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An Ecological Risk Assessment of Herbicides Used in Channels and Drains in the Goulburn-Murray Irrigation Areas

Master's Thesis in the International Master's Programme "Applied Environmental Measurement Techniques"

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Department of Civil and Environmental Engineering
Water Environment Technology
Chalmers University of Technology
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ABSTRACT

This master thesis is a study on Ecological Risk Assessment (ERA) of herbicide used in Golburn-Murray irrigation area in Victoria, Australia to control aquatic weeds. (G-MW) company in Victoria is supplying said water for irrigation, domestic and stock drinking and for raw town supplies via several channels and drains.

The objective of the current study is to assess the impact of four used herbicides (glyphosate, 2, 4-D amine, Amitrole and acrolein) for the potential ecological risks to a range of receptors such as human, domestic and stock, aquatic ecosystem, crops, and wetlands. Different exposure pathways are considered in calculating predicted environmental concentration (PEC) of herbicides; spraying directly in the water, on to plants and subsequent wash-off, onto the soil, embankments and spray drift (run off).

The methodology is based on the basic principles of risk assessment and provides a range of scenarios based on the available used herbicides' data in six irrigation areas of G-MW. A tiered or phased approach (1&2) has been used in this study and Hazard Quotient (HQ) evaluated risk of herbicide effects.

The assessments indicated that many scenarios do not pose a serious risk, whereas the risk is manifest in others. In many cases the assessments were limited by the availability of suitable data. This information is used to make recommendations both for management practice and for future research.

Keyword: ERA, PEC, Tier, HQ, wash off

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First of all I would like to give my sincerely thanks to my Supervisor Professor Greg Morrison for his help. I want to also thank my supervisors in CSIRO, Dr. Rai Kookana and Dr. Ray Correl for their enormous effort to guide me during six months the project. I want to also express my thanks to people who have helped me in Adelaide especially my best friend, Dr Laura Wendling who was always on my side and never left me alone.

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Contents

Abbreviation

ARMCANZ: Agriculture and Resource Management Council of Australia and New Zealand

CSIRO: Commonwealth Scientific and Industrial Research organisation

EPA: Environment Protection Authority

G-MW: Goulburn Murray Rural Water Authority

HQ= Hazard Quotient

LOAEL: Lowest Observed Effect Level; the lowest dose in an experiment which produced an observable effect

MCL: Maximum contaminant level

NOAEC: No observable effect concentration

NOAEL: No observed adverse effect level

PEC: Predictive Environmental Concentration

1. Executive Summary

1.1. *Introduction*

Goulburn-Murray Water (G-MW) is the largest rural water supply authority in Australia, supplying water for irrigation, domestic and stock drinking and for raw town supplies. G-MW's region covers 68,000 square kilometres from the Great Dividing Range north to the River Murray and from Corryong down river to Nyah near Swan Hill.

G-MW distributes water and accumulates drainage water from earth-lined channels or drains. These channels and drains can become choked with a variety of weeds. G-MW commonly uses four herbicides, namely acrolein, glyphosate, amitrole and 2, 4-D amine, to control aquatic weeds in the irrigation channels, drains and natural carriers so that normal water flow can be maintained. While application of these herbicides is aimed to control targeted plants or weed species, there remains a possibility of potential harm to other non-targeted species if the applications are not properly managed.

In recent time there has been some concern about the applications of herbicides by G-MWs and their possible detrimental impacts on other receptors. Fish kills at the Goulburn Weir, Nagambie, Victoria in January 2004 have enhanced awareness of potential issues. The possible impacts on environment caused by elevated application rates of glyphosate and 2, 4-D as used under special permits, also need to be examined. As a result of these concerns, the Goulburn River audit (EPA, Victoria) recommended an assessment of the risk to non-target receptors that is posed by spraying of G-MW's drains, channels and natural carriers.

The current herbicide risk assessment was based on several scenarios identified jointly by G-MW and CSIRO as a part of a collaborative research between CSIRO and G-MW. It used intellectual properties and tools available with CSIRO, developed new methods for the risk assessment, and utilized G-MWs raw data and information on herbicides.

The objective of the current study was to assess four commonly used herbicides (glyphosate, amitrole, 2, 4-D amine and acrolein) by G-MW for the potential ecological risks to a range of receptors (eg. humans, domestic and stock, food industry, fish, aquatic flora and fauna, pastures and selected crops, riverine ecosystems and wetlands); and to consider different exposure pathways (eg. spray landing directly in the water, spraying on to plants in the channel and subsequent wash-off, spraying onto the soil in a channel or a drain, spraying on channel and drain embankments and then run off occurring into the channel or drain and spray drift).

1.2. *Risk assessment approach (Tier 1 and Tier 2)*

This study employs the basic principles of risk assessment and provides a range of scenarios based on available herbicide use data in six irrigation areas of G-MW. A Tiered (phased) approach has been adopted in this risk assessment study. For example, in the first phase (termed Tier 1 risk assessment) a near-worst case scenario was considered, asking the question "What if all of the applied herbicides is available in water without allowing any losses?" In this case the absolute worst case will be taken in calculation to assess if there is any possible risk to the receptors, assuming all of the applied herbicides somehow becomes dissolved in the water in the channel or drain and there are no biotic or abiotic losses. While this is often an unrealistic possibility, it is a near worst case scenario. If the hazard quotient in this case is still acceptable, there is clearly no need for pursuing the assessment further.

Channel or drain depths together with the application rates and the no observable effect concentration (NOAEC) for the most sensitive receptors in each class were included in this assessment. The Tier 1 assessment identified those receptors that were not affected even by the highest expected exposure levels. If the hazard was rated to be significant than Tier 2 assessment was carried out.

In **Tier 2** a more refined assessment of the predicted environmental concentration (PEC) was considered for each herbicide. The estimation of the PEC considered dilution, volatilization, adsorption, biodegradation and effective half-life of herbicide in each compartment (e.g. water, soil and plant), an estimate of the fraction that would run off from the bank and the fraction of herbicide applied to a plant that would have washed off from the plant after a channel was refilled with water. In the case of acrolein, dispersion and diffusion models were adapted to predict PEC.

Both Tier 1 and Tier 2 risk assessments considered toxicity values of surrogate or actual receptors organisms such as EC_{50} (plants, algae or crops), LD_{50} (rats) and LC_{50} (*Daphnia*, fish), and NOAEC (or NOAEL) values. The criteria used in both Tier 1and Tier 2 risk assessments was obtained by dividing the PEC by NOAEC to give a hazard quotient (HQ). Scenarios with an HQ less than 1.0 were considered not to be at risk and hence did not require further consideration. However, if the HQ from the Tier 1 analysis exceeded 1.0, then a Tier 2 assessment was required.

1.3. *Results*

1.3.1. Tier-1 channels and drains

The Tier 1 risk assessment with **glyphosate** applied at a rate of 40L/ha in channels, even when the entire area was treated with a boom spray, resulted in an HQ of < 1.0 for rat or bird over all the G-MW areas. However, the effects on plants and crops depended on the application rate. For example, at an application rate of 40 L/ha, there was a potential for harm to many receptors (HQ>1), but at lower rates (10 L/ha applied for controlling milfoil and pond weed), the HQ was estimated to be less than 1 so most of receptors were considered not to be at risk. The HQ for drinking water, tomatoes, *Daphnia* and general aquatics all exceeded 1.0 when applied at 40L /ha so further investigation of those scenarios was required. The Tier 1 assessment of the applications of herbicides to drains showed that even in the worst case, the use of **glyphosate** is not likely to cause any problem for mammals (as represented by rat) or for birds (HQ<1). However the HQ exceeded 1.0 for plant, crops, tomatoes, irrigation, drinking water and aquatic organisms and these receptors were considered in Tier 2.

Application of **2, 4-D amine** to channels at a rate of 10L/ha was assessed to not cause harm to mammals (rat) and aquatic invertebrates (HQ<1). However, the HQs exceeded 1.0 for fish, drinking water and crops (tomato) and therefore further assessments of these scenarios were undertaken in Tier 2. 2, 4-D amine is not used in drains.

Amitrole is not used in channels but in drains. The tier 1 assessment showed that even under the near worst conditions, the application of amitrole in drains is unlikely to cause harm to mammals, birds and invertebrates but *Daphnia*, algae, fish, irrigation supply would be at risk (HQ> 1). The other receptors where the HQ exceeded 1.0 were further assessed in Tier 2.

Tier 1 assessment with **acrolein** considered the application rates of 3 mg/L and 0.3 mg/L. The results showed that application of acrolein in channels at 3 mg/L would exceed the acceptable values of drinking water and aquatic life and all other receptors considered with the exception of soybean. Application of acrolein even at 0.3 mg/L would have caused most of the receptors still at significant risk. Therefore, all receptors were included in Tier 2 risk assessment for acrolein.

1.3.2. Tier-2 channels and drains

The results were found to be sensitive to the assumption on the herbicide wash-off factor from plants in water, after spraying when water would be released in drain. This aspect was highly uncertain as there was little published information was available. Hence several scenarios with different wash-off fractions were used.

In Tier 2 assessment, herbicide properties such as half life in water, soil and plant, and wash off factors were incorporated to estimate the HQ of each receptor. Based on various wash off factors and the resulting PECs for **glyphosate**, it was noted that most receptors were not at risk when glyphosate was applied in G-MW channels at the highest levels of 40 L/ha. On the other hand, the application of **2, 4-D amine** at the highest level of 10L/ha could harm fish, crops, tomato and aquatic ecosystem but, it was safe for mammals, algae and *Daphnia*.

For **acrolein** the Tier 2 estimation, the initial injection concentration (3 mg/L or 0.3 mg/L), the channel geometry and the rates of channel flows were considered. The study found that the channel water would be safe for irrigation and aquatic life protection after 8 km and 30 km respectively from the injection point when applied at 3 mg/L and 1 km and 10 km respectively from the injection point when it was applied at 0.3 mg/L .

Tier 2 results showed that from application of **glyphosate** in drains at 27 L/ha there would virtually be no affect to most of receptors at 10% and 1% wash off levels. Whereas application of **amitrole** in drains could harm receptors such as fish, irrigation, crops and aquatic ecosystems but would be safe for algae, mammal and *Daphnia*.

1.4. *Conclusions and Recommendations*

The Tier 2 risk assessment (most realistic assessment) showed that application of **2, 4-D amine** and **amitrole** (at the current application rate) in G-MW channels and drains could cause harm to some receptors such as fish and certain crops (e.g. soy bean in case of 2,4D amine). PEC for 2,4D exceeded the irrigation water quality guideline and may require a 100-fold dilution to meet this guideline. The PEC for amitrole in drains exceeded the irrigation water guideline even when a wash off factor of 5% and an even higher dilution factor (perhaps1000 fold) may be required to meet that guideline depending on the wash-off factor assumed from plants.

In contrast, the assessment showed that application of **glyphosate** is likely to cause minimal effects to most receptors considered in this study.

The risk assessment further found that channels water injected with **acrolein** would be safe for the purpose of irrigation, aquatic life protection and others usage, if the water is drawn/used after the distances specified in this report.

1- Executive Summary

When **acrolein** is used to control weeds in channels, it should be used at the lower application rate of 0.3 mg/L to minimize the environmental impact, and that the water should be permitted to run in a channel to reach a “safe distance” as specified in this report for various receptors (e.g. drinking water, aquatic life, crop irrigation).

Irrigation water extracted from a drain that has been treated with **amitrole** has the potential for causing harm to crops, and should be used with caution. Such water should not be used for drinking purposes.

The current herbicide risk assessment was **based on assumed** wash off values. While the assumed values covered the feasible range of values, it was found that the risk assessment was very sensitive to these values. It is therefore recommended that estimates of the wash off fractions should be obtained initially using laboratory experiments and then verified in field situations. Secondly, there is also little data available on adsorption of pesticides by the soil at the bottom of the channels and drains. Such data should be collected from samples taken from channels and drains in the G-MW region. Both the wash off data and the soil absorption data should be incorporated into the risk assessment, prior to making specific decisions.

A summary of the results is given in Table 1 where intermediate values have been used for wash off, and acrolein concentrations were taken using the application rate of 3 ppm but with the results assessed 5 km down stream.

Table 1 Summary of results of scenarios (Dark grey HQ > 1, grey HQ 0.1 – 1.0, green HQ < 0.1), using typical values

Scenario	Location	Receptor	Glyphosate	2,4D	Amitrole	Acrolein
1 (coved via mammalian toxicity)	G-MW Channels	***Humans*** Drinking	0.109	9.6		1.81
2 (covered via mammalian toxicity-as scenario 1)	G-MW Channels	***Stock*** - Drinking		0.2		6.4
3	G-MW Channels	***Irrigation***	0.76	23		
		Crops	0.035	3.1		0.39
		Aquaculture	0.009	41		51
4	G-MW Channels	Fish	0.009	41		51
5 (covered via mammalian toxicity)	G-MW Channels	***Riverine ecosystems and wetlands***				580
		Macro-invertebrates (1)	0.063	0.2		
		Fish (1)	0.009	0.034		
		Algae (1)	0.002	0.026		11600
		Birds (1)	0			
		Humans (1) Stock	0.278		571	
6	G-MW Drains	Pastures (1)	0.088			
		Outfall to rivers & wetlands (5)	0.162		2.85	
		Irrigation	0.194		285	
7	G-MW drains	Aquatic ecosystems (5)	0.194		2.85	

1.5. *Recommendations*

Recommendation 1: Use of amitrole contaminated water from drains requires extra caution is needed since the PEC exceeds the irrigation water quality guidelines;

Recommendation 2: The thickness and organic matter content of the lining layer of the channels and drains should be measured;

Recommendation 3: Accurate data should be obtained under the conditions relevant to this study for the wash-off fractions, especially for glyphosate;

Recommendation 4: the guideline of 0.1 mg/L for glyphosate in irrigation water should be reviewed;

Recommendation 5: Data should be obtained for the sensitivity of crops and other plant species to the herbicides used (especially amitrole) with a view forming an objective; basis for the guideline for the maximum permitted concentration of amitrole in irrigation water;

Recommendation 6: The monitoring data as reported in the Goulburn River Audit (2005) should be continued and augmented to give a time series for the concentrations of pesticides in channels and drains following spraying and refilling the irrigation channel.

2. Introduction

Goulburn-Murray Water (G-MW) is the largest rural water supply authority in Australia, supplying water for irrigation, domestic and stock drinking and for raw town supplies. G-MW's region covers 68,000 square kilometres from the Great Dividing Range north to the River Murray and from Corryong down river to Nyah near Swan Hill. G-MW region (see Figure 1) has been divided into 6 irrigation areas as shown in Table 2

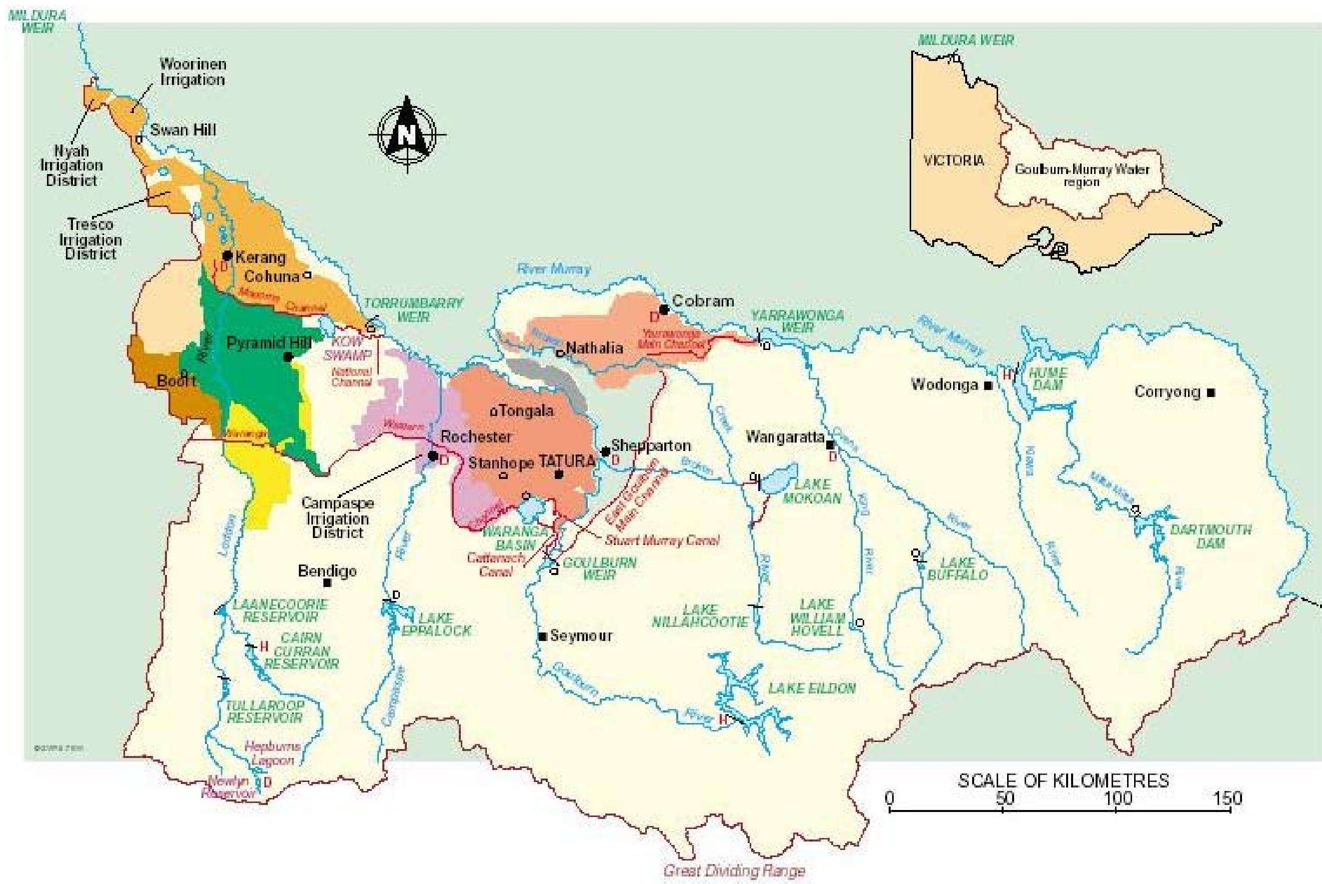

Figure 1 Map showing location of G-MW Region together with the irrigation areas under its control. Map is available from http://www.g-mwater.com.au/browse.asp?ContainerID=area_map.

The Region includes 6256 km of irrigation channels and 3146 km of drains.

Table 2 Areas of districts within the GM-W Irrigation Region, together with the lengths of channels and drains

Irrigation Area	Area (ha)	Irrigated area (ha)	Length of Channels (km)	Length of Drains (km)
Pyramid Boort	166,215	126,400	1302	111
Torrumbarry	167,000	150,000	1385	708
Rochester-Campaspe	117,050	66,710	599	507
Central Goulburn	173,053	113,106	1353	892
Shepparton	81,750	51,000	576	444
Murray Valley	128,372	88,969	1041	484
Total	596,185	596,185	6256	3146

Each of the irrigation areas uses different sizes of channels of various sizes to distribute the water to various parts of the region. There is also a network of drains that carry excess irrigation water from farms and deliver that water possibly back to the river system or to wetlands or at times to sumps where it is reused for irrigation.

A challenge facing the G-MW authority is to keep these channels and drains free of aquatic weeds to maintain normal irrigation flows. . This is generally achieved by the use of four herbicides, namely acrolein, glyphosate, amitrole, and 2, 4-D amine. While application of these herbicides affecting the target species, but may affect non-target receptors as well. G-MW is aware of the potential of collateral damage and has therefore commissioned this report to assess the risk of harm to a range of non-target species (Kookana, Barnes, Correll, Kibria 2003).

In recent times there has been increasing concern about G-MW’s herbicides spraying and its possible impacts on beneficial water users. These concerns include fish kills at the Goulburn Weir, Nagambie in January 2004. Further concern has also been expressed about the use of glyphosate and 2, 4-D at off levels/ elevated levels under minor permits and its possible impacts on environment. As a result the Goulburn River audit (EPA, Victoria) recommended an assessment of the risk to the beneficial uses associated with spraying of G-MW drains, channels and natural carriers. The current assessment was made for seven scenarios (see Table 3) that were identified jointly by G-MW and CSIRO, using intellectual properties and tools available with CSIRO, through development of new methods for risk assessment, and utilizing G-MW's raw data and information.

The main receptors that are considered include the water flea (*Daphni*a *spp*.) representing aquatic invertebrates, rainbow trout *(Oncorhynchus mykiss)* representing fish, and a range of crops (including tomatoes) as well as drinking water guidelines and water quality guidelines for irrigation and wetlands. These receptors were chosen in consultation with G-MW to represent the various ways the water is used.

Table 3 The summary of various scenarios assessed during the risk assessment

Scenario	Location	Transport Pathway	Receptor
1 (all covered via mammalian toxicity)	G-MW Channels	Direct in water, On the channel bed Spraying on channel embankment-input through runoff Noxious weed sprays on adjacent lands, weirs, access roads	***Humans*** Drinking Food Processing (equipment washing) Domestic supply Recreation (swimming, fishing)
2 (covered via mammalian toxicity-as scenario 1)	G-MW Channels	Direct in water, On the channel bed Spraying on channel embankment-input through runoff Noxious weed sprays on adjacent lands, weirs, access roads Through food contaminated with herbicides eg. Pastures	***Stock*** Drinking Washing of milking equipment etc (all covered via mammalian toxicity)
3	G-MW Channels	Direct in water, On the channel bed Spraying on channel embankment-input through runoff Noxious weed sprays on adjacent lands, weirs, access roads	***Irrigation*** Pasture (1) Tomatoes (1) Crop (wheat) (1)
4	G-MW Channels	Direct in water, On the channel bed Spraying on channel embankment-input through runoff Noxious weed sprays on adjacent lands, weirs, access roads	***Aquaculture*** Fish
5 (covered via mammalian toxicity)	G-MW Channels	Direct in water, On the channel bed Spraying on channel embankment-input through runoff Noxious weed sprays on adjacent lands, weirs, access roads Channels outfall	***Riverine ecosystems and wetlands*** Macro-invertebrates (1) Fish (1), Algae (1) Other aquatic plants (1) Birds (1), Humans and stocks
6	G-MW Drains	Direct in water, On the drains bed Spraying on drains embankment-input through runoff Noxious weed sprays on adjacent lands, access roads , Drift Drainage water discharge into rivers and wetlands	Humans (1) Stock Pastures (1) Outfall to rivers & wetlands (5)
7	G-MW Drains	Direct in water, On the drains bed Spraying on drains embankment-input through runoff Noxious weed sprays on adjacent lands, access roads , Drift Drainage water discharge into natural carriers	Natural carriers Pasture (1) Aquatic ecosystems (5)

The validity of the results is dependent on the quality of input data and the assumptions made in the assessments (including modelling assumptions and working approximations). These assumptions and approximations have been discussed in this the report where appropriate.

The study is based on the basic principles of risk assessment and provides a range of scenarios based on the available used herbicides' data in six irrigation areas of G-MW. A tiered or phased approach has been used in this study. In the first phase (termed Tier 1 in the risk assessment literature) a near worst case scenario is considered. In this phase, it is assumed that no losses of the herbicides occur either from degradation or absorption. In the second phase (or Tier 2) a more refined assessment of the expected environmental concentrations is used in the risk assessment. The first and second tier assessments both assess the exposure of each receptor organisms is likely to be exposed to the hazard (toxicity of herbicides). The first tier considers a first approximation where the near worst case is considered at each step. More realistic approximations are used in the Tier 2 assessments.

The assessments indicated that many scenarios do not pose a serious risk, whereas the risk is manifest in others. In many cases the assessments were limited by the availability of suitable data. This information is used to make recommendations both for management practice and for future research.

In compiling this report the authors encountered several new terms and common plant names. For completeness there is a full description of the plants (and others) considered in this report and also an extensive bibliography. These appendices are useful in their own right, so they have not been restricted to those that have been references in this report.

3. Herbicide use in Goulburn-Murray Irrigation Region

3.1. *Chemical used in irrigation channels and drains*

A summary of the properties of four important herbicides that are used in the G-MW irrigation district is shown in Table 4. The target weeds are identified by their local names and details of their botanical names are given in Appendix B.

Meanwhile, a supplement has been also provided regarding four herbicides' properties and comparison of different sources has been also collected to give a broader idea of the used chemicals.

3.1.1. Glyphosate

Glyphosate (360) is able to kill grasses and most broadleaf plants. Glyphosate is applied mostly to control cumbungi, water couch and offers temporary control of arrowhead in both channels and drains. The common form of glyphosate is Roundup®, but that form has been phased out by GM-W in favour of an aquatic registration because it has been recognised that the carrier in Roundup® may be potentially harmful to aquatic life.

3.1.2. 2, 4-D amine

2, 4-D amine (625) which is called Amicide LO500A® is mostly applied to control emerged weeds such as arrowhead and milfoil which are growing in the channels.

3.1.3. Amitrole

Amitrole T or Amitrole TL is mainly used in drains and especially when they are dry. This herbicide controls grasses including water couch and barnyard grass and umbrella sedge as well as some broadleaf plants.

3.1.4. Acrolein

Acrolein with Trade name of Magnacide H® is generally used to control submerged weeds and algae such as ribbonweed, pondweed and *Elodea*.

Table 4 Properties of herbicides used by G-MW and considered in this report

Properties	Glyphosate	Amitrole	2, 4-D amine	Acrolein	References
Water Solubility (mg/L)	12,000	280,000	900	208,000	Bowmer (1987)
Log K_{ow} (partition coefficient)	< -3.2	-0.97	2.58	1.08	Tomlin (2000)
K_{oc} (adsorption coefficient)	24,000	100	20	0.5	Layton 2000
Pesticide Mobility Rating	Low	Moderate	Moderate	Very High	Vogue *et al*. 1994
Volatilization	No	No	No	Yes	Bowmer (1987)
Vapor Pressure (mpa)	0.00131	<1	0.02	29,300,000	Tomlin (2000)
Photodegradation	No	No	Susceptible	Yes	Bowmer (1987)

Acrolein has very different properties from the other three herbicides (Table 2) and it is used in a very different ways. It is therefore considered as a special case apart from the other three herbicides.

3.2. ***Scenarios reflecting conditions in Goulburn Murray Irrigation Area***

3.2.1. Channels in the Murray Valley and Shepparton Areas

Murray-Valley (128,372 ha) with 88,969 ha irrigated area includes 1041 km of channels and 484 km of drains. The main land uses in this area are cropping and grazing (45%) and horticulture (stone fruit) (8%). The Shepparton Area occupies 81,750 ha of which 51,000 is irrigated. This area includes 576 km channel and 444 km drain in total.

Together there are 1617 km of channels in these two areas, with the channel sizes mainly varying from 3 to 5 m in width and 0.3 to 0.5 m in depth. Some of the trunk channels are sprayed with 2, 4-D amine to control arrowhead, are much larger. A typical cross-section of a channel is shown in Figure 2.

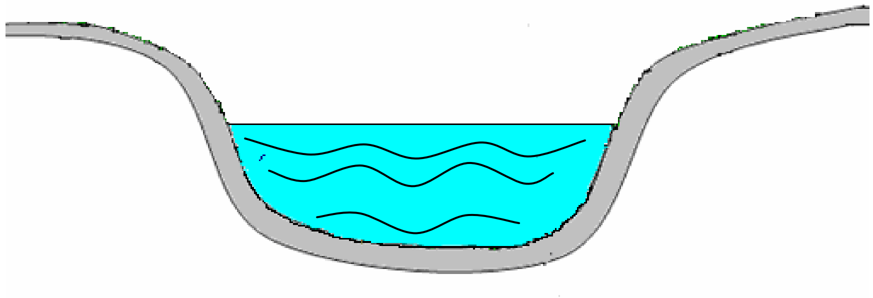

Figure 2 Typical cross-section of an irrigation channel

As shown in Figure 2, the surface are of the banks may exceed that of the water in the channel. The ratio of the area of the banks to the area of the water is an important factor used in the risk assessments as sprays applied to the banks have the potential to be washed into the channels. This risk is explored later in this report.

3.2.1.1. Use of Glyphosate in the Murray Valley and Shepparton Areas

Arrowhead

Glyphosate is used to control arrowhead when it covers much or the entire channel and restrict the flow of water. Spraying to control arrowhead is usually performed following a decrease in the water level in the channel and under these conditions there is no water movement. The channel bed is then sprayed with glyphosate at rates of 20-40 L/ha using a boom spray.

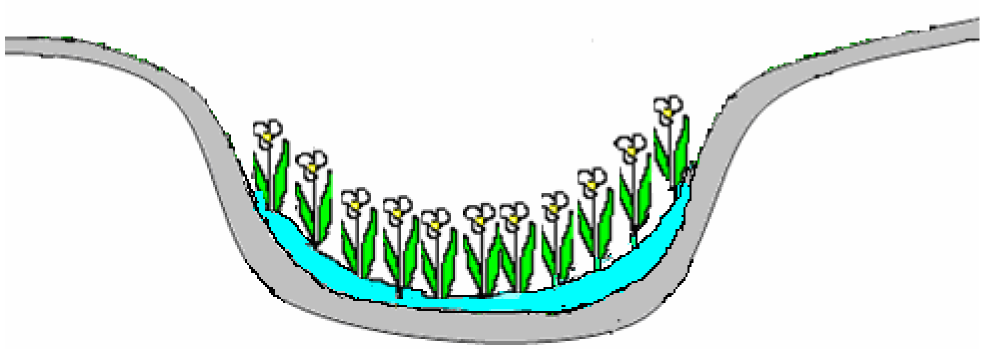

Figure 3 Cross-section of a channel showing arrowhead

Cumbungi

Cumbungi (bull rush) often occurs in small patches in channel and may occupy only 0.1% of channel system. These patches are spot sprayed at a rate of 9 L/ha by hand gun at that early stage to prevent them becoming too established.

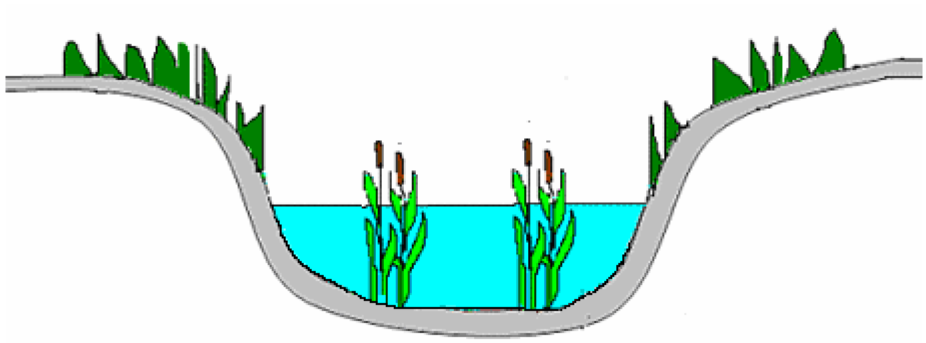

Figure 4 Cumbungi in an irrigation channel often the cover is as low as 0.1% of area of the channel

3.2.1.2. Use of 2, 4-D amine in the Murray Valley and Shepparton Areas

Arrowhead

2, 4-D amine is also used in this area to control arrowhead. Channels are sprayed at a rate of 10 L/ha. As in the case of glyphosate, the herbicide is applied with a minimum of water in the channel and where the water is static.

3.2.2. Channels in the Central Goulburn and Rochester-Campaspe Areas

The Central-Goulburn and Rochester-Campaspe Areas are centered on the townships of Tatura and Rochester and together comprise 290,103 ha of which 179,816 ha are irrigated. Some 44% of the water of each irrigation area is used for cropping and grazing and a further 15% is used for horticulture (stone fruits, pome fruits and tomatoes)

There are 1353 km of channels in the Central Goulburn Area and 599 km in the Rochester Area making a combined total of 1860 km. In these areas the channel sizes vary from 3 to 5 m in width and from 0.5 to 1 m in depth.

3.2.2.1. Use of Glyphosate in the Central Goulburn and Rochester-Campaspe Areas

Arrowhead

There are fewer arrowheads in the channels of these Areas as compared to other areas with coverage of 0.5% at a rate of 40 L/ha. This means than much less glyphosate is used.

Cumbungi

To control the cumbungi the only herbicide sprayed is glyphosate, which is sprayed at a rate of 9 L/ha

Cumbungi often occurs in patches in the channels and often they cover 0.1% of the channel system. These spots of channel are sprayed by hand gun when the channel is full.

While it would be more effective to treat the cumbungi when the water levels are low in the channels, this would cause major disruption to supply and consequently irrigation schedules so this is not financially feasible.

3.2.3. Channels in the Pyramid Boort Area

Pyramid Boort Area is centred on the township of Pyramid Hill and comprises 166,215 ha of which 126,400 is irrigated. The area includes 1302 km of channels which vary from 2 to 4 m in width and 0.3 to 0.5 m in depth.

3.2.3.1. Use of Glyphosate in the Pyramid Boort Area

Milfoil and Floating pondweed

Milfoil and floating pondweed both occur in the Pyramid Boort Area and they may cover up to 50% of the channel area. To control the weed the water level is first lowered and the channel bed is then sprayed with glyphosate at a rate of 20 L/ha using a boom spray.

Cumbungi and cane grass

Cumbungi in this area also grows in patches and covers 0.1% of channel system. Glyphosate is applied with a handgun at a rate of 9 L/ha to control the cumbungi and the canegrass.

3.2.4. Channels in the Torrumbarry Area

The Torrumbarry Area is centered on the township of Kerang and comprises 167,000 ha with 150,000 ha irrigation area is suitable for irrigation. The area includes 1385 km of channels. Some channels in this area are quite large being up to 8 meter in width and with 1.5 meter depth of water.

3.2.4.1. Use of Glyphosate in the Torrumbarry Area

Water Milfoil and Floating Pond Weed

Milfoil and floating pondweed both occur in the Pyramid Boort Area and they may cover up to 40% of the channel area. To control the weed the water level is first lowered and the channel bed is then sprayed with glyphosate at a rate of 20 L/ha using a boom spray.

Weeds on the channel banks

Weeds on the channel banks and the access pathways are also controlled with glyphosate. This would be applied with a boom spray at a rate of 20 L/ha.

3.2.5. Drains in the G-MW Irrigation Region

The drains in the region are lower than the surrounding paddocks to enable water from the local fields to be fed by gravity into them. This contrasts with the channels which are typically above the ground level so that water can be fed by gravity onto the fields.

The drains serve both to direct floodwaters back to the main river system or, as is more often the case, to remove excess irrigation water. In receiving water from fields there is potential for them to collect contaminants (including herbicide residues) from the fields.

The water depth in drains is much less than in the channels, and typically varies from between 0 - 0.3 m.

The drains are usually much narrower than the channels with their width varying between 1 and 2 m although some drains can be as wide as 6 m.

A further important difference between drains and channels is that channels are deeper than drains – often the water in a drain is less than 0.1 m deep, and at times the drains may dry completely.

3.2.5.1. Use of Glyphosate in Drains

Arrowhead

Arrowhead is a common weed in drains and retards flowing water. Arrowhead is typically sprayed with glyphosate at a rate of 27 L/ha.

General aquatics

Glyphosate is also used to control general aquatics. To control general aquatics it is applied by rate of 15 L/ha on drains sides.

Water milfoil and *Alisma*

Water milfoil and *Alisma* covers up to 70% of the drain area. This weed is controlled with glyphosate at the rate of 20 L/ha applied on drain bed.

3.2.5.2. Use of Amitrole in Drains

Arrowhead and general aquatic weeds

To control general aquatic weeds in drains, an application of amitrole at a rate of 11 mg/L (active ingredient of 250 g/L) is used. This gives total 3025 g/ha of the herbicide applied directly over the water in the drain. In addition, consideration needs to be made for run off from the banks of the drain – if it is assumed that the banks are each 0.5 m wide, and that 10% of the applied amitrole runs off into the drain, representing a further 151 g/ha making a total of 3176 g/ha. In a near worst case scenario, if the water in the drain was 0.1 m deep, the concentration would be 3.176 (or 3.2) mg/L.

4. Method used: Tiered approach to risk assessment

The tiered approach to risk assessment presented in this study is a process for a systematic, informed progression from the use of very simple assessments to increasingly more complex risk assessment methods.

The first approach is to make conservative simplifying approximations. This method of risk estimation is called Tier 1. In many cases, this approach will give a clear answer – often many scenarios can be seen as posing very little risk. Consideration is required for those cases that do not pass the Tier 1 assessment.

The second tier requires more complete information and usually an increased level of effort and complexity of risk assessment. Together these provide a more realistic assessment of the risk.

This report uses the hazard quotient approach, where the hazard quotient is the ratio of estimated site-specific exposure to a single chemical from a site over a specified period to the estimated daily exposure level, at which no adverse health effects are likely to occur (http://www.teachmefinance.com/Scientific_Terms/Hazard_Quotient.html).

This study employs the basic principles of risk assessment and provides a range of scenarios based on available herbicide use data in six irrigation areas of G-MW. A Tiered (phased) approach has been adopted in this risk assessment study. For example, in the first phase (termed **Tier 1 risk assessment**) a near-worst case scenario was considered, asking the question "What if all of the applied herbicides is available in water without allowing any losses?" In this case the absolute worst case will be taken in calculation to assess if there is any possible risk to the receptors, assuming all of the applied herbicides somehow becomes dissolved in the water in the channel or drain and there are no biotic or abiotic losses. While this is often an unrealistic possibility, it is a near worst case scenario. If the hazard quotient in this case is still acceptable, there is clearly no need for pursuing the assessment further.

4- Method Used

Channel or drain depths together with the application rates and the no observable effect concentration (NOAEC) for the most sensitive receptors in each class were included in this assessment. The Tier 1 assessment identified those receptors that were not affected even by the highest expected exposure levels. If the hazard was rated to be significant than Tier 2 assessment was carried out.

In **Tier 2** a more refined assessment of the predicted environmental concentration (PEC) was considered for each herbicide. The estimation of the PEC considered dilution, volatilization, adsorption, biodegradation and effective half-life of herbicide in each compartment (e.g. water, soil and plant), an estimate of the fraction that would run off from the bank and the fraction of herbicide applied to a plant that would have washed off from the plant after a channel was refilled with water. In the case of acrolein, dispersion and diffusion models were adapted to predict PEC.

4.1. *Tier 1 Assessment of Risk*

Problem formulation in each tier needs to be defined. Basic information such as exposure pathways and various receptors must be identified before any quantitative assessment of the risk(s) can be undertaken.

The effect of exposure on receptors (or species tolerance) is defined by two ways

1. The better documented EC50, LD50 and LC50s, which measures concentration which reduce functionality or survival rates to 50%. These measures are statistically robust and well defined; or

2. By the more sensitive and probably more realistic measures of NOAEC (or NOAEL). These measures give the maximum concentration at which no observable harm occurs to the receptor. While this concept is environmentally useful, they do present statistical problems and they are more difficult to obtain than the EC50, LD50 and LC50s.

Where they are available we have used NOAEC or NOAEL, and have indicated where both approaches are used in this report, and we have indicated where EC50, LD50 orLC50s have been used.

The species tolerance information must be considered in conjunction with the predicted environmental concentration (PEC) and if available the time of exposure. In this tier we find the near worst case scenario and see which receptors are not affected even by the highest expected exposure levels.

The criterion of risk level is defining by dividing the PEC by NOAEC to give a hazard quotient (HQ). If the HQ is less than 1.0, no harm to the receptor from that toxicant would be expected. To be very sure, a safety factor of 10 is sometimes included in the estimation of the HQ to allow for uncertainties in the estimation process. In this study we have aimed at producing realistic estimates of the HQs, so the safety factor has not been included in their estimation.

Scenarios with an HQ less than 1.0 are considered not to be at risk and hence do not need further consideration. This saves extra time and effort when some cases can be rejected. However, if the HQ from the Tier 1 analysis exceeds 1.0, then a Tier 2 assessment is required. These steps are illustrated in Figure 5.

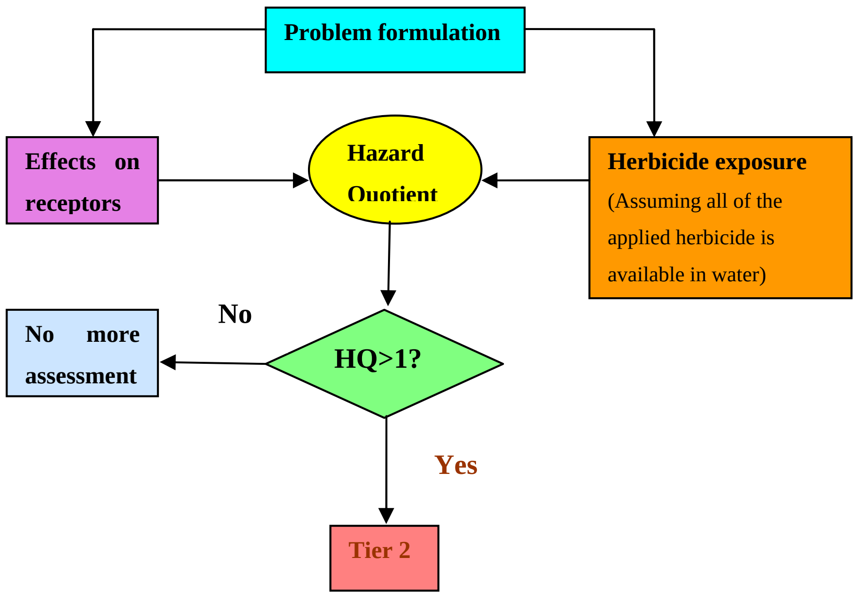

Figure 5 Diagrammatic steps involved in a Tier 1 assessment (after http://www.epa.gov/oppefed1/ecorisk/setac98b.pdf)

4.2. *Tier 2 Assessment of Risk*

Those receptor/toxicant combinations where the Tier 1 analysis estimated the HQ > 1.0 must be considered in a Tier 2 assessment as shown in Figure 6. The Tier 2 assessment is more detailed than Tier 1. All the assumptions and approximations made in Tier 1 are rechecked and typically many of the overestimations of PEC made in Tier 1will be reduced.

Tier 2 estimation of the PEC will include loss pathways of the toxicants such as dilutions, breakdown, volatilization and absorption.

The Tier 2 HQ will be calculated based on a more accurate PEC and may also include a safety factor (perhaps a factor of 10). The result typically is an HQ that is much less than that estimated in Tier 1. This will mean that scenarios considered as presenting an unacceptable risk in the Tier 1 analysis will be considered as presenting an acceptable risk in the Tier 2 analysis.

Where the risk is not acceptable (HQ > 1 in the Tier 2 analysis) the analysis used in estimating the PEC may suggest a risk mitigation strategy. For example, a minimum retention time might be appropriate to allow time for the toxicant to dissipate.

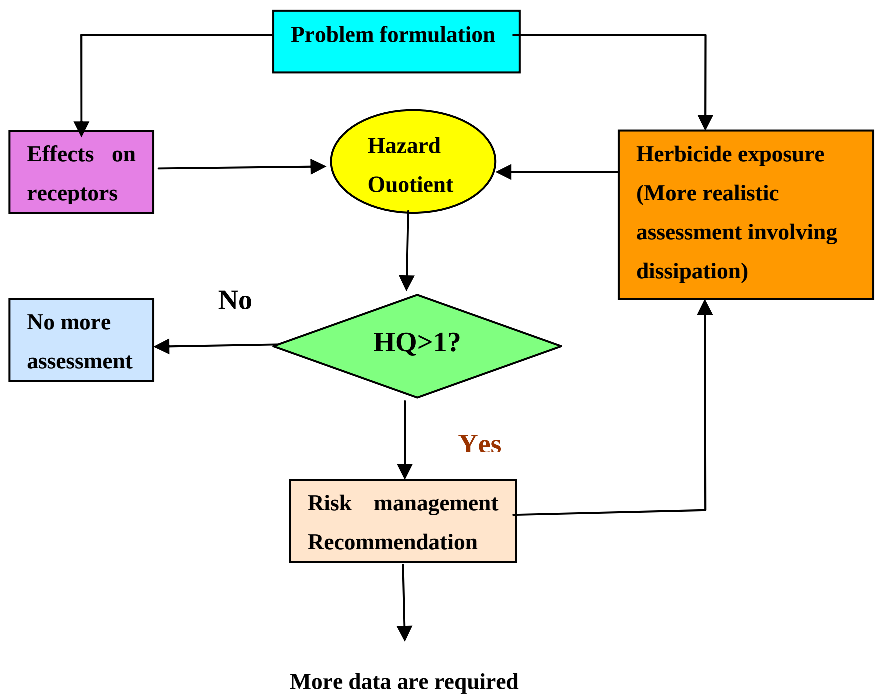

Figure 6 Diagrammatic steps involved in a Tier 2 risk assessments (after http://www.epa.gov/oppefed1/ecorisk/setac98b.pdf)

4.3. *Tier 1 Estimation*

In this model the absolute worst case will be taken in calculation to assess if there is any possible risk to the receptors, assuming all of applied herbicides somehow becomes dissolved in the water in the channel or drain and there are no biotic or abiotic losses. While this is often an unrealistic possibility, it is a near worst case scenario. If the hazard quotient in this case is still acceptable, there is clearly no need for pursuing the assessment further.

4- Method Used

The maximum application rate is assumed (expressed as L/ha) in each case where a herbicide is applied to a channel or drain. The given application rates of herbicides will be multiplied by the fraction of active ingredient (a.i.) and converted to the active rate of application. The PEC will be calculated for each herbicide using different assumptions involving channel depth or the drain depth together with the application rates for each scenario. The calculations are show in section 4.3.1.

Since we have to find out the safety exposure level, the NOAEL values are collected for the most sensitive receptors in each class where data are available. Also, in case of algae where there are limited data available, we work with the lowest available NOAEL value.

The Hazard Quotient (HQ) is then estimated using the following equation.

Equation 1: HQ = PEC/NOAEC or PEC/NOAEL

At this stage, no safety factor was included so the HQs will be less biased. This gives a more realistic estimate of the risk, and it is then the role of management to incorporate safety factors. This contrasts with an aim where the risk assessment is used to assess a safe level of concentration; in that case it would be appropriate to include a safety factor.

Estimation of Drinking Water Equivalent Level (DWEL)

Usually there are no data that give estimates of NOAELs for pesticides that are dissolved in drinking water, so an alternative approach is required. The drinking water equivalent level (DWEL) is the concentration of a contaminant in water (in mg/L) for which no adverse, non carcinogenic health effects are anticipated if a person is exposed to that concentration over a lifetime. The formula for calculating the DWEL is:

Equation 2: DWEL mg/L =dose (mg/kg/day) × Body Weight (kg) / Drinking Water Consumption (L/day)

This represents a best estimate but this estimate is subject to considerable uncertainty. It is usual practice to include a safety factor of 10 or even 100 is applied to DWELs before making recommendations as to whether the water is potable. The NOAEL values, which are expressed as mg/kg/day, should be converted to mg/L (i.e. ppm) drinking water consumption. Examples of this type of calculation are shown in Appendix D.

Note that in a Tier 1 analysis a high value of water consumption would be assumed together with a low body weight as the worst case scenario, and that these values would be independent.

4.3.1. Calculation process for herbicide applied directly to a channel or drain

In many situations weeds in a channel or drain are controlled by a boom spray directed at the weeds emerging through the surface of the water in a channel or a drain. Under those conditions it is possible to use a simple calculation to estimate the PEC. The steps used for such a calculation are given below.

The calculation are based on 1 ha sprayed area; for instance if the area is sprayed at a rate of 40 L/ha it would receive 40 L. Glyphosate could be sprayed over the entire channel (e.g. when targeting arrowhead) or it could be sprayed over less than 1% of the channel area when used to control plants like cumbungi. The PEC is estimated in the following manner:

1. Channel length (m) = area sprayed m^2 / channel width (m)

2. Active Application amount (mg) = application rate (L/ha) × fraction of a.i. (g/L) × area sprayed (1ha) ×conversion factor (1000 mg/g)

3. Active run off (mg)=active application amount ×run off % × (2× embankment sprayed width / channel width)

4. Total applied herbicide (mg)=active application (mg) +active runoff (mg)

5. Water volume (L) = sprayed area (m^2)× water depth (m) × conversion factor (1000 L/m^3)

6. PEC (mg/L) = Total active application amount (mg)/ water volume(L)

4- Method Used

An example of this case is given in Appendix H when Amitrole is sprayed in drain. In this study the sprayed area is the same as 1 ha and water volume is driven from:

Water volume (L) = 10000 m^2 × water depth (m) × conversion factor (1000 L/m^3)

In some cases of drains, when sprayed area of the banks are the same as the area of a channel (e.g. 1 m wide either side of a 2 m wide channel regarding no.3 above) and run off is assumed 10%, the PEC calculation is simplified to:

Equation 3= 0.11 × active application rate (kg/ha) /depth of water (m)

Active application rate= a.i. (g/L) **×** application rate (L/ha)

4.4. *Tier 2 Estimation*

Those cases (receptors) for which the HQ >1 in Tier 1 assessment are further assessed under Tier 2. The estimates used in Tier 2 are more realistic often more complex than those used in Tier 2.

In this step the factors which affect final herbicide concentration present in water are described and used in the calculation of PEC. Processes such as biodegradation and effective half-life of herbicide in each compartment (e.g. water, soil and plant), fraction run off and wash off from plant after application time are considered. These processes are described below.A useful source of information on herbicide properties is the data used in appendix; table P-1 in GLEAMS (Layton 2000). A summary of those data is given in Table 5.

Table 5 Herbicides used properties in GLEAMS (Layton 2000)

Herbicide	Half-life in water (days)*	Half-life in soil (days)	Half-life in plant (days)	K_{oc}	Estimated wash off fraction by GLEAMS
Glyphosate	70	47	2.5	24,000	0.60
Amitrole	26	14	5	100	0.95
2, 4-D amine	20	10	9	20	0.45
Acrolein	5 hr	Not used	Not used	0.5	Not used

*** Data from other sources as described in the text**

4.4.1. Processes considered in Tier 2

In the case of 2, 4-D amine, in 95% of cases there is no flow in channels and water level is kept between 5 and 15 cm. No water is released into channel until after 4 days after the application of the herbicide. Also no herbicides are applied when rain is forecast – typically this means there would be at least 4 days between the time of spraying and rain.

The applied herbicide would not be intercepted completely by the water because 50 -80% of that applied will be intercepted by foliages and only 20- 50% would be directly mixed into water. This in effect reduces the application rate to the water by a factor of 0.2 – 0.5. However, the fate of the herbicide that is intercepted by the leaves must also be considered.

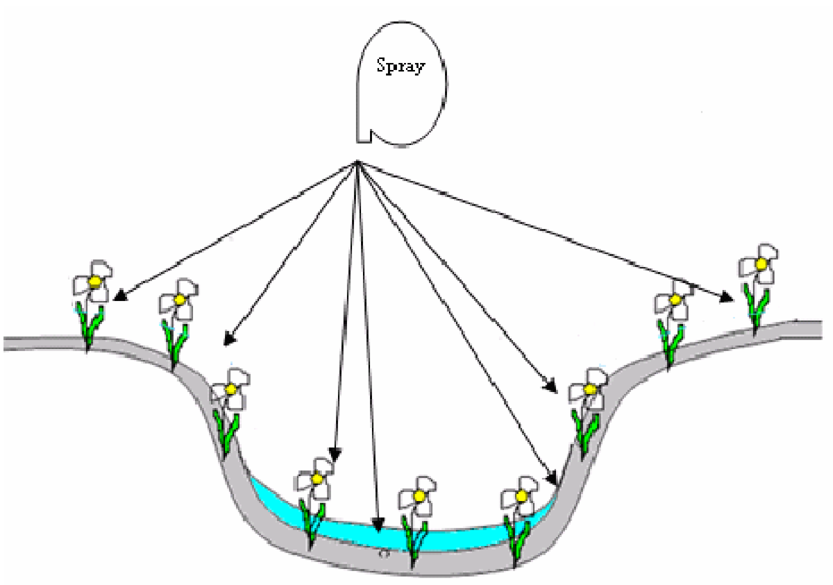

Figure 7. Diagram showing channel water status at the time of herbicide application

4- Method Used

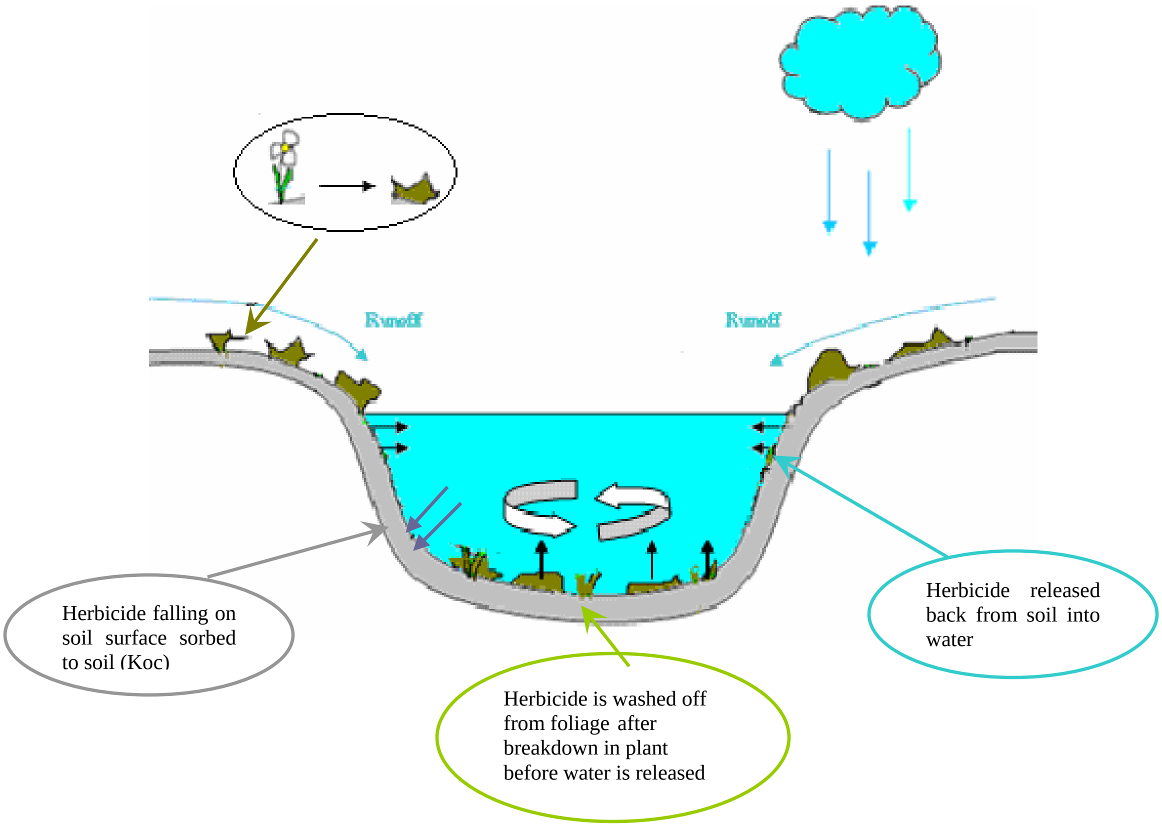

Figure 8. Herbicide release pathways from runoff, foliage, soil when water flows in the channels 4 days after herbicide application

4.4.2. Mass of soil affected

There are a range of soil types throughout the G-MW Area. There is little data available on the soil layer at the bottom and side of the channels or drains but it would be expected that there would be a thin layer that was rich in organic matter (a 'schlick') that would be formed on the surface. The thickness of this layer of soil in the channels and drains is assumed to be 10 mm.

The mass of soil used in the calculations was estimated by is assuming an incorporation depth of 10 mm and a soil bulk density of 1.33 t/m^3 .From these assumptions we can work out the mass of soil in 10 mm in our case

$$10{,}000\ m^2/ha \times 1/1000\ (mm/m) \times 10\ mm \times 1.33\ t/m^3 = 133\ t/ha$$

The amount of the organic matter present on the bottom of the channel (or drain) is critical to these calculations, but there is little if any data available. We therefore recommend that thickness and organic matter content of the lining layer of the channels (or drains) be measured.

Recommendation 2: The thickness and organic matter content of the lining layer of the channels and drains be measured.

4.4.3. Run off from soil

When the banks of a channel or drain are sprayed with herbicide, there is potential for there to be run off back to the channel or drain. No measures are available as the exact fraction that might run off, and it will be affected by many factors including soil texture, the organic matter content of the soil, the soil moisture content, the slope of the bank and the time between spraying and a significant rain event. Experience from other situations (Leonard 1990; FAO 1997) suggests the fraction is low. The experience shows that in case of glyphosate the highest runoff was 1.85% (Cheng *et al*. 1990) – in this report we have used a slightly higher runoff factor of 2%.

The run off from the bank to the bottom of the channel could occur soon after spraying, just before the spraying or any time in between. The breakdown rate of the herbicide would be in soil whether it was on the bank or after it was washed down into the channel. The time of run off does not therefore affect the final outcome of the analysis. Both possibilities are therefore covered.

4.4.4. Interception of herbicides by plants

Most of the applied herbicide is intercepted by foliage and translocates through the plant. The exact amount will depend on the plant cover. Generally once the herbicide has been applied it will be absorbed by the plant within a few hours. Recently research shows that herbicide's properties such as the octanol-water partition coefficient (K_{ow}) has important role in uptake amount of herbicide by plant (Briggs *et al*. 1982).

There are some models to simulate the foliage interception of herbicides. The GLEAMS model is one of the most accurate models which are used when a foliage residue is suspected. In this case the user must use intuitive judgment in arriving at the input value. The parameter units are Fg/g, but are not based on herbicide mass per mass of foliage residue. The unit is the herbicide concentration created in the 0-1 cm soil surface should the mass be displaced to the soil. The formulation used is shown below.

Table 6. Herbicide residue in foliage after application

FOLRES = 6.7 (APRATE) (FOLFRC) Exp (-0.693 DAYS/HAFLIF) Where: APRATE = Previous application rate (kg/ha) FOLFRC = Fraction of application intercepted by foliage DAYS = Number of days since application HAFLIF = Half-life of pesticide on foliage

Since in this study the amount of herbicide which is directly sprayed on weeds is known, the only other parameters needed are foliage interception and half-life in the plant. The GLEAMS model can be modified as below:

Equation 4: FOLRES (g) = APRATE (g/ha) × FOLFRC × Exp (-0.693 DAYS / HAFLIF)

4.4.5. Sorption and degradation in soil

Some herbicides are quickly sorbed by the soil particles. Soil type plays an important role in sorption of herbicides. The strength of sorption of a pesticide to a soil basically depends on that pesticide's soil sorption coefficient (K_d) which in turn is a function of the soil organic carbon sorption coefficient (K_{oc}) for most pesticides, but glyphosate is an exception, where clay plays an important role. There is a high correlation between the organic matter content of the soil and K_d. This is because the soil organic matter acts as a non-polar phase or surface, which is the main sorbent in soils; this attracts pesticides because they are typically non-polar organic molecules. The soil organic carbon sorption coefficient of a pesticide is calculated by following equation:

Equation 5: $K_{oc} = K_d / F_{oc}$

Where F_{oc} is organic matter percentages in soil (Wauchope *et al*. 2001)

After absorption by soil, the herbicide is mainly degraded by micro-organisms in the soil; meanwhile, due to equilibrium between soil and water phases, some fraction of the herbicide will be released into water.

The degradation rate of the herbicide depends on parameters such as temperature, pH, moisture, caution exchange capacity and clay content (PMEP 1984).

The amount of herbicide which is released into water after interception by soil will be calculated by Equation 6.

Equation 6: $$Fr = \frac{1}{\left(\frac{K_d}{V} \times ms\right) + 1}$$

Where:

Fr = Fraction of herbicide in water

K_d = Soil partition coefficient (mL/g)

m_s = mass of soil (g dry weight)

V = water volume (L)

The estimate of the mass of soil is given in Section 4.4.2.

The manner in which the channel is refilled could vary between situations. At one extreme the channel could be slowly filled and stand for a period following refilling. At another extreme there could be rapidly flowing water from the time it is refilled and for some time following. These two cases will be considered;

1. In the first case, the total amount of pesticide (the residual in the soil and the amount washed off from the plant) would come to equilibrium between the amount in the soil and the amount in the soil.

2. In the second case, the constant replacing of water would lead to a reduction of the amount of pesticide present in a section of channel. The reduction in the amount present would reduce the risk presented in this case.

We have therefore considered the first case where the total amount of herbicide in a length of channel is equilibrium between the soil and the channel water as this gives a near worst case scenario.

The release of pesticides from soil can be much slower than their absorption – this phenomenon is referred to as a hysteresis effect. Glyphosate binds strongly to soil so it is unlikely the glyphosate that is bound on soil would equilibrate rapidly. This strong binding would further decrease the expected concentration of glyphosate in the channel water, so the predicted concentrations given in this report are likely to be over estimates.

4.4.6. Herbicide runoff

Pesticide runoff potential is sensitive to K_{oc}, and for most soils, the fraction of pesticide in the surface runoff increases as K_{oc} decreases, especially for K_{oc} values that are less than 500. This decrease occurs because, for the high mobility compounds, the initial rainfall mobilises the herbicide present in the 0 -10 mm surface soil layer in runoff. For K_{oc} ranges greater than 1000, the herbicide is adsorbed to the sediments, and this reduces concentrations of herbicide in the water phase of the runoff. For such pesticides the colloid movement becomes an important transport pathway. The total surface transport of herbicides with a high K_{oc} is therefore strongly influenced by erosion and sediment transport (Layton 2000).

4.4.7. Degradation in water

The rate of degradation of herbicides depends on several factors. Some herbicides with higher vapour pressure volatilize quickly (refer to Table 4) and this process would be dependent on the water temperature, water depth, turbulence and the rate of air movement across the water surface. Another process is photolysis where the herbicide is broken down by light. Another important process is biodegradation whereby microorganisms can use the compound as carbon and energy source. The combination of these methods of pesticide degradation is typically expressed as a half-life. While there are many factors that contribute to the half-life, temperature and moisture are perhaps the most important and their effects can be readily incorporated into a model.

The following formula with considering half-life will be able to calculate amount of residue herbicide remaining at given time.

Equation 7 $$Ct = C_o \times \exp\left[-t_c \times \left(\frac{\ln 2}{T_{1/2}}\right)\right]$$

Where:

C_t = herbicide concentration at the time of releasing water into channel or drain

C_0 = herbicide concentration at the time of spraying the channel or drain

t_{c} = length of time between application and releasing water into channel or drain

$T_{½}$ = half-life of the herbicide.

4.4.8. Degradation of herbicides in plants

Weeds are capable of degrading some herbicides. The half-life of herbicides in plants also varies from a few hours to several days depending (amongst other things) on the species of the plant. There is a paucity of data on the degradation rates of herbicides in various weed species.

4.4.9. Wash off of herbicides from plants

The wash off is the removal of herbicides applied on a plant that is washed off by rain or irrigation water. This fraction is related to a number of factors including the nature of the leaf surface, plant morphology, pesticide solubility, and polarity of the pesticide molecule, formulation of the commercial product, and timing and volume of rainfall.

Values of wash off factor (WSHFRC) provided in GLEAMS for organochlorine, organophosphorus, carbamate, and pyrethroid insecticides are based primarily on the work of Willis *et al*. (1980), or computed from the algorithms provided relating wash off to rainfall volume and pesticide solubility. For other pesticides, solubility was used as a guide for estimating WSHFRC. Because of this paucity of data and its importance in the equations used to obtain PECs, we recommend that further data be obtained on this component.

Recommendation 3: Accurate data need be obtained under the conditions relevant to this study for the wash-off fractions, especially for glyphosate

4.4.10. Process of PEC calculation in Tier 2

The process of estimating all the predicted environmental concentration of herbicides in water following a spraying event must be brought together in the manner described in Figure 9. Initially it must be ascertained what was sprayed (bank or water-body) and the spray rate.

In the case of the bank being sprayed, the amount of run off is estimated and hence the diluted concentrated in the water body can be assessed. Where the target is plants growing on the surface of the water the amount of spraying the different components will be estimated in the manner shown in Figure 9.

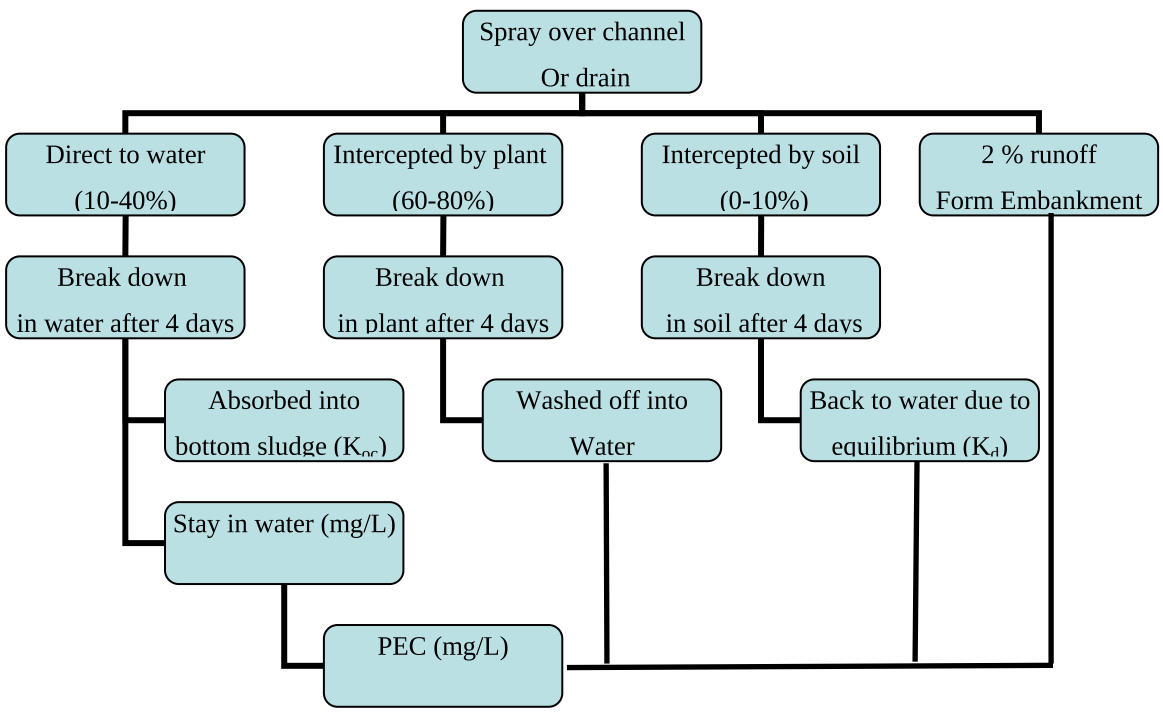

Figure 9 Method for assessing the PEC number in water following spraying with herbicide

5. **Environmental fate and toxicological properties of the herbicide and input data used in risk assessment**

5.1. *Glyphosate*

5.1.1. Toxicity of Glyphosate to different receptors

The toxicity of various receptors to Glyphosate is given in Table 7. Different endpoints are needed for different receptors. Some, for example tomato, have an EC05 that has been deduced from the literature (Table 7) whereas others such as the maximum permissible concentration in irrigation water are set by regulation.

Table 7 Toxicity of Glyphosate to different receptors

Species	Tolerance criterion	(mg/L)	Reference
Algae	EC50	48.5	FAO (2001)
Rainbow trout	LC50	8.2	Renzo (2000)
Plant and crop	NOAEL	2.2	Hughes *et al*. (1990)
Tomato	5% reduction	2.7	Calculated (Santos and Gilreath 2006) refer to Appendix G
Rat	NOAEL	300	Calculated (USEPA 2006) refer to Appendix D
Mallard duck	NOAEL	4000	Calculated from (FAO 2000) refer to Appendix D
Daphnia	Population reduction	1	Hutson and Roberts (1987)
Lemna	Physiology effect	16.9	O'Brien *et al.* (1979)
Aquatic life in fresh water	95% protection	1.2	ANZECC 2000
Drink water	MCL	0.7	USEPA 2007
Irrigation value	Permitted value	0.1	ANZECC 2000

5.1.2. Degradation in water

Glyphosate is strongly adsorbed to suspended organic and mineral matter of water and it is then largely unavailable and persistent since glyphosate is stable to breakdown by sunlight (USEPA 1992).

Volatilization or photo-degradation losses will therefore be negligible.in most cases. Glyphosate will dissipate rapidly from natural water bodies through adsorption to organic substances and inorganic clays, and dilution. Residues adsorbed to suspended particles will eventually settle into the bottom sediments.

There are a range of half lives given for glyphosate in water. The average half-life in pond water given by USEPA is 2 to 10 weeks (USEPA 1992). Other sources with different conditions are available in the supplement to this report. Comparison of different conditions indicates that half life of 10 weeks is reasonable and it will be taken into calculation.

5.1.3. Degradation in soil

Glyphosate is moderately persistent in soil. It is strongly adsorbed to most soils, even those with lower organic and clay content (Wauchope *et al*. 1992).

The major methods of glyphosate breakdown in the environment is microbial degradation of soil .Unbound glyphosate molecules are degraded at a steady and relatively rapid rate by soil microbes but bound glyphosate molecules are biologically degraded at a slower rate.

Glyphosate half-life values in soil quoted in the literature vary between 1 to 174 days by variation of soil type (Wauchope *et al*. 1992) .Glyphosate in moist silt, clay and loam soil will disappear in 2 or 3 weeks (EPA 1992). One Australian study has produced an estimate of 28 days for the half-life for local area (Bowmer 1987). There are more data in the supplement to this report pertaining to the half-life of glyphosate in soil in different conditions.

This report used an average half-life of 47 days (Wauchope *et al*. 1992). This is a commonly accepted value and it has been also presented in GLEAMS report.

5.1.4. Runoff of Glyphosate

Because glyphosate binds strongly to soils, it is unlikely to enter waters (even though it is highly soluble in water) through surface or subsurface runoff except when the soil itself is washed away by runoff (Rueppel *et al.* 1977).

Meanwhile, laboratory studies show it does not leach appreciably, and has low potential for runoff (except as adsorbed to colloidal matter) (Wauchope *et. al*. 1992).

Some research show that the average lost of glyphosate in run off is unlikely to exceed 2% of the applied chemical (Malike *et al.* 1989). This is consistent with other experimental data where the maximum runoff from experimental study was reported as 1.85% of the applied glyphosate (Cheng *et al.* 1990). A value of 1% was therefore taken as the reasonable estimate of run off for glyphosate.

The runoff was assumed to all go into the water and not intercepted by the plants.

5.1.5. Degradation of glyphosate in plants

Glyphosate is quickly absorbed by leaves and roots of plants. Once absorbed into the leaves, glyphosate is broken down slowly. Glyphosate moves quickly through the plant and accumulates in areas of active growth called meristems. Spraying a plant with glyphosate inhibits protein and amino acid synthesis in that plant. This lack of amino acids stops plants growing and within a week or so, the plant tissues and organs slowly degrade due to lack of proteins. Death of the weed ultimately results from lack of nutrients and dehydration occurs a week or so later (Ross and Childs 2007).

Metabolic degradation of glyphosate in plant is still disputed. Some scientists believe that glyphosate is not metabolized by plants (Schuette 1998), while some other researchers claim that some plants are able to metabolise glyphosate (Carlisle and Trevors 1988).

The half-life of glyphosate on foliage has been estimated at 10.4 to 26.6 days (Newton *et al.* 1984)

Different plants can apparently degrade glyphosate at different rates, and weeds are able to degrade glyphosate in a shorter period. The half-life of estimate of 2.5 days that is used by GLEAMS has taken this into account.

5.2. *Amitrole*

5.2.1. Toxicity of Amitrole to different receptors

The toxicity of Amitrole to different receptors is shown in Table 8.

Table 8 Toxicity of Amitrole to different receptors

Receptor	Tolerance criterion	(mg/L)	Reference
Aquatic Plant	EC50	2.5	Wolf (2001)
Rat	NOAEL	10	Calculated from Weber 1978 (Appendix D)
Dog	NOAEL	62.5	Calculated from Weber 1978 (Appendix D)
Quail, duck	Reproduction	100	Wolf (2001)
Invertebrates (honeybee)	NOAEL	100	Wolf (2001)
Water flea (*Daphnia magna*)	Reproduction	0.2	Ritter (1989)
Fish	Reproduction	0.2	Abbott (1994)
Rainbow trout	NOAEC	100	Wolf (2001)
Green algae (Pseudokirchneriella subcapitat)	EC50	1	Wang *et al.* (1990)
Irrigation	Permitted Con.	0.002	ANZEEC (2000)
Human health	Permitted Con.	0.001	ANZEEC (2000)

5.2.2. Degradation of amitrole in water

Amitrole is only expected to breakdown slowly by hydrolysis or photolysis in an aquatic environment, with a reported half-life of 40 days and the half-life is even longer in pond water (Howard 1989). Degradation of amitrole in open water may occur through oxidation by other chemicals. Amitrole does not volatilize because of its low vapour pressure and it will be remain in water due to its high solubility.

The main route of removal from water may be through adsorption to sediment particles. On the other hand with photo-degradation in the presence of the photosensitizer, humic acid and potassium salt, the half-life will decrease to several hours (Abbott 1994). Other estimates of half-lives with different condition and sources are given the supplement to this report.

The half-life estimate of 28 days as given by GLEAMS is considered more appropriate for this study.

5.2.3. Degradation of Amitrole in soil

Loss of amitrole from soils by volatilization or photo-degradation is minor. Some chemical degradation may occur in soil (Abbott 1994).

Amitrole does not adsorb strongly to soil particles and it is readily soluble in water, and it therefore has a moderate potential for groundwater contamination (PMEP1984).

Thin- and thick-layer chromatography, molecular topology, water solubility and octanol-water partition coefficient (K_{ow}) all predict that amitrole will be easily leached in soil.

Amitrole has highly mobile in soils of pH > 5 and medium to highly mobile in soils with lower pH. Generally, movement is most readily seen in sands and increased organic matter content reduces mobility (Abbott 1994)

The soil dissipation rate is affected by moisture, temperature, cation exchange capacity, and clay content, but is unaffected by soil pH. The half-life of amitrole in very low temperature and clay is quite long (100 days) (PMEP 1984), while in warm soil the period decreases to 14-21 days (WSSA Herbicide Handbook Committee 1989). The generally accepted value for the half-life is 14 days which is the value that is used in GLEAMS. That value has been used in this report.

Different half-life values due to different types of soils are given in fact sheet section.

5.2.4. Run off of Amitrole

Amitrole does not sorb significantly to soil particles and may be transported in the dissolved phase by runoff to surface water bodies. Amitrole's primary route of dissipation is microbial-mediated metabolism; however, amitrole is stable in anaerobic environments (Jones 1999).

Amitrole may contaminate surface water from runoff or spray drift associated with ground spray application. Amitrole is stable to degradation from abiotic hydrolysis and aqueous photolysis, and is slightly to moderately persistent (aerobic soil metabolism half-life 22-26 days; aerobic aquatic metabolism half-life 57 days) in aerobic environments. Amitrole does not adsorb significantly to soil particles and may be transported in the dissolved phase by runoff to surface water bodies. Amitrole's primary route of dissipation is microbial-mediated metabolism; however, amitrole is stable in anaerobic environments (Jones 1996).

5.2.5. Degradation of amitrole in plants

The metabolic pathways of amitrole in plants appear to be complex. There is evidence that when amitrole is applied to the leaves of plants, most of the material absorbed is metabolized (INCHEM 1974). Research has shown that this process takes from 1 to 4 weeks (Weed Science Society of America 1994). A shorter half-life of 4 days is reported for amitrole applied to cotton (Miller and Hall 1961). Further details are given in the supplement to this report.

GLEAMS uses an estimated half-life of 5 days for amitrole in weeds, and that is the value that has been used in this report.

5.3. *2, 4-D amine*

5.3.1. Toxicity to different receptors

The toxicity of 2, 4-D amine to a range of receptors is given in Table 9.

Table 9 Toxicity of 2, 4-D amine to different receptors

Receptor	Tolerance criterion	(mg/L)	Reference
Crop (soybeans)	Damage LOEL	0.22	Que *et al*. 1981
Tomato	No damage	0.15	Calculated from (Fagliari *et al*. 2005)
Rat	NOAEL	3.41	Calculated (Appendix D)
Rainbow trout	NOAEC	0.0164	Xie and Thrippleton (2005)
Algae (Selenastrum capricornutum)	NOAEC	26.4	Hughes *et al.* (1990)
Duckweed (*Lemna gibba*)	NOAEC	2.029	Hughes *et al.* (1997)
Aquatic Invertebrates	NOAEC	19.7	INCHEM (1997)
Aquatic life in fresh water	95% protection	0.28	ANZEEC (2000)
Drinking water	MCL	0.07	USEPA (2006)
Irrigation water	Permitted Concentration	0.03	ANZEEC (2000)

5.3.2. Degradation of 2, 4-D in water

In water with a low pH, 2, 4-D will remain in a neutral molecular form, increasing its potential for adsorption to organic particles in water, and this in turn increases its persistence. Absorption also increases in muddy water.

Microorganisms readily degrade 2, 4-D in the aquatic environment, with the rate increasing with increasing nutrients and dissolved organic carbon. (EXTOXNET 1996)

The half-life of 2, 4-D amine in an anaerobic aquatic environment can be as long as a year, but this time will significantly decrease to 15 days in aerobic aquatic environment (USEPA 2005).

In natural water a range of 4 to 28 days has been estimated by the USEPA (2006). A half-life of 20 days was chosen for this study. More data are available in the supplement to this report.

Soil organic content and soil pH are the main determinants of 2, 4-D adsorption in soils. Adsorption increases with increasing soil organic content and decreasing soil pH (Johnson *et al*. 1995). Inorganic clays can also bind 2, 4-D particles.

5.3.3. Degradation of 2, 4-D in soil

2, 4-D degradation rates in soils remained relatively constant with and without sunlight, suggesting that photo-degradation is not an important process in the field. (Johnson *et al.* 1995), suggesting that soil microbes are primarily responsible for 2, 4-D amine's disappearance (Howard 1991).

Degradation rates are determined by the microbial population, environmental pH, soil moisture, and temperature. A number of microbial organisms rapidly degrade 2, 4-D. In sediments with a sufficient microbial population, 2, 4-D can be degraded in a matter of hours (Aly and Faust 1964). A range of half-lives of 1.25 h to 40 days are present in the literature but most estimates are between 3 and 10 days. However, in cold dry soil the half-life is longer (FAO 1997).

Some available half lives for different type of soils are available in Appendices. In this study, a half-life of 10 days has been used.

5.3.4. Runoff of 2, 4-D

The rapid biodegradation of 2, 4-D in soil prevents significant downward movement under normal field conditions. Run-off from treated soil has been estimated at between 0.01 and 1% of the applied 2, 4-D; the maximum recorded concentrations following run-off were about 0.2 pg/L (FAO 1997).

5.3.5. Degradation of 2, 4-D in plants

2, 4-D is a plant hormone (auxin) mimic. It causes rapid cell division and abnormal growth. Absorbed 2, 4-D by foliage or roots tends to accumulate in growing tips. Metabolism of 2, 4-D in plants is by a variety of biological and chemical pathways (Herbicide Handbook 1994) but it is generally slow. 2, 4-D amine can usually remain active against susceptible plants for 1 to 4 weeks (Wilson *et al*. 1997). In one study the half-life of applied 2, 4-D on grass was estimated to be 14 days.

GLEAMS uses a half-life of 9 days for 2, 4-D amine in weeds. That half-life has been used in this study.

5.4. *Acrolein*

5.5. *Processes considered in Tier 2 – Acrolein*

In this process all the known pathways that lead to acrolein loss are considered. These pathways include break down in water, loss to the air. Since the channels are full and flowing at the time of application, some other factors such as flow rate and channel width together with channel length (which is used as a surrogate for time) also will affect dispersion and are considered in the calculations.

Moreover, duration of application rate is taken into account.

In contrast to the other three herbicides that have been considered, no acrolein will be directly intercepted by the soil so only the water phase has to be considered.

Using the above inputs, a table of predicted environmental concentrations (PECs) is created for different distances from the injection point and from that the safe distances from the injection point are estimated.

5.5.1. Toxicity of Acrolein to different receptors

The toxicity of Acrolein to different receptors is given in Table 10 together with the sources of that information

Table 10 Toxicity of Acrolein to different receptors

Species	Tolerance criterion	mg/L	Reference
Drinking water	MCL	0.32	USEPA (1987)
Toxic concentration for crops and pasture	Maximum allowable	1.5	USEPA (1980) Ambient WQ criteria for acrolein
Rabbit	NOAEL	0.05	Calculated from USEPA (2000) (Appendix D)
Dog	NOAEL	1	Calculated from USEPA (2000) refer to (Appendix D)
Lemna gibba	EC50	0.07	Tomlin (2000)
Selenastrum capricorutum	EC50	0.00005	Tomlin (2000)
Daphnia	LC50	0.022	Siemering *et al*. (2005)
Goldfish	NOAEC	0.0114	Bridie *et al.* (1979)
Aquatic life	Safe level	0.001	Victorian EPA (2006)
Soybean	NOAEC	15	USEPA (1973)

5.5.2. Sorption and break down of acrolein in water

Acrolein with high solubility in water and low K_{oc} if released into water is not expected to adsorb to suspended solids and sediments (HSDB 2003).

Generally acrolein has a short half-life in water in the field. The half-life in water depends on water temperature, turbidity, weed load, oxygen concentration, volatilization (due to high vapour pressure) and also the influence of micro-organisms (Bowmer and Sainty 1991). The rate of reaction of acrolein increased with increasing pH. In flowing water, the rate of loss was much faster reflecting the influence of turbulence in increasing loss through volatilization (Hutson and Roberts 1987, pp300)

USEPA's toxicological review on acrolein cites a half-life of 4.4 hours in a model river (HSDB 2003). USEPA Office of Pesticides Program calculated half-lives of acrolein from degradation rate constants in irrigation canals to be in the range of 3-7 hours (Turner and Erickson 2003). Other half-lives reported in literature in irrigation channels range from 4-10 hours.

The most relevant data are the Australian studies by Bowmer and colleagues reviewed by Bowmer and Sainty (1991) on dissipation of acrolein from irrigation channels under different flow conditions and temperature. That review showed the half-lives ranging from 3.3 to 6.7 hours. Most half-life data in literature also falls within 3.3 to 10.2 hours. For this study we have used 5 hours for the half-life of acrolein in channels.

Future information are available in the supplement to this report.

5.5.3. Degradation in plant

Biochemical and toxic effects of acrolein are probably caused by its reaction with critical protein and non-protein sulfhydryl groups (EPA 2003). The reaction of acrolein with sulfhydryl compounds is rapid and essentially irreversible, resulting in the formation of stable thiol ether.

When added to water as an aquatic herbicide, acrolein undergoes rapid decomposition, especially in the sunlight. At the same time, it reacts rapidly with amines, alcohols, and mercaptans of aquatic plants, destroying cell structure and killing the plants (Eisler 1994).

Future information are available in fact sheet section in the supplement to this report.

5.5.4. Dispersion

Tracer injected at a point in a flowing channel is immediately subjected to the processes of turbulent diffusion and dispersion and its concentration tends to become uniform in cross-section. The actual spread or rate of dilution depends on the channel geography and the large-scale turbulence structure of the flow. The distance required before there is complete mixing is typically of the order of hundreds of times the channel width. It is therefore difficult to predict the length of this initial phase of dilution. During the dispersion phase, the tracer behaves as a one-dimensional slug of material in the channel; the only significant concentration gradient is that in the direction of flow. The formula below predicts the tracer behaviour (O'Loughlin and Bowmer 1975).

Equation 8 $\frac{\partial c}{\partial t} + U\frac{\partial c}{\partial x} = D\frac{\partial^2 c}{\partial x^2} - Kc$

Where:

D= longitudinal dispersion coefficient;

K=the first order rate constant (tracer decay);

U= velocity of water; and

t= number of days since application.

Their analytical solution of the formula for case of acrolein (which is non-conservative material) and injected instantaneously gives

Equation 9 : $\frac{C(x,t)}{C_0} = 0.5\exp(\frac{-Kx}{U})\{\text{erfc}[\frac{x-U(t+\tau)(1+H)}{\sqrt{4D(t+\tau)}}] - \text{erfc}[\frac{x-Ut(1+H)}{\sqrt{4D(t+\tau)}}]\}$

Where

C(x, t) = concentration of herbicide in *x* m downstream after *t* hours;

C_0 = initial applied rate (mg/L); and

H=is derived from Equation 12.

There are some unknown parameters in the given formula such as *K*, *D*, and *H* which can be found in various ways, but estimates can be found for those parameters.

K for herbicide depends on the half-life of herbicide in water and is estimated by:

Equation 10: $K = \frac{0.693}{\text{half life}}$

The longitudinal dispersion coefficient D depends on the channel depth and the velocity of water and can be founded using the formula of Bowmer (1987):

Equation 11: $D = 5.9 \times U \times \textit{channel depth}$ where *U* is the velocity of the water.

Similarly, *H* is estimated using

Equation 12: $H = 2KD/U^2$.

6. **Results**

6.1. *Results of Tier 1 for Channels*

6.1.1. General assumption

There are many different channel sections that could be studied, and it is not practical to consider them all. Here we consider a representative channel that would be near the end user of the water and so is of most concern.

The channel is assumed with 4 meter width and 40 cm water in full position. Due to equations given in section 4.3.1 , 4 ML water volume per ha is calculated (more examples are given in Appendix H).

In normal case runoff would not exceed 1% but as a worst case, such as rain during application time, leakage of spray tank and other uncertainties 10% runoff is assumed for all the herbicides in channel and drain. The highest application rates are taken into account as worst cases.

In Tier 1 we assume that all the sprayed herbicide gets mixed into water without any losses such as degradation.

All the calculations are based on 1 ha sprayed channel area.

6.1.2. Tier 1 assessment of glyphosate in channels

Arrowhead and other floating weeds

Glyphosate may be sprayed directly on the water (or floating weeds on the water), and as well it may be sprayed on the banks of the channel where it may run back into the channel. Under the worst case, the amount applied to the water surface would be 40 L/ha, and this equates to 14400 g/ha after taking into account the fraction of active ingredient. In addition, the channel's banks (1 m width on either side) may also be sprayed at a rate of 40 L/ha and allowing for 10% of that amount running of the bank to the water, this contribution could also produce a load of 1440 g/ha, making a total load of 15.8 kg/ha.. When this amount is mixed with 4 ML of water (1 ha 0.4 m deep) the final concentration would be 3.96 mg/L.

Glyphosate is also used at a rate 20 L/ha to control water milfoil and floating pondweed in large channels in the Torrumbarry Area. These channels are 8 m wide and 1.5 m deep. Glyphosate spayed at a rate of 20 L/ha with active ingredient of 360 g/L the amount is the equivalent of applying 7200 g/ha of glyphosate. The contribution of runoff from the banks is the same for the large channel as for the small channel, but this would be spread across an 8 m wide channel rather than a 2 m wide channel , making its contribution 720 g/ha. In total, the application rate to the surface of the water would be 7200g/ha, and after this is mixed with 15 ML of water the final concentration would be 0.51 mg/L. These data are displayed in Table 12. When the concentrations are divided by the NOAEL values in Table 7, they form the HQs for glyphosate that are shown in Table 12

Glyphosate was found to have HQs of less than 0.1 for rat, duck and *Lemna* over all the areas in the G-MW, even when the entire area is treated with a boom spray. The effect on plants and crops from irrigation water from the channel was found to depend on the application rate. For example, when the target weed was arrowhead and an application rate was 40 L/ha was required, there was potential for harm. However, when lower rates were used (20 L/ha) for the control of milfoil or floating pondweed, the HQ was estimated at 0.9 in Pyramid Boort Irrigation Area. Typically this would not cause harm for plant and crops (see Table 12) but this would assume that all the estimates are accurate.

The estimate of HQ was sensitive to the channel size, with the larger (especially deeper) channels in Torrumbarry having lower HQs due to their greater depth and smaller relative contribution from runoff.

The HQ for drinking water, tomatoes, *Daphnia* and general aquatics all exceeded 1, so further investigation (Tier 2) of those scenarios was required.

A further consideration is when glyphosate is sprayed only on the banks. In that case, under the worst conditions, the HQs will be $1/11^{th}$ of those in Figure 10. HQ for herbicide sprayed on channel embankment would be 1/11 of HQ for herbicide sprayed on channel bed[1] and will be <1.0 for all receptors other than meeting the standard for irrigation water.

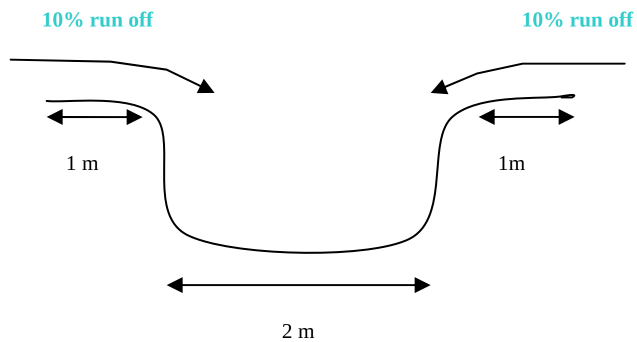

Figure 10. HQ for herbicide sprayed on channel embankment would be 1/11 of HQ for herbicide sprayed on channel bed

Cumbungi and milfoil

Channels in the 5 irrigation areas (MV, SH, G, PB, RC) are sprayed with glyphosate at a rate of 9 L/ha when the cover of cumbungi or milfoil is only 1%. That glyphosate is

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1 Channel width is twice as big as each embankment, thus two embankments (make 2 meter width) can be assumed as same size as channel width. Consequently application rate would be also same. It means that application rate of 40L/ha in channel bed is sprayed in same length of embankment.

Due to the assumption of 10% runoff from embankments just 4 L/ha will leach to the channel from sides.

$10\% \times 40$ (L/ha) = 4 (L/ha)

Total herbicide mixed in water would be:

40 (L/ha) +4 (L/ha) = 44 (L/ha)

Share or herbicide leach from embankment would be 4/44 which gives 1/11.

diluted into 4×10^6 L of water and this gives a PEC of 0.001 mg/L (refer to Table 12) and results in HQ<1 (safe condition) for all the receptors (refer to Table 12)

6.1.3. Tier 1 assessment of 2, 4-D amine in channels

Arrowhead is sometimes controlled with 2, 4-D amine by spraying at an application rate of 10 L/ha with 625 g/L active ingredient. The amount of active ingredient applied is 6250 g/ha herbicide. Under the worst case, a similar area of bank is also sprayed, and 10% of that load could run into the channel, contributing a further 625 g/ha. The total load in the water would therefore be 6875 g/ha, which when mixed with 4 ML of water gives a concentration of 1.72 mg/L of 2, 4-D in the channel water. When these concentrations are divided by the NOAEL values in Table 9, they form the HQs shown in Table 12.

The applied 2, 4-D amine in the worst case doesn't cause any problem for mammals (rat) not for *daphnia* and algae. However, the HQ exceeded 1.0 for aquatic life, fish, drinking water and crops and tomato. Further assessments of these scenarios were undertaken in Tier 2.

6.1.4. Tier 1 assessment of amitrole in channels

Amitrole is not used in channels so is not considered here.

6.1.5. Tier 1 assessment of acrolein in channels

Nowadays, acrolein is seldom used in irrigation channels, and when it is applied the application rate does not exceeded 3 mg/L in Goulburn-Murray Region. There is also a move to use a longer application time with much a lower dose of 0.3 mg/L.

Acrolein with specific gravity of 0.862 gives following concentration in water:

$3 \text{ mg/L} \times 0.862 \times 1.0 \text{ g/cm}^3$ (density of water) = 2.58 mg/L

$0.3 \text{ mg/L} \times 0.862 \times 1.0 \text{ g/cm}^3 = 0.258 \text{ mg/L}$

In this Tier 1 assessment, in common with our assessment of the previous herbicide, no losses are considered and all applied amount is assumed to be mixed in channel water. In this Tier 1 assessment the PEC number would be 2.58 mg/L for the higher application rate and 0.258 mg/L for the lower rate. The higher rate is used in the Murray Valley Area and the lower rate (but with 48 hour exposure) is used in the Torrumbarry Area.

Table 11 Tier 1 assessment of the risk posed by acrolein applied at two different methods, one higher doses in shorter time and *vice versa* (dark grey colour in cells denote HQ > 1, grey HQ 0.1 - 1.0 and white HQ < 0.1)

Receptors	NOAEC	HQ1=2.58/NOAEC	HQ2= 0.258/NOAEC
Selenastrum capricorutum	0.00005	52000	5200
Aquatic life	0.001	2600	260
Goldfish	0.0114	230	23
Rabbit	0.05	52	5.2
Lemna gibba	0.07	37	37
Drinking water	0.32	8.08	0.808
Dog	1	2.6	0.26
toxic for crops and pasture	1.5	1.72	0.172
Soybean	15	0.17	0.017

A summary of the Tier 1 assessment (Table 11) shows that the application of acrolein at the higher concentration could exceed all the acceptable values of HQ for irrigation, drinking water, aquatic life, crop plants, except Soybean.

In the second method (0.3 mg/L) most of the receptors are still at risk. There was therefore a need to undertake further assessment in Tier 2 for such receptors as irrigation value, algae (as represented by *Selenastrum capricorutum*), aquatic plants (as represented by the duckweed *Lemna gibba*), fish and drinking water.

6- Results

Table 12. PEC calculated Tier 1 for channel

Herbicide	Area	Weed	Application rate (l/ha)	Fraction of active ingredient (g/L)	Applied amount (g/ha)	Fraction Runoff	Total amount (g/ha)	Width (m)	Water level (m)	Water volume (L/ha)	PEC (mg/L)
Glyphosate	MV, SH	Arrowhead	40	360	14400	0.1	15840	4	0.4	4 ML	3..96
	PB	Milfoil and floating	20	360	7200	0.1	7920	4	0.4	4 ML	1..98
	MV,SH,CG ,RC, PB	Cumbungi (1% cover)	9	360	3240	0.1	3564	4	0.4	400 ML	0.001
	T	Milfoil and floating pondweed	20	360	7200	0.1	7920	8	1.5	15M	0.51
2, 4-D	MV,SH	Arrowhead	10	625	6250	0.1	6875	4	0.4	4M	1.72

Table 13. PEC calculated in Tier 1 for drains

Herbicide	Area	Weed	Application rate (l/ha)	Fraction of active ingredient	Applied amount (g/ha)	Fraction Runoff	Total amount (g/ha)	Width (m)	Water level (m)	Water volume (L/ha)	PEC (mg/L)
Glyphosate	MV,SH,CG,PB, RC	Arrowhead	27	360	9720	0.1	10692	2	0.1	1ML	10.7
	T	Milfoil and floating pondweed	20	360	7200	0.1	7920	2	1	10 ML	0.79
Amitrole	MV,SH,CG,PB, RC	general aquatic	11	250	2750	0.1	3025	2	0.1	1 ML	3.02

MV= Murray Valley, SH= Shepparton, CG= Central Goulburn, PB= Pyramid Boort, RC=Rochester Campaspe, T= Torrumbarry

Table 14 Summary of Tier 1 Results for Channels (dark grey colour in cells denote HQ > 1, grey 0.1 – 1.0 and white HQ < 0.1)

Herbicide	**Region**	**Weed**	**PEC (mg/L)**	**Rat**	**Bird**	**Drinking water**	***Daphnia***	**Aquatic life**	**Fish**	**Alga**	**Aquatic plant**	**Plants and crop**	**Tomato**	**Irrigation water**
Glyphosate	MV, SH, CG, RC	Arrowhead	3.96	0.01	0.001	5.6	4	3.3	0.46	0.082	0.23	1.8	1.5	40
	PB	Milfoil – Floating pondweed	1.98	0	0.0005	2.8	2	1.6	0.023	0.041	0.11	0.9	0.73	20
	T	Milfoil – Floating pondweed	0.51	0.001	0.0001	0.75	0.53	0.44	0.023	0.041	0.03	0.24	0.2	5..3
	MV, SH, CG, RC,PB	Cumbungi	0.001	0	0	0	0	0	0.01	0.02	0	0	0	0
2, 4-D amine	MV, SH	Arrowhead	1.72	0.5	NI	25	0.08	6.1	100	0.065	0.84	7.8	11.46	57.33

MV= Murray Valley, SH= Shepparton, CG= Central Goulburn, PB= Pyramid Boort, RC=Rochester Campaspe, T= Torrumbarry

Table 15 Summary of Tier 1 results for drains (dark grey colour in cells denote HQ > 1.0, grey HQ 0.1 – 1.0 and white HQ < 0.1)

Herbicide	Area	Weed	Application rate	Rat	Bird	Drinking water	*Daphnia*	Aquatic life	Fish	Algae	Plant and crop	Tomato	Irrigation water	Invertebrates	Health standard
Glyphosate	MV, SH, CG, RC, PB	Arrowhead	10.7	0.035	0.0027	15	10.7	8.9	1.26	0.22	4.84	3.96	107	NI	NI
	T	Milfoil and Floating pondweed	0.79	0.0026	0.0002	1.31	0.79	0.66	0.079	0.016	0.36	0.293	7.92	NI	NI
Amitrole	MV, SH, CG, RC, PB	general aquatic	3.02	0.302	0.0303	NI	15	NI	15.1	3	NI	NI	1512	0.0302	3025

MV= Murray Valley, SH= Shepparton, CG= Central Goulburn, PB= Pyramid Boort, RC=Rochester Campaspe, T= Torrumbarry

6.2. *Results of Tier 1 for Drains*

As a near worst case, it is assumed that the drain is 2 m wide and only 10 cm deep. The water volume per ha is then 1 ML (Appendix H). We further assume that 10% of applied herbicide enters into drain by runoff from the bank. The highest application rate in each area is taken into calculation.

All the calculations are based on 1 ha sprayed drain area.

6.2.1. Tier 1 assessment of glyphosate in drains

Glyphosate is sprayed in drains at a rate of 15 or 27 L/ha to control the arrowhead and general aquatics respectively.

Taking the worst case of 27 L/ha, with an active ingredient of 360 mg/L gives 9720 g/ha of glyphosate from direct application to the drain. In addition there could be run off from the banks, where it is assumed that the area of the banks is comparable to that of the drain and that there is 10% runoff. Taken together, these two sources would result in a concentration of 10.7 mg/L in the water in the drain (refer to Table 13)

Glyphosate is also used in large drains in the Torrumbarry Area at a rate 20 L/ha to control milfoil and floating pondweed. Spraying at a rate of 20 L/ha with active ingredients of 360 g/L requires 7200 g/ha of herbicide. These drains in Torrumbarry Area may be much deeper than those of other Areas, and this would result in a greater dilution of the glyphosate. For example, in drains that are 1 m deep (instead of 0.1 m) the dilution (Appendix H) would be 10 times greater giving an overall concentration of 0.792 mg/L.

Using the species tolerance data in Table 7 together with this PEC of 10.7 mg/L enabled the calculation of HQs shown in Table 15.

The Tier 1 assessment showed that even in the worst case, the use of glyphosate in drains doesn't cause any problem for mammals (as represented by rat) or for birds. However the HQ exceeded 1.0 for plant crops and tomatoes. The water also has the potential for causing harm to fresh water organisms such as algae and Daphnia, as well as for other purposes such as irrigation and drinking water. The cases where the HQ exceeded 1.0 are considered in the Tier 2 phase of the study (refer to Table 22).

6.2.2. Tier 1 assessment of amitrole in drains

Amitrole is used to control general aquatics in drain typically with an application rate of 11 L/ha with an active ingredient of 250 mg/L. Using calculations similar to those for glyphosate in drains, it can be shown that the PEC for amitrole is 3.025 mg/L. This value, together with the species tolerance data for amitrole as given in Table 8, were used to estimate the HQ values shown in Table 15.

The tier 1 assessment showed that even under the near worst conditions when amitrole is applied to drains it is not expected to cause harm to mammals (rat) and birds. General invertebrates were also rated as not threatened, but *Daphnia* was found to be at risk with an HQ of 15.1 (Table 15). HQs exceeding 1.0 were also found for most other receptors, including fish, drinking water and health advisory levels.

The receptors where the HQ exceeded 1.0 were further assessed in Tier 2 (Table 24).

6.2.3. Tier 1 assessment of 2, 4-D amine and acrolein in drains

Neither 2, 4-D amine nor acrolein are used in drains so no Tier 1 results are presented for those scenarios.

6.3. *Result of Tier 2 Assessment of Channels*

6.3.1. Result of Tier 2 assessment of Glyphosate

Initially the Tier 2 assessment indicated that many receptors were at risk when glyphosate was applied at a rate of 40 L /ha so further investigation was required. In a second phase we followed the procedure as shown in Figure 9 which included the effect of sorption of the glyphosate by the organic matter rich layer at the bottom of the channel.

Arrowhead

A heavy infestation of arrowhead covers almost the entire channel bed and severely restricts the flow of water. Control with glyphosate is used before this situation occurs when there may be 60% cover of the channel.

The water level in the channel is typically lowered to 10 – 15 cm prior to spraying, and this may further increase the percentage of the water surface that is covered by plants but at this stage this factor has not been included in the calculations.

Of the total area sprayed, 60% will be intercepted by the arrowhead leaves and 40% will miss the plant and be applied directly to the water.

During the four days between spraying and release of water there will be some decomposition, with the rates depending on whether the herbicide is in the water or on the plant. The half-life in water is relatively long (70 days) so most (96%) would persist. By contrast the half-life is short (2.5 days) on the surface of the plant so only 33% persists after 4 days.

When the water returns, a fraction of that glyphosate will be removed as wash off. The exact amount is not known so several values have been used in this report. Initially a 60% (following GLEAMS as shown in Table 5) was assumed to be washed of, but this value from the authors' experience seems too high. A value of 10% would correspond to the maximum fraction lost from a field situation, while a value of 1% also being feasible.

The final predicted environmental concentration for glyphosate was very dependent on the estimated of the wash off factor as can be seen in Table 17.

Table 16 Estimation of concentration of glyphosate in channel water, when there is 60% interception by plants, and assuming 60% of the residual herbicide is washed off and channel 2 m wide and 0.4 m deep

40 L/ha	Water +2% run off	Plant	soil	Total
Interception	40%	60%	0%	
Amount applied (kg/ha)	6.05	8.64	0	14.69
Days after exposed	4	4	4	
Half life (days)	70	2.5	47	
Faction remaining	0.96	0.33		
Amount remaining (kg/ha)	5.81	2.85	0	
Wash off	1	0.6		
Amount before water release (mg/ha)	5.81	1.71	0	7.2
Fraction to water	0.003	1	0.012	
water volume (L)	4000000	4000000	4000000	4000000
Final concentration (mg/L)		0.428		0.43

Table 17 Predicted environmental concentrations (PECs) of glyphosate using parameters from Table 5 but with various wash off factors estimated HQs (dark grey colour in cells denote HQ > 1, grey HQ 0.1 – 1.0 and white HQ < 0.1)

Wash off		60%	10%	1%
PEC (mg/L)		0.43	0.076	0.012
Receptor	Tolerance	HQ1	HQ2	HQ3
Irrigation water	0.1	4.3	0.76	0.117
Drinking Water	0.7	0.61	0.109	0.017
Daphnia	1	0.43	0.076	0.012
Aquatic life	1.2	0.36	0.063	0.01
Crops	2.2	0.195	0.035	0.005
Tomato	2.7	0.159	0.028	0.004
Rainbow trout	8.6	0.05	0.009	0.001
Lemna	16.9	0.025	0.004	0
Alga	48.5	0.009	0.002	0
Rat	300	0.001	0	0
Duck	4000	0	0	0

Spraying typically occurs when there is 60% cover, in reality 60% of plant height is exposed by glyphosate. This shows the water level at the time of spraying the water level is lowered to 10 cm and 15 cm of plant height is above the water level. As a result since sides are not deliberately sprayed and no herbicide is directly applied to soil, we will assume that 40% of the herbicide is sprayed onto water and none is intercepted directly by soil at the bottom of the channel.

We further assume that water flow after 4 days delay will fill the channel to 40 cm depth which gives 4 ML water volume per ha.

To control the arrowheads 40 L/ha is sprayed in the channel and 1% runoff is assumed due to given information in Section 3.

Cumbungi and milfoil are also controlled in channels using spot sprays of glyphosate. The Tier 1 analysis revealed that this was unlikely to cause harm to any receptor so the control of cumbungi and milfoil are not examined under the Tier 2 process.

Milfoil and floating pondweed

Milfoil and floating pondweed both grow in the Pyramid Boort Area and Torrumbarry Area irrigation channels and are controlled by an application of glyphosate. A handgun is used to spray for cumbungi or other weeds are sprayed with a boom spray at a rate of 20 L/ha. Water level in the channels at the time of spraying would not be lowered for spot spraying with the hand gun. As described above, the hand gun is unlikely to cause harm.

If a boom spray is used, the water level would be lowered to 20 cm at the time of spraying and then refilled to 1.5 m. Total water volume after 4 days would be 15 ML (1 ha area with 8 m width and 1.5 meter depth of water). Since the plants are quite dense we assume that 50% of the applied herbicide is intercepted by foliage and the other 50% is divided between water (50%) and little by the soil as there is water in the bottom of the channel (taken as 0%). The method of estimation for the highest wash off factor of 60% is shown in Table 18 and the results for this scenario are shown in Table 19. Potential harm to any of receptors is unlikely in this scenario, although with the highest wash off factor of 60% the limit for the concentration of glyphosate in irrigation water is approached.

Table 18 Estimation of concentration of glyphosate in channel water, when there is 50% interception by plants, and assuming 60% of the residual herbicide is washed off and channel 8 m wide and 1.5m deep and with application rate of 20 L/ha

20 L/ha	Water +2% run off	Plant	soil	Total
Interception	50%	50%	0%	
Amount applied (kg/ha)	3.74	3.6		
Days after exposed	4	4		4
Half life (days)	70	2.5	70	
Faction remaining	0.96	0.33		
Amount remaining (kg/ha)	3.60	1.19		
Wash off	100%	60%		
Amount before water release (mg/ha)	3.60	0.71		4.31
Fraction to water	0.003	1		
water volume (ML)	15	15	15	15
Final concentration (mg/L)				0.048

Table 19 HQ for glyphosate in different wash off factor in Pyramid Boort Irrigation Area (grey colour in cells denote HQ 0.1 - 1.0 and white HQ < 1)

Wash off		60%	10%	1%
PEC (mg/L)		0.048	0.009	0.002
Receptor	**Tolerance**	**HQ1**	**HQ2**	**HQ3**
Irrigation water	0.1	0.482	0.086	0.017
Drinking Water	0.7	0.069	0.012	0.002
Daphnia	1	0.048	0.009	0.002
Aquatic life	1.2	0.04	0.007	0.001
Crops	2.2	0.022	0.004	0.001
Tomato	2.7	0.018	0.003	0.001
Rainbow trout	8.6	0.001	0	0
Rat	48.5	0	0	0
Alga	300	0	0	0
Duck	4000	0	0	0

6.3.2. **2, 4-D amine**

2, 4-D *amine for arrowhead*

2, 4-D amine is sprayed by rate of 10 L/ha in Murray Valley and Shepparton channels to control the arrowhead. Due to 2, 4-D amine's properties, run off from paths of access are not expected to exceed 1% so this proportion is taken as a near worst case.

We further assume that water flow after 4 days delay will fill the channel to 40 cm depth which gives 4 ML water volume per ha.

Table 20 Estimation of concentration of 2, 4-D in channel water, when there is 60% interception by plants, and assuming 45% of the residual herbicide is washed off

10 L/ha	Water +1% run off	Plant	soil	Total
Interception	40%	60%	0%	
Amount applied (kg/ha)	2.562	3.75	0	6.88
Days after exposed	4	4	4	
Half life (days)	20	9	10	
Faction remaining	0.87	0.73		
Amount remaining (kg/ha)	2.22	2.73	0	
Wash off	1	0.45	1	
Amount available influence (kg/ha)	2.22	1.23	0	3.96
Fraction to water	0.79	1		
Water volume (L)	4000000	4000000		4000000
Final concentration (mg/L)	0.44	0.31	0	0.75

It was found that if 45% wash off occurred, harm would be caused to several receptors (Table 21). However, the effluent from the drains is likely to be diluted when it reaches a water body such as a natural carrier or wetland. If the dilution is 10-fold and the wash-off factor was 45%, rainbow trout and aquatic ecosystems are likely to be affected. Furthermore, the concentration of 2, 4-D amine would still exceed the guidelines for irrigation water and drinking water. However, if the dilution was 100-fold no harm would be expected from 2, 4-D amine (Table 21).

Table 21 HQs for 2, 4-D applied to channel for different values of wash off assuming 10 kg/L application rate and 60% plant cover in the channel (dark grey colour in cells denote HQ > 1, grey HQ 0.1 – 1.0 and white HQ <0. 1)

Wash off		45%	20%	5%	95% wash off at 10× dilution	95% wash off at 100 × dilution
PEC (mg/L)		0.75	0.58	0.47	0.047	0.004
Receptor	Tolerance	**HQ1**	**HQ2**	**HQ3**	**HQ'3**	**HQ"3**
Rainbow Trout	0.0164	45.73	35.37	28.66	2.87	0.24
Aquatic Ecosystem	0.028	26.79	20.71	16.79	1.68	0.14
Irrigation value	0.03	25	19.33	15.67	1.57	0.13
Drinking Water	0.07	10.71	8.29	6.71	0.67	0.06
Tomato	0.15	5	3.87	3.13	0.31	0.03
Crops	0.22	3.41	2.64	2.14	0.21	0.02
Lemna	2.029	0.37	0.29	0.23	0.02	0
Rat	3.41	0.22	0.17	0.14	0.01	0
Daphnia	19.7	0.04	0.03	0.02	0	0
Alga	26.4	0.03	0.02	0.02	0	0

6.4. *Result of Tier 2 Assessment of Drains*

The use of herbicides in drains is similar across all five areas in the G-MW Irrigation Region

6.4.1. Glyphosate

Arrowhead

Arrowhead is controlled in drains by spraying with glyphosate at a rate of 27 L/ha. Drains that are 2 m wide and 0.1 meter deep contains one ML of water per ha of drain. We assume that the drains are not sprayed until there is 80% plant cover.

At the time of spraying, 80% of applied herbicide is intercepted by foliage and 20% of the rest is mixed into water and intercepted by soil. The amount of wash off is not well known, so values of 60%, 10% and 1% were used as shown in Table 22. At the highest wash off rate of 60% there is the potential of harm to *Daphnia* and to aquatic ecosystems.

The concentration of glyphosate in the water would exceed guidelines for both irrigation water and drinking water. Even at 10% wash off, the concentration still exceeds the guideline for irrigation water despite the HQ for tomato being only 0.1 and that for irrigation water being 2.62. This would imply that the guideline value of 0.1 mg/L for irrigation water is possibly too low and that the value should be reviewed.

Recommendation 4 the guideline of 0.1 mg/L for glyphosate in irrigation water should be reviewed.

Table 22 HQs for glyphosate applied to arrowhead in drains for different values of wash off assuming 27 L/ha application rate and 80% plant cover in the drain (dark grey colour in cells denote HQ > 1, grey HQ 0.1 – 1.0 and white HQ < 0.1)

Wash off		60%	10%	1%
PEC (mg/L)		1.54	0.262	0.031
Receptor	**Tolerance**	**HQ1**	**HQ2**	**HQ3**
Irrigation water	0.1	15.4	2.62	0.31
Drinking Water	0.7	2.2	0.37	0.04
Daphnia	1	1.54	0.26	0.03
Aquatic life	1.2	1.28	0.22	0.03
Crops	2.2	0.7	0.12	0.01
Tomato	2.7	0.57	0.1	0.01
Rainbow trout	86	0.02	0	0
Rat	300	0.01	0	0
Alga	485	0	0	0
Duck	4000	0	0	0

General aquatics

General aquatic weeds are controlled with glyphosate sprayed at a rate of 15 L/ha on the bottom and sides of drain. 80% of applied herbicide would be intercepted by foliage and rest is intercepted equal by water. The calculations are similar to those for arrowhead but the PEC values are less due to the lower application rates. As shown in Table 23, the HQs are also lower, with the only values exceeding 1 being for the irrigation water and drinking water.

Table 23. HQs for glyphosate applied to general aquatics in drains for different values of run off assuming 15 kg/L application rate and 80% plant cover in the drain (dark grey colour in cells denote HQ > 1, grey HQ 0.1 – 1.0 and white HQ < 1)

Wash off		60%	10%	1%
PEC (mg/L)		0.858	0.146	0.018
Receptor	**Tolerance**	**HQ1**	**HQ2**	**HQ3**
Irrigation water	0.1	8.58	1.46	0.234
Drinking Water	0.7	1.226	0.209	0.033
Daphnia	1	0.858	0.146	0.023
Aquatic life	1.2	0.715	0.122	0.02
Crops	2.2	0.39	0.066	0.011
Tomato	2.7	0.318	0.054	0.009
Rainbow trout	86	0.01	0.002	0
Rat	300	0.003	0	0
Alga	485	0.002	0	0
Duck	4000	0	0	0

6.4.2. Amitrole

General aquatic weeds

Amitrole is used in some situations to control the general aquatic weeds in drains. For this use, amitrole is sprayed at a rate of 11 L/ha in strips 0.5 m wide on each side of the drain wall (total 1 m width sprayed width). The total water volume affected in 1 ha sprayed area would be 2 ML (Appendix H).

In the following it is assumed that 80% of applied herbicide would be sprayed on foliage, and that the wash off factor could be represented by 95%, 20% or 5%.

Table 24 shows that the HQs for the use of amitrole in drains exceed 1.0 for *Daphnia*, and grossly exceed the value for irrigation water and drinking water. It would also cause harm to the green alga and the aquatic plant (*Lemna*), noting that those HQs were based on EC50s and not NOAECs.

Table 24 HQs for amitrole applied to drains for different values of wash off assuming 11 L/ha application rate and 80% plant cover in the drain (dark grey colour in cells denote HQ > 1, grey HQ 0.1 – 1.0 and white HQ < 1). * indicates values based on EC50.

Wash off		95%	20%	5%
PEC (mg/L)		1.52	0.57	0.38
Receptor	**Tolerance**	**HQ1**	**HQ2**	**HQ3**
Drinking Water	0.001	1519	571	381
Irrigation value	0.002	759	285	191
Daphnia	0.2	7.59	2.85	1.91
Green alga*	1	1.52	0.571	0.381
Aquatic plant (*Lemna*)*	2.5	0.607	0.228	0.153
Rat	10	0.152	0.057	0.038
Rainbow Trout	100	0.015	0.006	0.004
Duck	100	0.015	0.006	0.004

Water milfoil and alisma

Water milfoil and alisma can be important weeds in the Torrumbarry Area. Amitrole may be sprayed at a rate of 20 L/ha to control these weeds when they cover 70% of drain.

Since drain size is varies between 1 to 6 m wide and 0.3 to 2 m deep, the drain is assumed with 2 meter width and 1 meter depth which create big volume of 10 ML channel water.

Table 25 HQ for amitrole applied to drain in Torrumbarry irrigation area for different values of wash off assuming 20 L/ha application rate and where milfoil cover 70% of drain (dark grey colour in cells denote HQ > 1, grey HQ 0.1 – 1.0 and white HQ < 1). * indicates values based on EC50.

Wash off		95%	20%	5%
PEC (mg/L)		2.68	1.17	0.87
Receptor	**Tolerance**	**HQ1**	**HQ2**	**HQ3**
Drinking Water	0.001	1519	571	381
Irrigation value	0.002	759	285	191
Daphnia	0.2	7.59	2.85	1.91
Green alga*	1	1.52	0.571	0.381
Aquatic plant (*Lemna*)*	2.5	0.607	0.228	0.153
Rat	10	0.152	0.057	0.038
Rainbow Trout	100	0.015	0.006	0.004
Duck	100	0.015	0.006	0.004

Table 25 shows that the HQs for the use of amitrole in drains exceed 1.0 for irrigation water and drinking water. Were a drain of depth of only 0.1 m considered, the HQs for irrigation water and drinking water would have been ten times higher.

There are no available data for the NOAEC for amitrole on crops or other plant species, so there is no way of assessing whether the guidelines for irrigation water is realistic. This is identifies as a data deficiency.

Recommendation 5 Data should be obtained for the sensitivity of crops and other plant species to amitrole with a view forming an objective basis for the guideline for the maximum permitted concentration of amitrole in irrigation water.

A summary of the HQs for drains is given in Table 26.

Table 26 Summary of the Tier 1 assessments for drains

Herbicide	Area	Weed	Application rate (l/ha)	Active ingredient (g/L)	Applied amount (g/ha)	Runoff fraction	Total amount (g/ha)	Drain width (m)	Water depth (m)	water volume (ML)	PEC (mg/L)
Glyphosate	MV,SH,CG,PB, RC	Arrowhead	27	360	9720	0.1	10692	2	0.1	1.0	10.7
	T	Milfoil and floating pondweed	20	360	7200	0.1	7920	2	1	10	0.79
Amitrole	MV,SH,CG,PB, RC	general aquatic	11	250	2750	0.1	3025	2	0.1	1.0	3.02

6.5. *Tier 2 assessment for Acrolein*

6.5.1. Prediction of environmental concentration

The environmental concentration depends on a number of factors including the initial injection concentration, the channel geometry and rates of flow.There are two injection concentrations that need to be considered in the G-MW Irrigation Region:

1. 3 mg/L product (2.58 mg/L acrolein) used in the Murray Valley Area; and
2. 0.3 mg/L product (0.258 mg/L) used in the Torrumbarry Area.

The concentration of acrolein decreases with increasing distance away from the injection point through a combination of dilution and loss of the active ingredient (as described in Section 3.1.4). Based on the data discussed in that section, we have used a half-life of 5 hours in the following calculations. The estimated of the concentration were made using the equations of O'Loughlin and Bowmer (1975).

The predicted concentrations of acrolein for different distances from the point of injection are shown in Figure 11 for an injection rate of 3 mg/L and Figure 12 for the lower rate of 0.3 mg/L. The maximum PEC is shown in Table 27 for the injection concentration of 3.0 mg/L and in Table 28 for the proposed injection rate of 0.3 mg/L

6.5.2. Channel sizes and application method

Scenario 1: MV N0 3 CHANNEL

PARAMETER/VARIABLE	MEASUREMENT/CONDITION
Information Source	Ross Gledhill
(Irrigation Area) Channel	MV No.3 @ Offtake from 2 Main
Design Flow rate	350 ML/d
Weed Restricted Flow R.	200 ML/d
Channel profile	12 – 15 m wide X 1.5 m deep
Weeds treated	(Submerged) Elodea and Aponogeton
Infestation density	Patchy. Some very dense
Time of treatment	Mostly January, but could start in December
Treatment	Acrolein @ 2- 3 ppm, Baker Petrolite method
Length of treatment	Target weeds over 10-12 km for 5 hours
Treatment flow rate	200 ML/d
Treatment water conditions	Very turbulent ,Channel is relatively flat and there are 7 drop regulators that will increase local turbulence Water temperature 20˚- 30˚ C in Dec, 25˚ - 30˚ C in Jan; Water likely to be turbid; pH likely to be 6 -8.

Scenario 2: Torrumbarry Small Channels

PARAMETER/VARIABLE	MEASUREMENT/CONDITION
Information Source	Roger Baker
(Irrigation Area) Channel	Torrumbarry 1/17/2
Design Flow rate	40L/d
Weed Restricted Flow R	10 ML/d (in 75% of all treatments in Torrumbarry Irrigation area)
Channel profile	3m wide x 0.8m deep
Weeds treated	Floating pond weed and Ribbon weed
Infestation density	~60%
Time of treatment	2 applications – November and February. 3 applications may be needed if the seasonal water allocation is 120% or more of entitlement.
Treatment	Acrolein @ 0.3 ppm, Acrolein Dispensing Unit
Length of treatment	48 hrs
Treatment flow rate	10 Ml/d
Treatment water conditions	Low velocity Water temperature 20˚- 30˚ C before January, 25˚ - 30˚ C post Jan; Water likely to be very turbid, pH likely to be 7

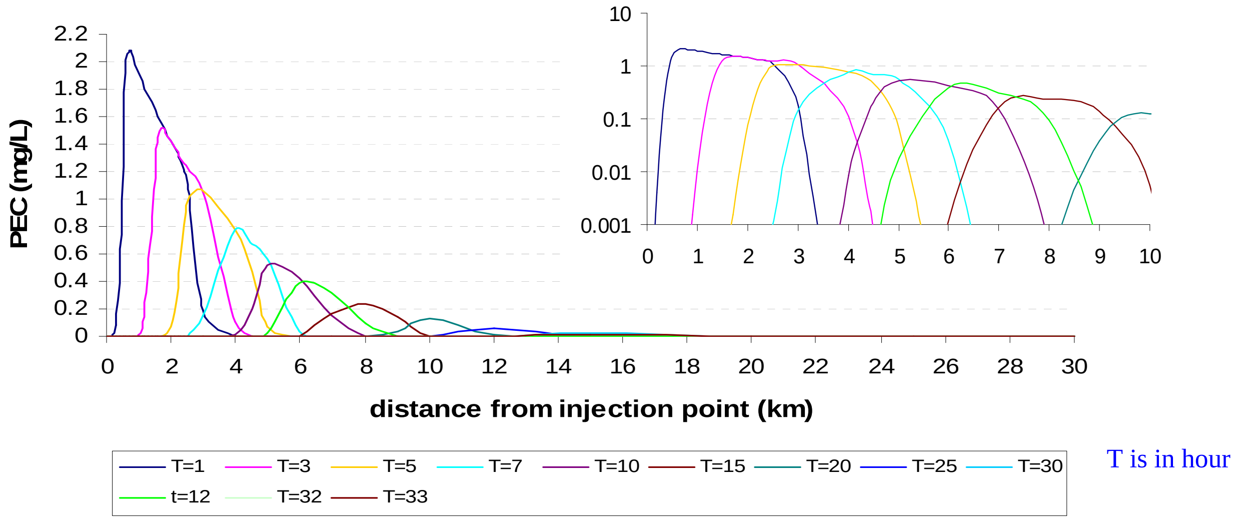

Figure 11 Estimated concentrations of acrolein at different times and distances from the point of injection following an injection at 2.58 mg/L for a channel 12 m wide and 1.5 m deep and a water velocity of 463 m/hour (after O'Loughlin and Bowmer 1975)

Estimation of hazard quotients for acrolein

The estimated hazard quotients for acrolein at the higher injection rate are shown in Table 27 for the 3 mg/L injection rate and in Table 28 for injection rates of 0.3 mg/L acrolein.

At the higher injection rate of 3.0 mg/L there concentration 1 km down stream is almost 2 mg/L, and this would be expected to cause harm to all the receptors except soybean. There is a likelihood of potential for harm to algae up to 35 km down stream from the injection point with the other receptors but for typical aquatic life no harm would be expected beyond 25 km from the injection point. Crops are generally more tolerant, with no harm expected to crops when water is taken beyond 3 km from the injection point. The concentration is expected to be sufficiently low beyond 10 km that they are likely to meet drinking water guidelines.

Injection of acrolein at the lower concentration would produce much fewer HQs that exceed 1.0. In this method the acrolein concentration in treated water beyond 1 km from the injection point is always under 0.2 mg/L which is less than the maximum acceptable level for drink water and irrigation. To be on safe side, for drinking water consumption 5

5 km downstream would be more appropriate as safe intake point. The water concentrations of acrolein in this case are expected to be in the safe range for aquatic life 10 km downstream from injection point.

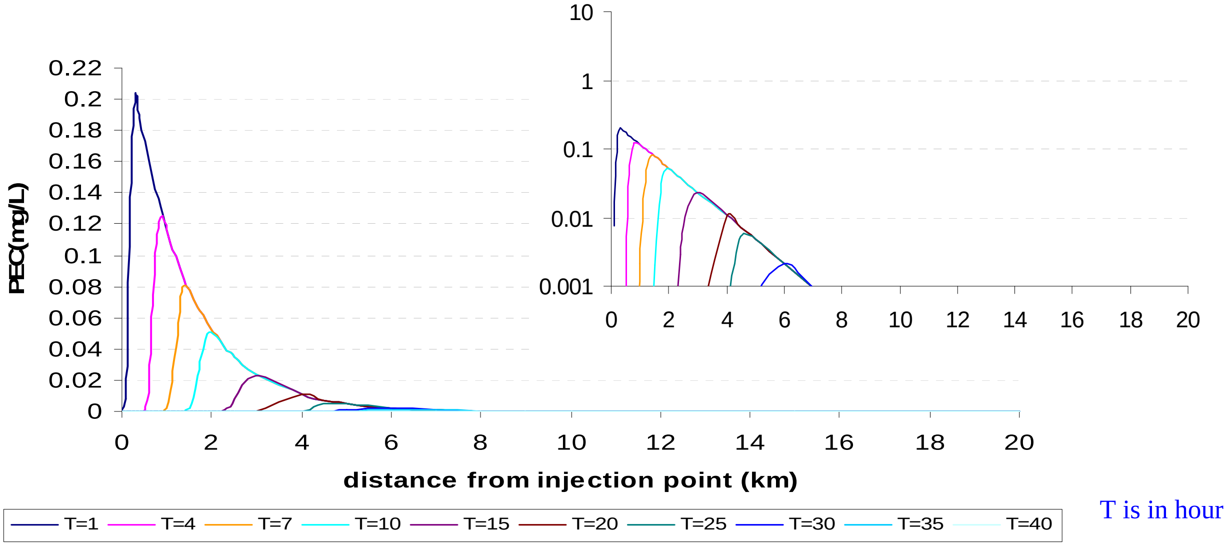

Figure 12. Estimated concentrations of acrolein at different times and distances from the point of injection following an injection at 0.258 mg/L for a channel 3m wide and 0.8 m deep and a water velocity of 173,61 m/hour (after O'Loughlin and Bowmer 1975)

6.5.3. Comparison between 2 different methods

The comparison between 2 methods - injection 3 mg/L acrolein for 5 hours or 0.3 mg/L for 48 hours using HQs only gives part of the picture as the HQs do not consider the duration of the exposure. Much of the ecotoxicological data is based on a 48 h exposure, so the results for the low rate of injection should be realistic. However, the results for the 3.0 mg/L injection rate for only 6 h may over-estimate the toxicity to acrolein.

The use of a lower concentration of acrolein for a longer creates a larger volume of water contains herbicide than when higher concentrations are used for shorter times. This may create a disposal problem for the larger volume of contaminated water.

Table 27. HQ at different distances from source of application of 3.0 ppm acrolein (dark grey colour in cells denote HQ > 1, grey HQ 0.1 – 1.0 and white HQ < 1).* values based on EC50.

Species	NOAEC mg/L	HQ 1 km	3 km	Distance from the injection point (km) 5 km	7 km	10 km	15 km	20 km	25 km	30 km	35 km	Safe distance 40 km
PEC (mg/L)		**1.91**	**1.05**	**0.58**	**0.32**	**0.13**	**0.029**	**0.006**	**0.0014**	**0.000072**	**0.000016**	**0.000003**
Selenastrum capricorutum*	0.00005	38400	21120	11600	6400	2600	600	130	28	6.6	1.5	0.33
Aquatic life	0.001	1920	1056	580	320	130	30	6.5	1.4	0.33	0.01	0
Goldfish	0.0114	168	93	51	28	11	3	0.57	0.12	0.03	0	0
Rabbit	0.05	38	21	11.6	6.4	2.6	0.6	0.13	0.03	0.01	0	0
Lemna gibba*	0.07	27	15	8.3	4.6	1.9	0.43	0.09	0.02	0	0	0
Drink water	0.32	6	3.3	1.81	1	0.41	0.09	0.02	0	0	0	0
Dog	1	1.92	1.06	0.58	0.32	0.13	0.03	0.01	0	0	0	0
Toxic for crops-pasture	1.5	1.28	0.7	0.39	0.21	0.09	0.02	0	0	0	0	0
Soybean	15	0.13	0.07	0.04	0.02	0.01	0	0	0	0	0	0

Table 28. HQ at different distances from source of application of 0.3 mg/L of acrolein (dark grey colour in cells denote HQ > 1, grey HQ 0.1 – 1.0 and white HQ < 1).* values based on EC50.

Species	NOAEC mg/L	HQ 1 km	Distance from the injection point (km) 3 km	5 km	6 km	10 km	12 km
PEC (mg/L)		**0.116**	**0.023**	**0.0048**	**0.0021**	**0.00009**	**0.000018**
Selenastrum capricorutum*	0.00005	2320	460	80	42	1.8	0.04
Aquatic life	0.001	116	23	4	2.1	0.09	0
Goldfish	0.0114	10.2	2.02	0.35	0.18	0.01	0
Rabbit	0.05	2.32	0.46	0.08	0.04	0	0
Lemna gibba*	0.07	1.66	0.33	0.06	0.03	0	0
Drinking water	0.32	0.36	0.07	0.01	0.01	0	0
Dog	1	0.12	0.02	0	0	0	0
toxic for crops-pasture	1.5	0.08	0.02	0	0	0	0
Soybean	15	0.01	0	0	0	0	0

7. Discussion

7.1. *Comparison of predictions with monitoring data*

There has been some monitoring in channels and drains reported in a Goulburn River Audit (2005). A summary of the results are shown in Table 29. The glyphosate levels observed in the drains were consistent with those modelled in this study a part form one extreme value of 10.5. This high value was found following sampling almost immediately after spraying and there may have been incomplete mixing including absorption by the soil at the bottom of the drain.

The predicted amitrole concentration is consistent with the monitored data, especially taking into account the modelled predictions were based on a near worst case scenario.

The similarity between the predicted and monitored data gives confidence in the modelling methods used in this study.

Table 29 Range of monitored data and predicted values for glyphosate, 2, 4-D and amitrole

Reference	Treatment	Channel or Drain	Glyphosate	2,4-D	Amitrole
Table 1	Glyphosate and amitrole	Drain	< LOD - 0.08	NT	< LOD – 0.029
Table 2	Glyphosate	Drain	0.01 – 0.94	NT	0.002 – 1.06
Table 3	Glyphosate	Drain	< LOD – 10.5	NT	NT
Table 4	2,4-D	Channel	NT	< LOD	NT
Table 5	2,4-D	Channel	NT	< LOD – 2.96	NT
Table 6	2,4-D	Channel	NT	< LOD	NT
This study	Glyphosate and amitrole	Drain	0.018 – 1.54	NA	0.29 – 1.42
This study	Glyphosate and 2,4D	Channel	0.002– 0.43	0.51 – 0.81	NA

7.2. *Comparison of herbicide effects*

7.2.1. Glyphosate

Glyphosate is widely used in the removal of weeds from waterways. It is used in a variety of ways including spraying when the water levels are low or in target spraying with a hand gun to remove potentially troublesome patches of weeds. There were few threats posed by the use of glyphosate, particularly when glyphosate was applied to weeds in a channel.

The only threat posed by glyphosate was to irrigation water, and that threat occurred only when a high wash-off value was assumed.

There was a similar result for drains, where again the main threat posed was to irrigation water. There was a possibly threat to *Daphnia*, aquatic ecosystems and drinking water if a 60% wash-off occurred.

Further risk reduction has been achieved by using a hand gun to target patches of potentially troublesome weeds. Such a reduction in glyphosate application has the added beneficial effect of reducing the amount of carrier that is being applied.

7.2.2. 2,4-D amine

2,4 D has the potential for causing more harm than glyphosate. It is more mobile and less sensitive to the wash-off fraction. In its undiluted form channel water treated with 2,4 D has the potential to affect tomatoes and other crops almost independent of the wash-off fraction. It is surprising that two of the plant indicators (alga and *Lemna*) had HQs below one and were therefore as not posing a risk.

7.2.3. Amitrole

Amitrole when applied to drains has the potential to cause harm to *Daphnia* when it is applied at a high rate and there is a high (>20%) fraction of runoff. Caution should be used in allowing drainage water from a drain that has been sprayed with amitrole should not be allowed to enter directly into a wetland.

There is also the potential that it will exceed the recommended levels for irrigation water. Irrigation from drainage water following spraying with amitrole should therefore be undertaken with caution.

7.2.4. Acrolein

Acrolein is a potent herbicide and has the potential to cause harm many kilometres from the injection point. If applied at 3.0 mg/L level, for general aquatic life this could be 25 km and for algae as much as 35 km. The position is much safer if acrolein is injected at the lower rate of 0.3 mg/L. Were acrolein to be applied to drains, there is the potential for longer half-life due to the lack of turbulence as well as the threat to its receiving water body. Acrolein should not be used in drains – we understand this is G-MW policy.

7.2.5. Overview

In general there is little potential for harm from the herbicides. The greatest threat is to exceeding the irrigation water guideline, but as discussed below, this guideline should be reviewed.

7.3. *Extrapolation to other receptors*

Although this report considers a limited range of receptors, a method being developed by CSIRO (Morton *et al*. 2007) would enable the extrapolation of end points from one species to another. The ability to extrapolate would enable much more general statements to be made concerning the findings given in this report.

7.4. *Guideline values for irrigation water*

A comparison of the tolerance values of plant receptors to the four herbicides is given in Table 28. In each case, the irrigation guidelines are many times less than those of the other plants. This is particularly so for amitrole, suggesting that the guideline value irrigation water is too low. For 2, 4-D there is a factor of 5 between the tolerance value of tomatoes and that of irrigation water – such a difference is reasonable as some safety factor should be allowed. For glyphosate the minimum difference is a factor of 22. Because there is concern about the possible detrimental effects of the herbicides on non-target species, it is recommended that local data be obtained on the susceptibility of local crops to enable more reliable irrigation water limits to be obtained for these four herbicides.

Table 30 Comparison of tolerance values across receptors

Receptor	Tolerance values (mg/L)			
	Amitrole	2, 4-D	Glyphosate	Acrolein
Alga	1(W1)	26.4 (H1)	48.5 (T)	0.00005 (T)
Lemna	2.5(W2)	2.029 (H1)	16.9 (O)	0.07 (T)
Crops		0.22 (Q)	2.2 (H2)	1.5 (G)
Tomatoes		0.15 (F)	2.7 (S)	
Irrigation water	0.002 (G)	0.03 (G)	0.1 (G)	N/A

F= Fagliari et al. (2005) G= Goulburn Murray manual, H1= Hughes et al. (1990), H2= Hutson and Roberts (1987), O= O'Brien et al. (1979),Q= Que *et al.* (1981), S= Santos and Gilreath (2006), T= Tomlin (2000), W1= Wang *et al.* (1990), W2=wolf (2001)

7.5. *Other risk not considered in this report*

This report has considered only the active herbicide component of the products that are applied. Typically the products contain some type of carrier and possibly a surfactant (adjuvants), with a result that the fraction of active ingredient may be significantly less than 1.

Table 31 Toxicity of components of Roundup® to rainbow trout (after Bowmer *et al*. 1998)

Chemical	24 h LC50
Surfactant	2.1 mg/L
Glyphosate	140 mg/L
Roundup®	8.3 mg/L

There is research that shows that the product can be more toxic to amphibians than the so called active ingredient. This is particularly so for Roundup® as compared to glyphosate (Schmuck 1994). This is highlighted by the data shown in Table 31. This problem has been recognised by G-MW and as a result they have changed their formulation that contains glyphosate (pers. comm. workshop in Tatura November 2007).

7.5.1. **Daughter products**

It is well known that pesticides form breakdown products, some of which can be toxic and persistent. Scribner et al. (2003) reported on 154 samples that were collected from 51 streams in nine Midwestern States during three periods of runoff. Results showed that glyphosate was detected in 55 (36 percent) of the samples, and aminomethylphosphonic acid (a degradation product of glyphosate) was detected in 107 (69 percent) of the samples. There is therefore evidence that daughter products do persist and their presences should not be ignored.

The problem of daughter products needs to be considered as part of the overall herbicide fate considerations, and this should be factor in the choice of herbicides.

7.5.2. **Acute versus chronic risks**

This study has focussed on acute risks which is appropriate for the assessment of local effects. There may also be a much lower threshold for chronic risks. For example, the acute NOAEL for rainbow trout exposed to amitrole is 100 mg/L (Wolf 2001), but the limit for reproduction is only 0.2 mg/L. Caution must therefore be applied not only to the acute levels but also to the chronic levels that could arise as the sum of many small effects upstream of the receiving water.

7- Discussion

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9. **Appendices**

Appendix A Herbicides usages during 2001/2002 and 2004/05 (after G-MW)

Herbicides	Control of weeds	Log K_{ow}	Amount used (2001/02 figures)	Amount used (2004/05 figures)
Acrolein (Trade name : Magnacide H)	Submersed weeds and algae (Ribbonweed, pondweeds, Elodea) Used in channels	1.08	5445kg	794kg
2, 4,D Amine (Amicide LO500A)	Emergent weeds (Arrowhead, and some Milfoils) Used in channels	2.58-2.83	10,100L	3284L
Amitrole (Amitrole T or Amitrole TL)	Grasses and some broadleaf plants, mainly in drains & dryland situations (Water couch, Barnyard grass and Umbrella sedge) Used in drains	-0.97	28,666L	8618L
Glyphosate (with an aquatic registration)	Grasses and some broadleaf plants in all situations eg Cumbungi, Water couch, temporary control of Arrowhead Used in drain and channels	<-3.2	38,560L	28,862L

Appendix B: Acronyms and glossary of terms

Acute toxicity : Adverse effects occurring within a short time of administration of a single dose of a chemical, or immediately following short or continuous exposure, or multiple doses over 24 hours or less

Bioaccumulation : The total accumulation of chemical in the body of an organism through all possible routes (e.g. absorption, via breathing, eating, drinking or active uptake).

Bioavailability : The extent to which a substance is available for biological metabolism

Boom spray : The most commonly used equipment for applying pesticides is the tractor-powered boom sprayer fitted with conventional hydraulic nozzles. Conventional boom sprayer consists of spray tank, pump, and a boom to which is fixed the spray line, droppers and nozzles.

Channels : Open channel or flume designed to convey water from upstream source to farms. Supply channels can be categorised as *Main channels* whose primary purpose is to convey bulk water from headworks storage or river diversion point into the distribution system; or Distribution channels whose primary purpose is to deliver water from main channels to individual farms

Chronic : Long term, low level exposure to a toxic chemical

Concentration : The amount of active ingredient or pesticide equivalent in a quantity of diluent

Contaminant : Any biological, chemical, physical and radiological substance or matter that has an adverse response (effect) on air, water, soil or living things

Degradation: A chemical alteration to a pesticide. Chemical or biological breakdown of a complex compound (e.g. pesticide) into simpler compounds (water, CO_2 etc.)

Domestic & stock water (D&S): This is a small water entitlement, for supplying households, watering of cattle and other stock, water of animals kept as pets. D&S water is untreated and is not to be used for human consumption or drinking

DWEL (see page 27)……..

EC_{50} or Median effective concentration. The concentration of material in water that is estimated to be effective in producing some toxic/lethal response in 50% of the test organisms

Ecosystem : Community of organisms interacting with each other and the chemical and physical factors making up their environment

End-point : In toxicity testing and evaluation it is the adverse biological response in question that is measured. End points vary with the level of biological organization being examined but include changes in biochemical markers or enzyme activities, mortality, or survival, growth, reproduction, primary production, and changes in structure (and abundance) and function in a community. End points are used in toxicity tests as a criteria for effects

Environmental fate : The destiny of a chemical after release to the environment; involves considerations such as transport through air, soil and water, bio-concentration, degradation, etc

Exposure : The amount of physical or chemical agent that reaches a target or receptors

Foliage : leaf: the main organ of photosynthesis and transpiration in higher plants

Goulburn River : The Goulburn River is a major inland river in Victoria, Australia. The headwaters of the Goulburn River rise in the western end of the Victoria Alps, near Mount Buller. The Eildon Dam creates Lake Eildon, a major storage of water for irrigation. From Lake Eildon, most of the irrigation water goes to Goulburn Weir and Waranga Basin. North of Eildon the Goulburn River enters the northern plains of Victoria and eventually flows into the Murray River near Echuca. This area is a very productive irrigated agricultural area. The Goulburn River was named after Henry Goulburn. There is also a Goulburn River in New South Wales.

Guideline trigger values : These are the concentrations (or loads) of the key performance indicators measured for the ecosystem, below which there exists a low risk that adverse biological (ecological) effects will occur. They indicate a risk of impact if exceeded and should 'trigger' some action, either further ecosystems specific investigations or implementation of management /remedial actions

Half-life (T ½) : The time required for half of the residue to lose its analytical identity whether through dissipation, decomposition, metabolic alteration or other factors

Hand guns : This type of applicator commonly used for tree crops or spot spraying of herbicides consists of a hand-held gun or wand fed from a large container on a vehicle though a long hose. The pesticide is pumped from the drum by a motor driven pump or tractor PTO(see below). The gun may consists of 1-3 nozzles.

Hazard : (1) Likelihood that exposure to a chemical will cause an injury or adverse effect under the conditions of its production, use or disposal; (2) The potential or capacity of a known or potential environmental contaminant to cause adverse ecological effect/s

Hazard Quotient (HQ) : The ratio of estimated site-specific exposure to a single chemical from a site over a specified period to the estimated daily exposure level, at which no adverse health effects are likely to occur. Or Hazard quotient means the value which quantifies non-carcinogenic hazard for a single chemical for an individual receptor over a specified exposure period. The hazard quotient is equal to the ratio of an intake of a chemical to the chemical's reference dose. Hazard quotient shall be based on similar-acting non-carcinogens, i.e., systemic toxicants that act on the same organ or organ system

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Irrigation : Irrigation is the artificial application of water to land for the purpose of agricultural production. Effective irrigation will influence the entire growth process from seedbed preparation, germination, root growth, nutrient utilisation, plant growth and regrowth, yield and quality

K_d : Soil-water adsorption coefficient, calculated by using measurements of pesticide distribution between soil and water **K_d** = **(**concentration sorbed/concentration dissolved).

K_{oc} or sorption coefficient :A measure of a materials tendency to sorb onto soil particles. High K_{oc} indicate a tendency for the material to be sorbed by soil particles rather than remain dissolved in the soil solution. In general strongly sorbed molecules will not leach. K_{oc} values of <100 indicate little sorption and a potential for leaching
K_{oc} **=** **(**concentration sorbed/concentration dissolved)/% organic carbon in soil

K_{ow} : see Octanol-water coefficient: chemicals with log K_{ow} >2.5 are considered hydrophobic

LC_{50} or median lethal concentration : The concentration of material in water that is estimated to be lethal to 50% of the test organisms. The LC_{50} is usually expressed as a time-independent value, eg. 24 hour or 96- hour LC_{50} , the concentration estimated to be lethal to 50% of the test organisms after 24 or 96 hours of exposure

LD_{50} or median lethal dose : The concentration of material in water that is estimated to be lethal to 50% of the test organisms. Appropriate to use with test animals such as rats, mice and dogs. It is rarely applicable to aquatic organisms because it indicates the quantity of a material introduced directly into the body by injection or ingestion rather than the concentration of the material in water in which aquatic organisms are exposed during toxicity tests

Mammals : The class of organisms that have backbones (vertebrates); includes all animals that have hair and suckle their young

Murray River : The Murray River, or River Murray, is Australia's second-longest river in its own right (the longest being its tributary the Darling). At 2,575 kilometres (1,600 miles) in length, the Murray rises in the Australian Alps, draining the western side of Australia's highest mountains and, for most of its length, meanders across Australia's inland plains, forming the border between New South Wales and Victoria as it flows to the northwest, before turning south for its final 500 kilometres or so into South Australia. The waters of the Murray flow through several lakes that fluctuate in salinity (and were often fresh until recent decades) including Lake Alexandrina and The Coorong before emptying through the Murray mouth into the Indian Ocean (Southern Ocean according to Australian maps) near Goolwa. Despite discharging considerable volumes of water at times, particularly before the advent of large scale river regulation, the Murray mouth has always been comparatively small and shallow.

Octanol-water partition coefficient (K_{ow}) :The ratio of a chemicals solubility in *n*-octanol ($C_8H_{17}OH$) to its solubility in water. Symbol K_{ow}. The ratio indicates the chemicals propensity for bio-concentration by aquatic organisms. It is an important parameter reflecting hydrophobicity of a compound and is used often in the assessment of environmental fate and transport for organic chemicals

Outfall : Regulating structure located at the downstream end, or intermediate points, of a supply channel to allow safe discharge of surplus flows arising in the system due to the effects of rainfall inflow, planned channel shutdown or operational error. An outfall can also be used to drain water from the channel at the end of the irrigation season. Water released through the outfall is usually discharged to a drainage channel, natural waterway or Regulating Storage

Partition coefficient : A ratio of the equilibrium concentration of the chemical between a non-polar and polar solvent

Pesticides : Any chemical compound used to kill pests that destroy agriculture production or are in someway harmful to humans. Pesticides include *herbicides* (eg. 2, 4-D) which kill unwanted plants or weeds; *insecticides* (eg. endosulfan) which kill insect pests; *fungicides (*eg. copper hydroxide) which kill fungi

Predictive Environmental Concentration (PEC) : The Predicted Environmental Concentration is an indication of the expected concentration of a material in the environment, taking into account the amount initially present (or added to) the environment, its distribution, and the probable methods and rates of environmental degradation and removal, either forced or natural.

Rate : The amount of active ingredient or acid equivalent applied per unit area or other treatment

Receptor : In exposure assessment, an organisms that receives, may receive, or has received environmental exposure to a chemical or Receptor means environmental resources, including but not limited to, plant and animal species, humans, sensitive environments and habitats, water supply wells, and locations that have the potential to be, or have actually been, exposed to contamination

Residue : That quantity of pesticide, its degradation products, and/or its metabolites remaining on or in the soil, plant parts, animal tissues, whole organisms, and surfaces

Risk : A statistical concept defined as the expected likelihood or probability of undesirable effects resulting from a specified exposure to known or potential environmental concentrations of a material. A material is considered safe if the risks associated with its exposure are judged to be acceptable

Risk assessment: A qualitative or quantitative evaluation of the environmental and/ or health risk resulting from exposure to a chemical or physical agent (pollutant). Risk assessment or "site-specific risk assessment" means a site-specific characterization of the current or potential threats that may be posed to human health and the environment by contamination migrating to or in groundwater or surface water, discharging to the air, leaching through or remaining in soil, bio-accumulating in the food chain, or other complete and significant exposure pathways identified in the Site Conceptual Exposure Model (SCEM). Key components of a risk assessment are the identification of hazard (i.e., identifying site-related chemicals and their concentrations in the exposure media), exposure assessment (identifying complete and significant exposure pathways and quantifying intake), toxicity assessment (identifying the toxic effects and dose-response [toxicity value]), risk characterization, and discussion of uncertainties. For the purposes of these regulations, a Tier 3 Risk Assessment is considered a "site-specific risk assessment."

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River : A river is a large natural waterway. The source of a river may be a lake, a spring, or a collection of small streams, known as headwaters. From their source, all rivers flow downhill, typically terminating in the ocean. The mouth, or lower end, of a river is known as its base level.

Runoff : That portion of precipitation which is not absorbed into the soil, but flows into surface streams

Soil mobility : Movement of a compound through soil from the treated area by leaching, volatilization, sorption and desorption or dispersal by water

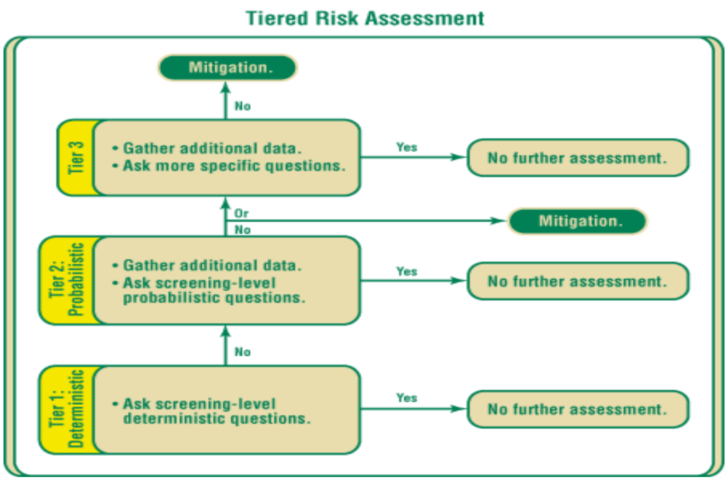
Sub-lethal : Having an effect less severe than death

Surface water : Water in open bodies such as streams, rivers, ponds, lakes and oceans

Toxicants: substances that is harmful to living organisms

Target : The target species is the organism which the pesticide is intended to control

Tiered approach for risk assessment : A tiered assessment is a risk assessment that is set up in a number of sequential steps of increased complexity and effort and there are specifies decision criteria for each step. It involves evaluating whether or not the next step of assessment should be undertaken based on these criteria (Figure source : USEPA)



Toxicant : An agent or material capable of producing an adverse response (effect) in a biological system, seriously injuring structure and/or function or producing death

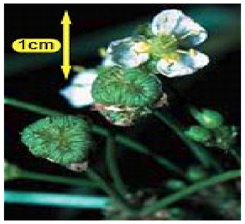
Toxicity : The inherent potential or capacity of an agent or material to cause adverse effects in a living organism when the organism is exposed to it

Toxicity test : A measure of the degree of response of an organism exposed to a particular concentration of a chemical or a particular level of some other environmental variable

Uptake : A process by which materials are absorbed and incorporated into a living organism

Wash off : The removal of herbicides applied on a plant that is washed off by rain or irrigation water

Appendix C. Weed species (G-MW web site, CRC for Australian Weed Management, and Sainty & Associates Pty Ltd)

Common name, Weed category Chemicals for controlling	**Binomial name**	**Family**	**Distinguishing features**	**Photographs of Weeds**
Alisma Water plantain - Aquatic herb Distribution : Europe, North Africa, West Africa	*Alisma lanceolatum (serious weed of rice crops-* Perennial) *Alisma plantago-aquatica (foliage and scapes eaten by stocks-* Perennial, annual)	Alismataceae	▪ Erect aquatic perennial herb, ▪ submerged leaves strap-like, emergent leaves lanceolate shaped, large open inflorescence (50cm long and 30 cm wide) ▪ Spread by seeds and movement of tuberous rhizomes ▪ Use : weed	 Mature flowering plants  Submerged strap leaves  Flowers and Immature fruit
Arrowhead Emergent water plant- aquatic herb, Distribution	*Sagittaria graminea*-weed-ornamental-perennial	Alismataceae	▪ Serious problems in irrigation areas (four G-MW irrigation areas) spread rapidly, block channels and greatly reduces the effectiveness of the water distribution	 

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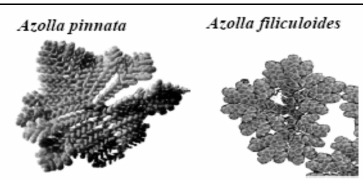
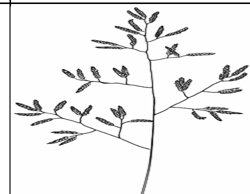
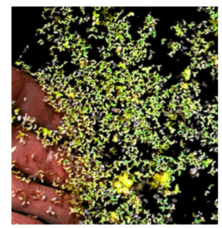
: North America Noxious in WA, T and SA (2,4-D amine, Glyphosate)			system ▪ Leaves : two types emergent and submerged , lance shaped or arrow-shaped leaves (green in colour) ▪ Flowers : occur below leaf, three flower whorls, white or pink ▪ Found in irrigation channels and drains , and river and creek banks ▪ Spread by germination of seeds and vegetatively through rhizomes ▪ Use : weed, ornamental	Flowers positioned below the top of the plant
Azolla Free floating aquatic fern Distribution : NZ, America (A. pinnata), , NZ, PNG Africa Asia (*A. filiculoide)*	*Azolla pinnata (*Ferny azolla-perennial) *and A filiculoides (*Pacific azolla-perennial)	Azollaceae	▪ Small free floating aquatic plants, Native to Australia as well as tropical and warm temperate regions ▪ Invasive weed which form cohesive mats of vegetation interfering boating, fishing recreational activities and degrade WQ by reducing oxygen levels ▪ Impedes flow in slow moving water	 The differences between the two species are as follows: *Azolla pinnata* (ferny azolla) — *Azolla filiculoides* (pacific azolla) Triangular in shape — Polygonal in shape Obtuse leaf shape — Acute leaf shape Lateral rootlets — No lateral rootlets Regularly branched — Irregularly branched  Difference between two species

			▪ Plant is called a frond (fern like leaves and adventitious roots) consists of a main stem growing on the surface, leaves are green in spring or early in summer become red when mature or in full sunlight ▪ Spread by forming dense mats over still waters ▪ Reproduces by rapid vegetative fragmentation ▪ Use : weed	
Canegrass Emergent	*Eragrostris australasica* Perennial	Poaceae	▪ Coarse perennial to 2 m or more high, branching along the stem and with few foliage leaves; lateral nerves of lemma subequal to midvein, all 3 fading halfway along the lemma	
Common water milfoil aquatic herb (Approved herbicides- 2,4-D amine))	*Myriophyllum papaillosum-* Perennial	Halloragaceae	▪ Native, perennial plants recognisable by its above surface leaves and stems (shape and branch like pine tree) ▪ Attractive weed that can block water flow in irrigation supply channels	

			and drains ▪ Propagate vegetatively from fragmented stems, rhizomes and sexually by seeds ▪ Use : weed	
Cumbungi or Bullrush Aquatic herb, emergent (Glyphosate) Distribution : native	*Typha domingensis (native)(*narrow leaved-weed of irrigation channel and rice crops, noxious in NT, perennial*),* *T. orientalis (native)(*broad leaved weed of irrigation channel and rice crops, noxious in NT, perennial *),*	Typhaceae	▪ An emergent, erect perennial plant that grows in dense strands ▪ Weed of irrigation channels and rice crops ▪ Leaves are 2-5cm wide, long stiff, emerging from the base & often extending the full height of the plant (plant can be about 4m), ▪ Seed heads (1-2cm in diameter, about 25cm long) are situated at the ends of stalks and are firm, brown and cylindrical ▪ Dense growth of cumbungi can reduce visual and physical access to a body of water, may cause severe water flow restriction in channels and drains	 *Typha domingensis (narrow leaved) and T. orientalis(braod leaved) are native, whereas T. latifolia (bull rush) is introduced*

			▪ Spread by seed and underground stems or rhizome ▪ Food and shelter for water birds ▪ Use : food (aboriginal - young rhizomes eaten) ▪ weed, shelter, fibre (aboriginal)	
Duckweeds Aquatic herb–free floating	*Lemna spp (*perennial) (common duckweed) , *Wolffia* spp (tiny duck weed) (perennial) *and Spirodela spp* (thick duck weed)((perennial)	Lemnaceae	▪ Small floating plants found in still or sluggish water (wetlands, creeks, marshes, ponds, rivers, lakes) ▪ Duckweeds (*Wolffia* spp.) are the smallest (also called tiny duck weed) flowering plants on earth ▪ Each plant has 2-several leaves joined at the base and a single root hangs beneath ▪ Reproduces by seed and vegetatively (asexual) ▪ Use : weed	 Water meal *(Wolffia* spp), weed  Small duckweed (*Lemna* spp)  *Spirodela* spp (giant duck

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Floating pondweed Submerged (Glyphosate, acrolein)	*Potamogeton tricarinatus* or *P. spp.* (Perennial)	Potamogetonaceae	▪ Rhizomatous, emergent aquatic perennial, herb, leaves thick oval (emergent) or narrow-elliptic (submerged). ▪ Native rhizomatous perennial plant with both submerged and floating leaves and emergent inflorescence ▪ Grows in stationary and slow moving freshwaters ▪ Can cover the surface of lakes and ponds and could be major problems in waterways ▪ obstructive in irrigation channels and weed of farm dams ▪ Use : weed	 
Milfoil Herb-yarrow Distribution : Europe, New Zealand, W. Asia	*Achillea millefolium* Perennial	Asteraceae	▪ Herbaceous perennials, most with fragrant lacy foliage and small daisy-like flowerheads borne in rounded corymbs ▪ Common yarrow has leaves that are greyish green, aromatic, and very finely dissected, like soft dainty ferns	 

			▪ . The plant forms dense spreading mats of lacy leaves from rhizomes that creep beneath the ground surface.. ▪ Use : Weed, ornamental	
Noogora burr-herb Distribution : N. America, temperate and tropical countries Noxious in Australia (MCPA or Glyphosate)	*Xanthium occidentale* Noxious	Asteraceae	▪ The weed prefer flood prone areas and can be found in Murray Valley Irrigation Areas ▪ Leaves darker green on upper , upper leaves alternate, and lower leaves opposite, stems : blotched or streaked with purple ▪ The plant is toxic to stock at the seedling stage and can cause contact allergy, dermatitis and mechanical injury to both humans and animals ▪ Spread can be by wind or by animals (as the burrs have hooked spines that cling to the wool or fur of animals or bags and clothing) ▪ Seed survive in water logging and can be	  Leaves 3-5 lobed Flowers and fruits

			transported by water ▪ Use : Poison, weed	
Umbrella sedge Herb (Amitrole)	*Cyperus eragrostis*	Cyperaceae	▪ Native to America ▪ problems in waterways ▪ Common in wet areas (river banks, seasonal drainages and road sides, ditches ▪ Perennial sedge with short thick rhizomes and coarse fibrous roots	▪   A cluster of inflorescences
Water couch herb (Amitrole)	*Paspalum distichum*	Poaceae	▪ Tufted perennial, grass-like or herb ▪ Stoloniferous and rhizomatous perennial to 0.5 m high; stolons to 5 m long. ▪ Leaves with sheath pilose on the margins towards the summit, otherwise glabrous;	

Appendix D: calculation of DWEL (NOAEC in mg/L) from NOAEC (mg/kg)

Herbicide	Species	NOAEC	References	Weight	Water consume	DWEL mg/L
Amitrole	**Rat**	10 mg/kg	Weber, 1978	0.1kg	0.1L	10
	Dog	12.5 mg/kg	Weir ,1958	5kg	1L	62.5
	honeybee	100 µg/bee	Wolf ,2001		1mL	100
Glyphosate	**mallard duck**	1000 mg/kg	Renzo ,2000	2kg	0.5 L	4000
	Rat	300 mg/kg	EPA, 2006	100 g	0.1L	300
Acrolein	**Rabbit**	0.1 mg/kg	USEPA ,2000	1kg	0.2 L	0.5
	Dog	0.05 mg/kg	USEPA ,2000	20 kg	1L	1

Appendix E: 2, 4-D amine NOAEC for Tomato

In on study 13.44 g a.i. ha (-1) applied 2, 4-D amine after full development of fourth truss stage or latter had no effect on crop yield or development. (Fagliari *et. al*, 2005)

Due to Langdon K *et. al.* (2006) research 1 ha area with 75 mm soil column gives 1000 tonne soil. With assuming 20 mm soil the mass of soil would be 266.7tonne/ha:

(1000tonne/ha) x 20mm/ 75mm=266.7tonne/ha

Moreover usually, 1 cm3 soil absorbs 0.5 ml water thus; the herbicide concentration would be 0.15 mg/L.

(13.44g herbicide/ha)/ (266.7tonne soil/ha) = 0.05039g herbicide/tonne soil

(0.05039g herbicide/tonne soil) × (1 tonne/10^6 g) =0.05039×10^{-6} g/g soil

$(0.05039 \times 10^{-6}$ g/g soil$) \times (1.5$g soil /0.5 ml water$) = 1.5 \times 10^{-7}$ g/ml

$(1.5 \times 10^{-7}$ g/ml$) \times (10^{6}) = 0.15$ mg/L

Appendix F: 2, 4-D amine NOAEC for rat

In one of the studies, rat exposed to 50 mg/kg 2, 4-D for 22 days which doesn't cause any effect.

We will assume that the rat consumes 100 ml water per day. Then total water consumption in 22 days will be 2.2 L. DWEL will be calculated as below:

DWEL = (50 mg/kg) x 0.150 kg/ 2.2 L= 3.41 mg/L (ppm)

Appendix G: Example of calculation of PEC in Tier 1- Glyphosate at 40L/ha

Glyphosate applied at rate of 40L/ha; a.i. = 360 g/L; runoff= 10%; channel depth=40 cm

<u>Calculation of PEC</u>:

40 L/ha × 360 g/L = 14400 g/ha
14400 g/ha + (10% ×14400) g/ha= 15840 g/ha

Water volume in 1 ha sprayed area= 10000 m^2 ×0.4 m (depth of water) = 4,000,000 L

$$\text{PEC (mg/L)} = \frac{15840 \text{ g/ha} \times 1000 \text{ (convert g to mg)}}{4{,}000{,}000 \text{ L}} = 3.96 \text{ mg/L}$$

Appendix H: Calculation of water volume-Drain length

- **Typical drain- 10 cm depth of water**

Drain size: 2 m width and 0.1m depth.

Water volume: 10000 m^2 × 0.1 m ×1000 (conversion factor) = 1,000,000 L = 1 ML.

- **Torrumbarry Drain**

Drain size: 2 m width and 1 m depth of water

Water volume: 10,000 m^2 × 1m = 10000 m^3 ×1000(conversion factor) = 10 ML