quantities of chlorine and ammonia in dried alum sludge would be negligible.

4 Threshold calculations

4.1 Usage thresholds

The NPI has six different threshold categories and each NPI substance has at least one reporting threshold. If the 'use' of any NPI substance exceeds the thresholds for Category 1, 1a or 1b, then all of the emissions of that substance from the facility must be reported. This also applies to mandatory transfers.

'Use' and 'usage' is defined as the receipt, storage, handling, manufacture, import, processing, coincidental production or other uses of NPI substances. The *NPI Guide* provides detailed information on thresholds for all categories.

For conventional potable water treatment, determining chlorine use is the initial step. If the use is 10 tonnes or more, then a report to the NPI is required even if the emissions are very small. Depending on the processes used, the total annual process inflows for other substances (e.g. ammonia, fluoride) may also exceed 10 tonnes.

Some chemical additives are transported as liquids. The weight of NPI substances is less than the weight of product delivered. This means that the actual mass of chemical product inflow is usually well over 10 tonnes for the substances to exceed the Category 1 threshold. Box 2 below provides an example.

Box 2. Estimating a threshold volume for hydrochloric acid

For a 36% percentage weight solution of hydrochloric acid with a specific gravity of 1.2: the weight of acid in solution is $0.36 \times 1.2 = 0.432$ (kg/L)

The threshold volume of acid that would trip the threshold of 10 tonnes is: 'threshold volume' = 10,000/0.432 = 23,148 L

If the facility purchased and had delivered 23,150 litres or more of this strength hydrochloric acid then the Category 1 threshold for hydrochloric acid would be tripped. You would need to prepare emission and transfer reports for hydrochloric acid.

The threshold for Category 1 acids refers to the amount of the acid compound used (for example, in the case of hydrochloric acid, the threshold refers to the amount of hydrogen chloride used). This amount can be calculated as a factor of volume and concentration.

The quantities of chemical additives brought onsite are best calculated from treatment plant purchases, delivery records and inventory records. Concentrations are presented within the material safety data sheets.

Table 1 provides a list of water treatment chemicals, however, the substance quantities are often only a portion of the overall chemical mass. Table 2 below provides assistance in estimating the quantity of substances within chemical additives commonly used for potable water treatment.

Name	Formula	Percent by weight	Specific gravity	Concentration of substance in liquid (kg/L)	Threshold volume (L)
Hydrochloric acid	HCl	36%	1.2	0.432	23,150
Sulphuric acid	H_2SO_4	98%	1.84	1.803	5,550
Fluorosilicic acid	H_2SiF_6	22.5%	1.18	0.265	37,670
Chlorine (liquid gas)	Cl_2	99.5%	1.467	1.460	6,850
Sodium hypochlorite	NaOCl	12.5%	1.18	0.148	67,570
Sodium chlorite	NaClO ₂	31%	1.266	0.392	25,510
Ammonium hydroxide	NH ₄ OH	30%	0.90	0.270	37,040

Table 2: Threshold volumes for some commonly used substances

Raw water contains trace quantities of NPI substances. For facilities with large throughputs, the annual mass of some substances may exceed the thresholds. Box 3 below provides an example.

Box 3. Estimation of the inflow of boron by regular sampling

A facility sampled the inflowing raw water monthly to determine the concentration of boron: average daily flowrate was determined from records.

Month	Conc. (c) (mg/L)	Flowrate (f) (ML/day)	Days (d)	Quantity (kg/month) (= c x f x d)
July	0.10	50	31	155.0
August	0.11	50	31	170.5
September	0.12	48	30	172.8
October	0.09	46	31	128.3
November	0.08	48	30	115.2
December	0.09	51	31	142.3
January	0.11	53	31	180.7
February	0.12	55	28	184.8
March	0.13	52	31	209.6
April	0.10	50	30	150.0
May	0.11	48	31	163.7
June	0.13	48	30	187.2
Total				1960.1kg/year

In this case the total inflow of boron was below the Category 1 threshold of 10 tonnes for the reporting year and so no report is required for boron.

Substances do not have to be 'used', in the normal sense (i.e. added to the water) to be included in the estimate; being brought onsite and stored is sufficient for inclusion. Use in the reporting year comprises new deliveries plus whatever was initially in storage. The initial quantity in storage is the quantity that remained unconsumed from the previous year's deliveries as illustrated in Table 3 below. This is especially important for facilities whose use is extremely close to the threshold value.

		sounde si sugne sinsi	.,,
Quantity	First year	Second year	Third year
Already onsite, in	$S_{o} (= 0)$	So	So
storage			
Delivered during the	D	D	D
year			
Remaining in storage	(S _f)	(S _f)	$\mathbf{S}_{\mathbf{f}}$
at the end of the year			
Consumed during the	$C_1 = S_o + D - S_f$	$C_1 = S_o + D - S_f$	$C_1 = S_o + D - S_f$
year			

Table 3: Calculating the quantity of a substance brought onsite, used, and stored

Note: The quantity consumed during the year is used to determine whether thresholds have been tripped.

The *NPI Guide* provides specific advice about what should be measured/analysed for other substances. The advice for ammonia (total) and chlorine and compounds is as follows:

The threshold for 'Ammonia (total)' refers to the total amount of both ammonia (NH_3 CAS number 7664-41-7) and the ammonium ion (NH_4^+) in solution. There is no need to convert the quantity of ammonium ion into an ammonia equivalent.

The threshold for 'Chlorine and compounds' includes the amount of chlorine compounds used that may produce emissions of chlorine gas (Cl_2) , free residual chlorine, hypochlorite ion (OCI), hypochlorous acid (HOCl) or chloramines.

4.2 Desktop screening

Desktop screening may help determine which substances in raw water are most likely to trip the Category 1 threshold and should therefore be included in the data gathering. The following tasks provide a method for desktop screening:

- A. Obtain the plant's inflow (ML/day).
- B. Lookup the corresponding 'threshold concentration' in Table 4 below.
- C. Obtain the concentration for each substance in the following order of preference:
 - 1) from your own monitoring records
 - 2) from records for similar water
 - 3) from typical values for type of raw water (e.g. Table 5).
- D. Compare the 'expected' concentration with the 'threshold' concentration.
- E. If the expected concentration is:
 - close to, equal to, or greater than the threshold then either analyse for this substance or obtain data from existing monitoring

- moderately lower than the threshold then you should conduct at least one analysis (to check the prediction) for this substance, and
- greatly lower than the threshold then this substance could be omitted from NPI reporting considerations.

The following table shows the relationship between treatment capacity, threshold use quantities, and corresponding threshold concentrations of substances in raw water and in wastewater for Total nitrogen (TN) and Total phosphorus (TP). Box 4 provides an example showing how Table 4 can be used.

	Threshold use (tonnes/year)				
Treatment	10	0.005	3	15	
plant	Cor	responding thres	hold concentrat	ions	
capacity	Category 1	Mercury	TP	TN	
(ML/day)	(mg/L)	(µg/L)	(mg/L)	(mg/L)	
5	5.48	2.74	1.64	8.22	
10	2.74	1.37	0.82	4.11	
15	1.83	0.91	0.55	2.74	
20	1.37	0.68	0.41	2.05	
25	1.10	0.55	0.33	1.64	
30	0.91	0.46	0.27	1.37	
35	0.78	0.39	0.23	1.17	
40	0.68	0.34	0.21	1.03	
45	0.61	0.30	0.18	0.91	
50	0.55	0.27	0.16	0.82	
60	0.46	0.23	0.14	0.68	
70	0.39	0.20	0.12	0.59	
80	0.34	0.17	0.10	0.51	
90	0.30	0.15	0.09	0.46	
100	0.27	0.14	0.08	0.41	
110	0.25	0.12	0.07	0.37	
120	0.23	0.11	0.07	0.34	
130	0.21	0.11	0.06	0.32	
140	0.20	0.10	0.06	0.29	
150	0.18	0.09	0.05	0.27	
160	0.17	0.09	0.05	0.26	
170	0.16	0.08	0.05	0.24	
180	0.15	0.08	0.05	0.23	
190	0.14	0.07	0.04	0.22	
200	0.14	0.07	0.04	0.21	
300	0.09	0.05	0.03	0.14	
400	0.07	0.03	0.02	0.10	
500	0.05	0.03	0.02	0.08	
600	0.05	0.02	0.01	0.07	
700	0.04	0.02	0.01	0.06	
800	0.03	0.02	0.01	0.05	
900	0.03	0.02	0.01	0.05	
1000	0.03	0.01	0.01	0.04	
2000	0.01	0.01	0.004	0.02	
3000	0.01	0.005	0.003	0.01	

Table 4: Relationship between treatment plant capacity and thresholds

Box 4. Identifying the relevant substances in raw water

- 1. A treatment plant, that processes surface freshwater using conventional methods, has a capacity of 500ML/day.
- 2. All treated water goes to supply and so Category 3 substances (TN and TP) can be ignored as there are no substantial emissions to water.
- 3. The relevant threshold concentrations, from Table 4 are:
 - a. for Category 1 substances: 0.05 mg/L
 - b. for Mercury and compounds: 0.03 µg/L
- 4. Using default values from Table 5, the 'expected concentrations' of **fluoride** (0.5 mg/L), **boron** (0.1 mg/L), and **mercury** (0.0005 mg/L) are greater than the threshold concentrations. Raw water should be analysed for these substances; it is possible that they will trip the inflow use threshold.
- 5. It would be prudent to analyse for the following Category 1 substances with an 'expected concentration' of 0.01 0.05 mg/L: arsenic; copper; manganese; nickel; selenium; and zinc.
- 6. The other substances could be omitted from consideration.
- 7. Note that Table 5 contains indicative concentrations for use in determining where source specific analyses are required; Table 5 should not be used directly in calculations for reporting to the NPI.

	Average concentrations (mg/L)		
		Surface	Ground-
Substance	Seawater	water	water
Antimony	0.000330	0.000150	0.000150
Arsenic	0.003000	0.010000	0.010000
Beryllium	0.000001	0.000010	0.000010
Boron	4.600000	0.100000	4.000000
Cadmium	0.000110	0.000100	0.005000
Chromium	0.000200	0.001000	0.001000
Cobalt	0.000270	0.001000	0.001000
Copper	0.003000	0.010000	0.120000
Fluoride	1.300000	0.500000	2.300000
Hydrogen sulfide	0.000000	0.000000	0.500000
Lead	0.000050	0.000150	0.022000
Manganese	0.002000	0.016000	0.005000
Mercury	0.000030	0.000500	0.002000
Nickel	0.005400	0.010000	0.139000
Selenium	0.000020	0.010000	0.030000
Total nitrogen	0.500000	3.240000	5.400000
Total phosphorus	0.070000	0.118000	0.118000
Zinc	0.010000	0.010000	0.025000

Table 5: Indicative concentrations of NPI listed substances in different types of raw water.

Sources: Nott et al 2004; Cotruvo J A 2004; Bearmann G 1989; WHO. Note: Surface water and groundwater quality will vary considerably from the indicative values shown.

Box 5. Threshold calculations for the production of chlorine dioxide

Chlorine dioxide cannot be compressed or stored commercially as a gas because it is explosive under pressure. It is therefore made onsite. Generation of chlorine dioxide commonly involves reacting sodium chlorite with chlorine gas, hypochlorous acid or hydrochloric acid. Other methods include generation from sodium chlorite electrochemically, and from sodium chlorate using hydrogen peroxide and sulphuric acid.

Necessarily if the quantity of chlorine dioxide produced onsite trips the Category 1 threshold then the quantity of pre-cursor reactant brought onsite will also trip this threshold. Generators of chlorine dioxide produce dilute solutions that are stored before use. Production is either batch or continuous.

The annual production of chlorine dioxide can be calculated as follows:

For chlorine dioxide produced in batch production

- Batch mass = concentration of chlorine dioxide (mg/L) x volume of the batch (L)
- Annual production (t/yr) = sum of production for all batches / 10⁹
- $(1 \text{ tonne} = 10^9 \text{ mg})$

For continuous production

• Annual production $(t/yr) = ave. \text{ conc. } (mg/L) \text{ x total volume } (L)/10^9$

4.3 Fuel and electricity thresholds

Large facilities employing energy intensive processes such as reverse osmosis may trigger the Category 2a or 2b thresholds for fuel use and electricity consumption.

The NPI reporting thresholds for Category 2a are:

- burning of 400 tonnes or more fuel or waste in a year, or
- burning 1 tonne or more of fuel or waste in an hour at any time during the reporting year.

The NPI thresholds for Category 2b substances are:

- burning 2 000 tonnes or more of fuel or waste in a year
- consuming 60 000 megawatt hours or more of energy (e.g. electricity in a year), or
- a facility that has maximum potential power consumption of 20 megawatts or more at any time in the year.

If a facility exceeds the fuel burning threshold, refer to the EET manual for combustion in boilers. If a large, energy intensive potable water treatment exceeds the electricity consumption threshold, certain substances can be assumed to be negligible provided that there is no combustion processes or fuel burning. Carbon monoxide, for example, should be assumed to be zero in a wastewater transfer. The health /environmental impact of the substance carbon monoxide is as an air emission only.

For a facility that has no combustion processes or fuel burning, the table below indicates the substances that may be reported as zero. Substances shown with a strikethrough need not be considered.

ruste of Sundance for reporting Substances to mater			
Arsenic and compounds	Magnesium oxide fume (zero)		
Beryllium and compounds Mercury and compounds			
Cadmium and compounds	Nickel and compounds		
Carbon monoxide (zero)	Oxides of nitrogen (zero)		
Chromium (III) compounds	Particulate matter (2.5 micrometres or less in		
	diameter) (zero)		
Chromium (VI) compounds	Particulate matter (10 micrometres or less in		
	diameter) (zero)		
Copper and compounds	Polychlorinated dioxins and furans (as TEQs) (zero)		
Fluoride compounds	Polycyclic aromatic hydrocarbons (PAH) (zero)		
Hydrochloric acid	Sulfur dioxide (zero)		
Lead and compounds	Total Volatile Organic Compounds (TVOC) (zero)		

 Table 6: Guidance for reporting Category 2b substances to water

4.4 Total nitrogen and Total phosphorus thresholds

If your facility emitted to water (excluding groundwater), and/or transferred to a mandatory reporting transfer destination:

- 15 tonnes or more of total nitrogen, or
- 3 tonnes or more of total phosphorus

then you must report both substances.

The calculations relate to the quantities flowing out of the facility, as shown in Figure 4. However, unless there is a nutrient reduction process, the mass in and out are virtually the same.



Figure 4: Relationship between threshold categories, inflows and outflows

Category 3 thresholds for potable water treatment may be relevant to reverse osmosis (or similar process) facilities with a significant volume of discharge. Desktop screening, using Tables 3 and 4, can give an indication whether your facility needs to examine the Category 3 thresholds for nutrients.

Total nitrogen and Total phosphorus in waste discharged from a potable water treatment plant would have originated from the raw water inflow and would consist of dissolved inorganic and organic, and particulate forms. The thresholds for total nitrogen and total phosphorus relate to the following terms:

- **emission** refer only to the amounts of those Total nitrogen and Total phosphorus compounds that give rise to nitrate/nitrite and phosphate ions respectively and,
- **transfers** refer only to the amounts of soluble compounds of nitrogen and phosphorus that are in materials that readily permit the dissolution of these substances.

Total nitrogen is considered to be the sum of nitrate, nitrite, ammonia, and organic nitrogen all expressed as nitrogen. Total phosphorus is the sum of all inorganic and organic forms in water, expressed as phosphorus.

5 Emission estimation techniques

There are five types of emission estimation techniques (EETs) that may be used to calculate emissions from your facility. These are:

- sampling data or direct measurement
- mass balance
- fuel analysis or engineering calculations
- emission factors, and
- an approved alternative.

Select the EET (or mix of EETs) that is most appropriate for your purposes.

This manual seeks to provide the most effective EETs for the NPI substances relevant to the potable water treatment industry. However, the absence of an EET for a substance in the manual does not imply that an emission should not be reported to the NPI. The obligation to report on all relevant emissions remains if reporting thresholds have been exceeded.

5.1 Direct measurement

Direct measurement is a good option for reporting to the NPI, particularly if you already undertake sampling and analysis to meet other regulatory requirements or internal quality control objectives. If the raw water quality and the treatment processes remain consistent, then only a minimal amount of analyses are required as input to the calculations.

Direct measurement may be employed for emissions to water. For a reverse osmosis (or similar process) facility with a high volume wastewater stream, direct measurement of the reportable substances may be the most straightforward solution.

Box 6. Direct measurement of boron emissions to water

A seawater desalination plant conducts the threshold calculations using the technique outlined in Box 3 and determines that the facility exceeds the 10 tonne threshold and therefore needs to report. Flow rate data and laboratory analyses of boron in the brine discharge to the ocean are used to provide the annual emission to water. The reporting team decides to augment their NPI report and supply some contextual information on their seawater intake and emissions so that people accessing the facility's report will better understand the context of the emission.

5.2 Mass balance

Emissions to air: point source emissions

In the initial stages of treatment hydrogen sulphide might be stripped from raw water by aeration (refer Figure 2). This could be classified as a point source emission. The quantity released can be calculated as:

$$Q = (C_{in} - C_{out}) \times V$$

Where:

Q	quantity is hydrogen sulphide emitted (t/yr)
Cin	concentration of hydrogen sulphide in raw water pre-aeration (mg/L)
Cout	concentration of hydrogen sulphide in the water post-aeration (mg/L)
V	volume of water that is aerated (GL/yr)

The concentrations of hydrogen sulphide can best be determined by sampling and analysing raw and post-aeration water. As the emission to air is calculated from analyses of the water, this calculation is a mass balance and not a direct measurement. Direct measurement of hydrogen sulphide in air is possible, but the measured concentration needs to be related to a volume of air emitted. This involves a more complicated procedure than the mass balance example provided below.

Box 7. Estimation of hydrogen sulphide (H₂S) emission to air by regular sampling

A treatment plant processes groundwater that contains unacceptable concentrations of hydrogen sulphide and this substance is removed by aeration. The concentration of H_2S in the water before and in the water after aeration is determined by regular sampling. The average daily flowrate of water through the aeration unit was determined from records.

Sample	Cin	Cout	Flowrate (f)	Days (d)	Quantity
	(mg/L)	(mg/L)	(ML/day)		(kg/month)
					$(= (C_{in} - C_{out}) \mathbf{x} \mathbf{f} \mathbf{x} \mathbf{d})$
1	1.1	0.04	30	31	986
2	0.8	0.03	30	31	716
3	1.2	0.04	28	30	974
4	1.3	0.04	26	31	1016
5	0.9	0.03	28	30	731
6	1.0	0.03	30	31	902
7	0.8	0.02	32	31	774
8	1.1	0.04	34	28	1009
9	1.2	0.04	32	31	1151
10	1.3	0.04	31	30	1172
11	0.9	0.02	30	31	818
12	1.0	0.03	31	30	902
Total					11,151 kg/yr

The emission to air of hydrogen sulphide is calculated by a mass balance and was **11,000 kg** (after rounding) for the reporting year.

Emissions to water

An alternative to the analysis of a wastewater stream is the direct measurement of the raw water together with a mass balance to estimate emissions and transfers. The system diagram together with process knowledge must be sufficient to predict the emission/transfer fate of the reportable substances.

5.3 Engineering calculations

Engineering calculations should be used to estimate emissions and transfers where other methods are insufficient. For example, you may not be able to directly measure data related to non-routine events. The data gaps should be filled with the best available engineering estimates.

Spills, overflows and discharges need to be estimated and their contribution added to the reported process emissions and/or transfers. The emission resulting from a spill is the net emission, that is the quantity of the substance spilled, less the quantity recovered or consumed during cleanup operations. Table 2 provides data on the concentrations of substances in chemicals commonly used in water treatment. At a minimum, the following data should be recorded after a non-routine discharge:

- quantity discharged
- quantity recovered/removed
- destination of the discharge, and
- concentrations of substances.

If a water main bursts, then the concentrations of chlorine and fluoride are known, but the volume of water discharged needs to be estimated. The calculation should be based on the estimated duration and estimated flow rate. These estimates are best calculated by experienced and competent personnel. If more than one treatment facility contributes to the distribution network where a spill occurs, the emission can be proportioned to the facilities based on the volumetric contribution.

5.4 Emission factors

An emission factor is a tool that is used to estimate emissions to the environment. In this manual, it relates to the quantity of substances emitted from a source to some common activity associated with those emissions. Emission factors are usually expressed as the weight of a substance emitted multiplied by the unit weight, volume, distance or duration of the activity emitting the substance (e.g. kilograms of substance per tonne of product).

When using emission factors, you should be aware of the associated emission factor rating (EFR) code and what the rating implies. An A or B rating indicates a greater degree of certainty than a D or E rating. The main criterion affecting the uncertainty of an emission factor remains the degree of similarity between the equipment/process selected in applying the factor and the target equipment/process from which the factor was derived.

The EFR system is:

- A Excellent
- B Above average
- C Average
- D Below average
- E Poor
- U Unrated

Emission factors are used to estimate a facility's fugitive emissions to air when other methods such as development of unit-specific correlation equations or application of existing correlations are not available.

Generally, the application of an emission factor takes the following form:

$$ER = A \times T \times EF \times [1-(CE/100)]$$

Where:

ER is emission rate (kg/yr) A is 'activity' rate (t/hr) T is number of operating hours for the reporting year (hr) EF is the uncontrolled emission factor (kg/t) CE is the control efficiency (%) for the substance

Control efficiency is unlikely to apply for the majority of water treatment plants and the part in [] could be omitted from the calculations.

Only small fugitive emissions of chlorine, chlorine dioxide, or ammonia would be expected from such things as leaks in valves and fittings. In these circumstances, engineering judgement could be used to estimate fugitive releases (U.S. EPA 1998).

At normal operating pH, essentially no free gaseous forms would exist in solution (Fair et al. 1968) and only very small losses through volatilization would be expected. Engineering judgement could be used to estimate fugitive releases from open water surfaces (Appendix B).

Equipment and facility design specifications may minimise fugitive emissions from equipment leaks. If these specifications apply to your treatment plant then fugitive emissions from such equipment could be treated as negligible.

No releases to water would be expected for the gaseous form of chlorine, chlorine dioxide, or ammonia. The site of application – just prior to distribution – means that no emission to water of ionic forms would be expected either. In desalination plants water is dechlorinated before it reaches RO membranes and becomes waste brine: chlorine emissions to water would be unlikely.

5.5 Approved alternative

You are able to use emission estimation techniques that are not outlined in this document. You must, however, seek the consent of your state or territory environmental agency. For example, if your facility has developed site-specific emission factors, you may use these if they have been approved by your environmental agency.

Box 8. Example calculation for emission of copper applied as copper sulphate

During a reporting year 48 tonnes of copper sulphate was applied to a storage reservoir to control algal blooms. The copper sulphate used had the chemical formula $CuSO_4.5H_2O$.

The proportion of copper (Cu) in this form of copper sulphate is equal to:

(atomic weight of Cu)/(molecular weight of the whole salt) 63.54/249.68 = 0.254

The quantity of copper emitted is therefore 0.254×48 tonne: or 12.2 tonnes. If the storage reservoir is considered to be outside of the system boundary, i.e. not part of the reporting facility, then addition is classed as an **emission**. The entire amount is reported to the NPI.

If the storage reservoir is considered to be within the system boundary, i.e. within the operating control of the reporting facility, then addition of 48 tonnes is classed as a **use**. Potentially there is no emission of copper. However, discharges from the storage reservoir that are not for treatment and distribution, such as an overflow or creek discharge, must account for emissions of copper to the natural environment (emission to water).

Many factors influence the fate of copper in a storage reservoir (e.g. dissolved or precipitated in sediments) and in an associated discharge event. A scientifically sound method of estimating this emission should be developed and then approved by the state or territory environmental agency.

6 Transfers of NPI substances

The NPI requires the mandatory reporting of NPI substances that are transferred as waste to a final destination. Transfers are required to be reported if a Category 1, Category 1b or Category 3 reporting threshold is exceeded. Both emissions and transfers are reportable in kilograms. For example, if the threshold has been exceeded for the Category 1 substance – hydrochloric acid – as a result of use of this substance on site, transfers to final destination of hydrochloric acid as well as the emissions are reportable. Both emissions and transfers are reportable in kilograms.

There is no requirement to report transfers of:

- substances that are exclusively Category 2a or Category 2b,
- substances which are both Category 2a or Category 2b and Category 1 or Category 1b (e.g. copper and compounds), in the event that the substance has tripped the Category 2 threshold only, or
- TVOC (Category 1a and Category 2a).

The transfer of NPI substances to a destination for reuse, recycling, reprocessing, purification, partial purification, immobilisation, remediation or energy recovery can be reported voluntarily. This is an opportune way for facilities to provide appropriate context about transfers to their local community.

Further information regarding transfers of waste, including how to estimate and report, can be found in the *NPI Guide*.

Emission and transfer of substances in waste sludge

Sludge from pre-filtration and filtration stages is the main waste generated by potable water treatment. In most cases, the sludge would be moved offsite. The most likely destinations would be:

To **mandatory** reporting destinations

- landfill
- sewerage system

Or to voluntary transfer reporting destinations

• for composting and soil conditioning

For typical dried alum sludge, the chlorine and ammonia content can be considered to be negligible.

7 Additional reporting information

This manual has been written to reflect the common processes employed in potable water treatment plants. To ensure a complete report of the emissions for your facility, it may be necessary to refer to other EET manuals. These are listed in Section 1.4.

When you have a complete account of substance emissions from your facility, report these emissions according to the instructions in the *NPI Guide*.

Additional reporting information

The following advice is compiled from relevant references and is presented below to aid in reporting.

The amount of a Category 1 acid emitted refers to the amount of the actual acid compound emitted or transferred (for example, in the case of 'Hydrochloric acid', the amount emitted or transferred refers to the amount of hydrogen chloride emitted). It does not include any amounts of the acid that have been neutralised before release as the acid no longer exists.

The amount of 'Chlorine and compounds' emitted or transferred refers to the total amount of chlorine gas (Cl_2) , free residual chlorine, hypochlorite ion (OCI), hypochlorous acid (HOCl) and chloramines emitted or transferred, expressed as the equivalent weight of chlorine (Cl).

The amount emitted or transferred in relation to a substance listed as "(a metal) and compounds" refers only to the amount of the metal emitted or transferred (for example, the amount of "Lead and compounds" emitted refers only to the amount of Lead emitted).

Significant figures

Quantities should be reported to two significant figures. The rounding method used should be in accordance with Australian Standard AS 2706. Rounding should be made in 'one step'. Examples are:

Original Value	Rounds to
8.2501	8.3
8.3499	8.3

If figures to be discarded fall midway between two numbers (i.e. end in a 5) then the value should be rounded to the nearest even number. Examples are:

Original value	Rounds to nearest even value
8.45	8.4
8.5500	8.6

Reporting emissions as zero

Caution should be taken when reporting an emission of a tripped substance as zero. Emissions should only be reported as zero in circumstances where there is certainty that the NPI substance is not emitted or emissions are negligible. The reported emission for a substance should be left blank if no emission estimation factors or techniques are available and if there is uncertainty about whether that emission is in fact zero. If a blank emission is included in a report for an NPI substance where usage has tripped the reporting thresholds, written documentation with the appropriate reason must be provided, for example "No emission estimation technique available".

Detection limits

If a result is below the detection limit

- and you are sure that the substance was not present, then report a zero value,
- otherwise, report a value that is half the detection limit.

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Definition Term Australian and New Zealand Standard Industrial Classification ANZSIC a measure of pressure (bar = 10^5 Pascal) bar emission estimation technique EET GAC granular activated carbon gram; 10⁻³kg g Gigalitre; 10^9 L; (10^6 m^3) GL kilogram; SI base unit kg kilograms per month kg/month kilograms per year kg/year Litre; 10^{-3} m³ (m: metre is an SI base unit) L milligram; 10^{-6} kg; $(10^{-3}g)$ mg milligrams per litre mg/L Megalitre; 10^6 L; (10^3 m^3) ML ML/day megalitres per day MSDS Material safety data sheet MWh megawatt hour (used for electrical energy) NHMRC National Health and Medical Research Council NPI The National Pollutant Inventory contains data on 93 substances that substances have been listed based on their potential health or environmental impact. PAC powdered activated carbon parts per million ppm RO **Reverse Osmosis** tonne; 1000kg t Trihalomethanes THM TDS Total dissolved solids TN Total nitrogen TP Total phosphorus TVOC Total volatile organic compounds Ultraviolet radiation UV WHO World Health Organisation microgram; 10^{-9} kg; $(10^{-6}$ g) μg micrograms per litres μg/L

Appendix A: Abbreviations and definitions

Appendix B: Potable water treatment processes

Raw water collection, abstraction, storage

Commonly fresh surface waters are collected by impoundment of rivers: construction of dams and weirs. These storages remain part of the natural environment connected to the downstream river system by overflows (spillways) or mandatory releases. The storages might be located close to, or many kilometres from the treatment plant. Water may reside in such reservoirs for years before extraction and treatment.

Occasionally reservoirs are constructed off-stream. Residence time of the stored water is normally relatively short compared with dams and weirs. They have no outflow to the source river: only an outflow into the treatment plant. Water abstracted from groundwater and seawater sources is usually treated immediately.

For NPI purposes, the system boundary extends to the limit of operational control. The infrastructure associated with storages (e.g. inlet pipes, screening equipment) are within the system boundary. The inclusion of storages (e.g. dams, weirs) depends on whether there is operational control. Chemicals added to these structures for microbial control must be included in calculations.

Storages (lakes and reservoirs) can develop blooms of nuisance algae. Copper sulphate and derivatives of copper sulphate have been used to control such blooms. Application rates are generally designed to create a final concentration of copper of between 0.1 to 0.5 mg/L. The action can be relatively slow (days rather than hours) and copper can precipitate (before affecting the algae) by combining with other dissolved substances.

Blooms are often associated with periods of stratification. In warmer months a water body might separate into an upper epilimnion, a lower hypolimnion and an intermediate layer, the metalimnion. Water in the hypolimnion might become anoxic, algal blooms might occur in the epilimnion (and metalimnion). Bubbling air through the water column, or creating subsurface jets of water, can disrupt stratification. Water quality is improved and the intensity of algal blooms reduced.

Aeration and oxidation

Occasionally raw water has to be extracted from sources that are anoxic (from the hypolimnion of lakes; groundwater, and seawater from beneath the sediment surface). Water quality can be improved by chemical oxidation (e.g. addition of potassium permanganate), and by aeration (compressed air) to precipitate substances such as iron and manganese. Aeration will strip gases, including the NPI substance hydrogen sulphide, from the water. The gas might be trapped in a scrubbing process or it might be released to air.

Activated carbon adsorption

Activated carbon has a high affinity for organic compounds. It is normally used either in powdered (PAC) or in granular (GAC) form. PAC is dosed as slurry into the water: GAC is normally used in fixed beds. Activated carbon is used for the removal of pesticides and other organic chemicals, taste and odour compounds, cyanobacterial toxins and total organic carbon.

Chemical coagulation

Chemical coagulation-based treatment is the most common approach for treatment of surface waters. Coagulants, usually aluminium or iron sulphates (and chlorides), are added to the raw water to form a flocculent. Precipitating floc removes suspended and dissolved contaminants. The floc is removed by sedimentation or by dissolved air flotation. The sludge is periodically removed. Coagulation removes heavy metals and low-solubility organic chemicals, such as certain organochlorine pesticides.

Ion exchange

Ion exchange is a process in which ions of like charge are exchanged between the water phase and a solid resin phase. Calcium ions and magnesium ions in the water can be replaced by sodium, or hydrogen ions. Ion exchange can be used to remove contaminants such as nitrate, arsenic, selenium, and heavy metals.

Filtration

Particulate matter can be removed from raw waters by rapid gravity, horizontal, pressure or slow sand filters. Slow sand filtration is primarily a biological process, whereas the others are physical treatment processes. Rapid gravity, horizontal and pressure filters can be used for direct filtration of raw water, without pretreatment. Rapid gravity and pressure filters are commonly used to filter water that has been pre-treated by coagulation and sedimentation. An alternative process is direct filtration, in which coagulant is added to the water, which then passes directly onto the filter where the precipitated floc (with contaminants) is removed; the application of direct filtration is limited by the available storage capacity within the filter.

Slow sand filters

Slow sand filters usually consist of tanks containing sand (effective size range 0.15–0.3mm) to a depth of between 0.5 and 1.5m. The raw water flows downwards, and turbidity and microorganisms are removed primarily in the top few centimetres of the sand. A biological layer develops on the surface of the filter and can be effective in removing microorganisms. Treated water is collected in underdrains or pipework at the bottom of the filter. The top few centimetres of sand containing the accumulated solids are removed and replaced periodically. Slow sand filtration is effective for the removal of organics, including certain pesticides and ammonia.

Rapid gravity filters

Rapid gravity sand filters usually consist of open rectangular tanks (usually <100m²) containing silica sand (size range 0.5–1.0mm) to a depth of between 0.6 and 2.0m. The water flows downwards, and solids become concentrated in the upper layers of the bed. Treated water is collected via nozzles in the floor of the filter. The accumulated solids are removed periodically by backwashing with treated water. Multimedia filters incorporate several layers of materials (coarse to fine pore size). Rapid gravity filters are most commonly used to remove floc from coagulated waters. They may also be used to reduce turbidity (including adsorbed chemicals) and oxidized iron and manganese from raw waters.

Membrane processes

The membrane processes of most significance in water treatment are reverse osmosis, ultrafiltration, microfiltration and nanofiltration. These processes have traditionally been applied to the production of water for industrial or pharmaceutical applications but are now being applied to the treatment of drinking water.

High-pressure membrane processes

Reverse osmosis uses membranes with pore sizes less than 0.002μ m. High pressure (15–50 bar) forces water through the membrane against a concentration gradient. The process results in the production of a treated water stream and a relatively concentrated waste stream. Reverse osmosis rejects monovalent ions and organics of molecular weight greater than about 50 Daltons (atomic mass units). Some ions are not removed with such great efficiency: for example boron and arsenic.

Membranes are made of polymeric materials (cellulose tri-acetate, polyamides or polysulphones), with very small pores. Membranes are housed in casing and can be configured as hollow fibres, spirals, plates or tubes. Membrane thickness is of the order 0.05mm (attached to a porous supporting material).

The most common application of reverse osmosis is desalination of saline groundwater, brackish water and seawater. More recently, in Australia it is being used to process treated sewage effluent.

Pretreatment of source water is necessary before reverse osmosis: suspended solids are removed by filtration; pH adjustment is made to protect the membranes and to control precipitation of salts; anti-scaling inhibitors are added (to control, for example, calcium carbonates and sulphates); disinfection is necessary to prevent biofouling of the membranes: disinfectants include use of chlorine, ozone, and UV light. Dechlorination is required before water reaches the reverse osmosis membranes. Membranes are cleaned with a variety of proprietary cleaning agents (cleaning can occur *in-situ*). Additives can be discharged with the wastewater stream.

Post-treatment is required: pH is adjusted; corrosion inhibitors (polyphosphates) might be added; elements might be removed (e.g. boron) others are added in a remineralisation step to bring the water's composition to acceptable levels (WHO); disinfection occurs before and during distribution.

Nanofiltration uses a membrane with pore sizes between 0.001 and 0.01 μ m. Nanofiltration membranes allow monovalent ions such as sodium or potassium to pass but reject a high proportion of divalent ions such as calcium and magnesium and organic molecules of molecular weight greater than 200 Daltons. Operating pressures are typically about 5 bar. Nanofiltration may be effective for the removal of colour and organic compounds.

Lower-pressure membrane processes

Ultrafiltration is similar in principle to reverse osmosis, but the membranes have larger pore sizes (typically $0.002-0.03 \ \mu$ m) and operate at lower pressures. Ultrafiltration membranes reject organic molecules of molecular weight above about 800 Daltons and usually operate at pressures less than 5 bar.

Microfiltration is a direct extension of conventional filtration into the submicrometre range. Microfiltration membranes have pore sizes typically in the range $0.01-12 \,\mu\text{m}$ and do not separate molecules but reject colloidal and suspended material at operating pressures of 1-2 bar. Microfiltration is capable of sieving out particles greater than $0.05 \,\mu\text{m}$. It has been used for water treatment in combination with coagulation or PAC to remove dissolved organic carbon and to improve permeate (freshwater) flux.

Disinfection

Disinfection to inactivate potentially harmful microbes is one of the essential objectives of potable water treatment. Several processes may be used.

Chlorination

Disinfection using chlorine has been in operation for about one hundred years. Currently, chlorination is achieved by using liquefied chlorine gas, sodium hypochlorite solution or calcium hypochlorite granules and onsite chlorine generators.

Liquefied chlorine gas is supplied in pressurized containers. Dosing is by a chlorinator, which both controls and measures the gas flow rate.

Sodium hypochlorite solution is dosed using a positive-displacement electric dosing pump or gravity feed system.

Calcium hypochlorite is generally supplied in tablet form. These are dissolved in water (automated systems are available) and then mixed with the main supply.

Chlorine dissolves in water to form hypochlorous acid (HOCl) and hypochlorite ion (OCl): their sum is the 'total available chlorine' concentration. Hypochlorous acid is the more effective disinfectant of the two species. The reaction is effectively instantaneous and at normal levels of pH no free chlorine gas exists in solution.

Different techniques of chlorination can be used, including breakpoint chlorination, marginal chlorination and superchlorination/dechlorination.

Breakpoint chlorination is a method in which the chlorine dose is sufficient to rapidly oxidize all the ammonia nitrogen in the water and to leave a residual of free chlorine available to protect the water against reinfection from the point of chlorination to the point of use.

Superchlorination/dechlorination is the addition of a large dose of chlorine to effect rapid disinfection and chemical reaction, followed by reduction of excess free chlorine residual. Removing excess chlorine is important to prevent taste problems. It is used mainly when the bacterial load is variable or the detention time in a tank may be insufficient.

Marginal chlorination is used where water supplies are of high quality and is the simple dosing of chlorine to produce a desired level of free residual chlorine. The chlorine demand in these supplies is very low, and a breakpoint might not even occur.

Chlorination is employed primarily for microbial disinfection. However, chlorine also acts as an oxidant and can remove or assist in the removal of some chemicals – for

example, decomposition of easily oxidized pesticides; oxidation of dissolved species (e.g., manganese(II)) to form insoluble products that can be removed by subsequent filtration; and oxidation of dissolved species to more easily removable forms (e.g., arsenite to arsenate). Chlorine in the presence of organics in raw water can produce carcinogenic trihalomethanes (THM). This has created an incentive to use alternative disinfection processes.

Sufficient chlorine is added to water to achieve adequate disinfection. The quantity required, the chlorine dose, varies with several factors that effectively remove chlorine. These factors include: reactions induced by solar radiation, reactions with inorganic (e.g. ammonia), and organic compounds; and volatilisation. The total quantity of chlorine removed is the 'chlorine demand'. It is calculated as follows:

Chlorine demand = chlorine dose – chlorine residual

There are no adequate emission factors for estimation of chlorine loss by volatilisation. Chang et al. (2001) suggest that 20% of chlorine demand is due to volatilisation: but this was based on 'expert opinion / engineering judgement' and not scientific investigation. Kruger et al. (2000) found that chlorine concentrations could reach 0.3 ppm in air above chlorinated water (with chlorine concentrations of 1.0 to 3.0 mg/L) in small covered reservoirs.

Chlorine concentrations in air above chlorinated water in small covered reservoirs (Table 1 in Kruger et al (2000)

Chlorine concentration at	Chlorine concentration in	Chlorine concentration in
the water surface (mg/L)	the air above the water: no	the air above the water
	stirring (ppm)	with stirring (ppm)
0.7	0.1	0.0 - 0.1
1.0	0.2	0.0 - 0.2
1.3	0.3	0.3 - 0.4
2.6	0.3	0.3 - 0.4
65.0	0.6	0.6 - 0.8

Disinfection - chloramination

Chloramines (monochloramine NH_4Cl , dichloramine $NHCl_2$ and "trichloramine," or nitrogen trichloride NCl_3) are produced by the reaction of aqueous chlorine with ammonia. Monochloramine is the only useful chloramine disinfectant, and conditions employed for chloramination are designed to produce only monochloramine. Monochloramine is a less effective disinfectant than free chlorine, but it is persistent, and it is therefore an attractive secondary disinfectant for the maintenance of a stable distribution system residual.

Chlorine dioxide

Chlorine dioxide (ClO₂) has been used for drinking-water disinfection on a large scale in Europe for about 50-60 years. In about the past decade, its use as a drinking-water disinfectant has been growing. Chlorine dioxide decomposes in water to form chlorite and chlorate. Unlike chlorine, it does not produce trihalomethanes (THM), it is a superior disinfectant to chlorine (i.e. against bacteria, viruses, protozoa and their cysts). When used with ozone the mixture reduces the generation of carcinogenic bromates.

Chlorine dioxide cannot be compressed or stored commercially as a gas because it is explosive under pressure. It is therefore made onsite. Generation of chlorine dioxide commonly involves reacting sodium chlorite with chlorine gas, hypochlorous acid or hydrochloric acid. Other methods include generation from sodium chlorite electrochemically, and from sodium chlorate using hydrogen peroxide and sulphuric acid. Generators of chlorine dioxide produce dilute solutions for use.

Disinfection - ozonation

Ozone is a powerful oxidant and has many uses in water treatment, including oxidation of organic chemicals. Ozone can be used as a primary disinfectant. Ozone gas (O_3) is formed by passing dry air or oxygen through a high-voltage electric field. The resultant ozone-enriched air is dosed directly into the water by means of porous diffusers at the base of baffled contactor tanks. Ozone is effective for the degradation of a wide range of pesticides and other organic chemicals but ozone does not provide a disinfectant residual.

UV radiation

Use of UV radiation in potable water treatment has typically been restricted to small facilities. UV radiation, emitted by a low-pressure mercury arc lamp, is biocidal between wavelengths of 180 and 320nm. It can be used to inactivate protozoa, bacteria, bacteriophages, yeast, viruses, fungi and algae. Recently a combination of UV radiation and hydrogen peroxide has been used successfully to treat potable water on a large scale. Turbidity can inhibit UV disinfection. UV radiation can act as a strong catalyst in oxidation reactions when used in conjunction with ozone.

Iodine based disinfection

This technology is claimed to be an effective replacement for chlorine. Systems are self contained (iodine is recovered), automated, and can be scaled to treat from less than 1 ML/day to hundreds of ML/day.

Ionization using copper and silver

A process that produces copper (Cu^{2+}) and silver (Ag^+) ions that attach to the cell membranes of microbes causing their death. This technology was developed in Europe and the USA in the 1950s and has been used successfully for many years.

Elemental iron

Experimental treatments using elemental iron (Fe) and coated-silica particles have successfully disinfected water to drinking quality standards at laboratory scale (Chiu and Jin, 2007).

Advanced oxidation processes

Hydroxyl radicals are generated and can effectively destroy chemicals that are difficult to treat using other methods, such as ozone alone. Chemicals can react either directly with molecular ozone or with the hydroxyl radical. The formation of hydroxyl radicals can be encouraged by using ozone at high pH or ozone and hydrogen peroxide.

Electrodialysis

These processes use selective membranes that contain cation and anion exchange groups. Under a direct current, ions migrate to their respective electrodes so that ionrich and ion-depleted streams form separately in spaces between the membranes. Reversal of the direct current reduces scaling and flushes the membranes.

Treatment for corrosion control

Corrosion is the partial dissolution of the materials constituting the treatment and supply systems, tanks, pipes, valves and pumps. It may lead to structural failure, leaks, loss of capacity and deterioration of chemical and microbial water quality. The internal corrosion of pipes and fittings can have a direct impact on the concentration of some water constituents, including lead and copper. Corrosion control is therefore an important aspect of the management of a drinking-water system for safety.

Corrosion control involves many parameters, including the concentrations of calcium, bicarbonate, carbonate and dissolved oxygen, as well as pH. The detailed requirements differ depending on water quality and the materials used in the distribution system. The pH controls the solubility and rate of reaction of most of the metal species involved in corrosion reactions. It is particularly important in relation to the formation of a protective film at the metal surface. For some metals, alkalinity (carbonate and bicarbonate) and calcium (hardness) also affect corrosion rates.

Distillation

Water is heated and vaporized; the vapour is condensed and collected. This technology has been in use worldwide, for more than 50 years, to process seawater: but not in Australia. Use of this technology is not likely to increase on a large scale in Australia: reverse osmosis being the currently preferred option. Electrodialysis and vacuum freezing are minor distillation technologies that have also been used for desalination and production of pure water.

Distillation of seawater produces water that has TDS of between 1 and 50mg/L: a stream of waste, concentrated brine, is generated. The major forms of distillation process are multistage flash distillation, multi-effect distillation and vapour compression distillation.

Multistage flash distillation

Pressure of vapour is rapidly reduced below the vapour pressure of the source water: the water boils rapidly. The vapour is condensed (and collected): heat from condensation is used to heat the inflowing source water. Between 25 to 50% of inflow is recovered as freshwater. This process can treat large volumes and, is therefore capable of using large quantities of treatment chemicals.

Multi-effect distillation

Steam is condensed on one side of a tube: the heat is used to evaporate saline water on the other side. Pressure is reduced sequentially in each stage as the temperature falls.

Vapour compression distillation

Pressure (and boiling point) is lowered on the inflow side; pressure is increased to condense vapour on the other side. The heat of condensation is transferred to the inflowing water.

Potable water treatment process information in this Appendix was compiled from various sources but mainly from: CRC Water Quality and Treatment; Sharp (2007); Barron (2006); Water Consultants International (2006); WHO (2006); Gebbie (2005); Younos (2005); LeChevallier and Au, (2004); URS (2002); Buros (2000); U.S. EPA (1999), and Fair et al (1968).

Appendix C: Modifications to the potable water treatment emission estimation technique (EET) manual (Version 2.0, June 2008)

Page	Outline of alteration
2	added Section 1.2 Structured approach to NPI reporting
5	revised Figure 1 Processes
7, 10	added Figures 2 and 3 System diagrams
8-9	added Table 1 Chemicals approved for potable water treatment
14-21	added Chapter 4 Threshold calculations
22	added Box 6 Direct measurement of boron emissions to water
23	added Box 7 Estimation of hydrogen sulphide emission to air, removed Fugitive losses of chlorine
26	added Box 8 Emission of copper applied as copper sulphate
27	added Chapter 6 Transfer of NPI substances
28-29	added Chapter 7 Additional reporting information
30-31	augmented Chapter 8 References
32	added Appendix A Abbreviations and definitions
33-40	added Appendix B Process descriptions
41	added Appendix C Modifications to manual revision