Open Hydroponics:
Risks and Opportunities

Open Hydroponics Ecological Risk Assessment (ERA)

June 2005
LWA DAN 22

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Acknowledgements

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Prof. Barry Hart (Monash University) and Dr Terry Walshe (University of Western Australia) are acknowledged for their contribution and assistance to the development of the ecological risk assessment for this project.

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Introduction to Ecological Risk Assessment

The purpose of this component of the research was to develop a method to identify likely ecological risks associated with Open Hydroponics (OH) in the Mallee region, using an ecological risk assessment approach.

Ecological Risk Assessment (ERA) is the process of **defining and assessing the risks to ecological resources** of anthropogenic hazards and determining the acceptability of those risks. The hazard(s) can be any chemical, physical or biological entity that causes an adverse ecological response. In order to pose a risk, the hazard must 1) cause an adverse effect and 2) must be in association with the target end-point for long enough and at sufficient strength to elicit the effect. In this context, the model that defines risk is:

Risk = Likelihood x Consequence

Traditional risk assessment involves a single hazard and a single endpoint. In an ecological context, this is very limited, since many environmental problems involve multiple hazards that affect several parts of an ecosystem. ERA seeks to account for this complexity and variability in natural ecosystems and provide the framework to assess the ecological consequences of environmental hazards.

The aim of ERA is to contribute to the protection and management of the environment through scientifically credible evaluation of ecological risks. It supports a broader risk-based approach to natural resource management and environmental decision-making processes. The important phases of an ERA can best be described as:

1) **Planning** – determine the focus of a risk assessment, assemble the risk assessment team and relevant scientific experts, and engage stakeholders in the ERA process.
2) **Problem formulation** – determine the scope of the study, including spatial and temporal scale, develop conceptual models of the ecological system in question, determine the ecological values to be protected (management goals), and identify specific hazards, ecological effects and pathways.
3) **Risk analysis** – determine likelihood of hazard causing an adverse effect or consequence, determine magnitude of effect in ecological context, and identify and quantify uncertainties.
4) **Risk characterisation** – interpret risk analysis information, communicate risk assessment results as well as uncertainties/assumptions to managers.

The ERA process (Figure 1) has a number of key features:

- It effectively deals with multiple hazards that affect several parts of an ecosystem, and considers consequences beyond a single species, to the population, community and ecosystem level.
- It is an inter-disciplinary, iterative process, allowing the incorporation of new information into the risk management plan as it becomes available, to improve decision-making.
- It characterises and quantifies uncertainty, making it an explicit part of the risk assessment process.
- It aims to quantify the changes in ecological systems in response to hazards.
- It focuses on management goals as well as knowledge.

The aim of this research was to apply the ERA process to OH to assess its usefulness, as described by numerous researchers for similar applications, particularly Hart *et al.* (2004).

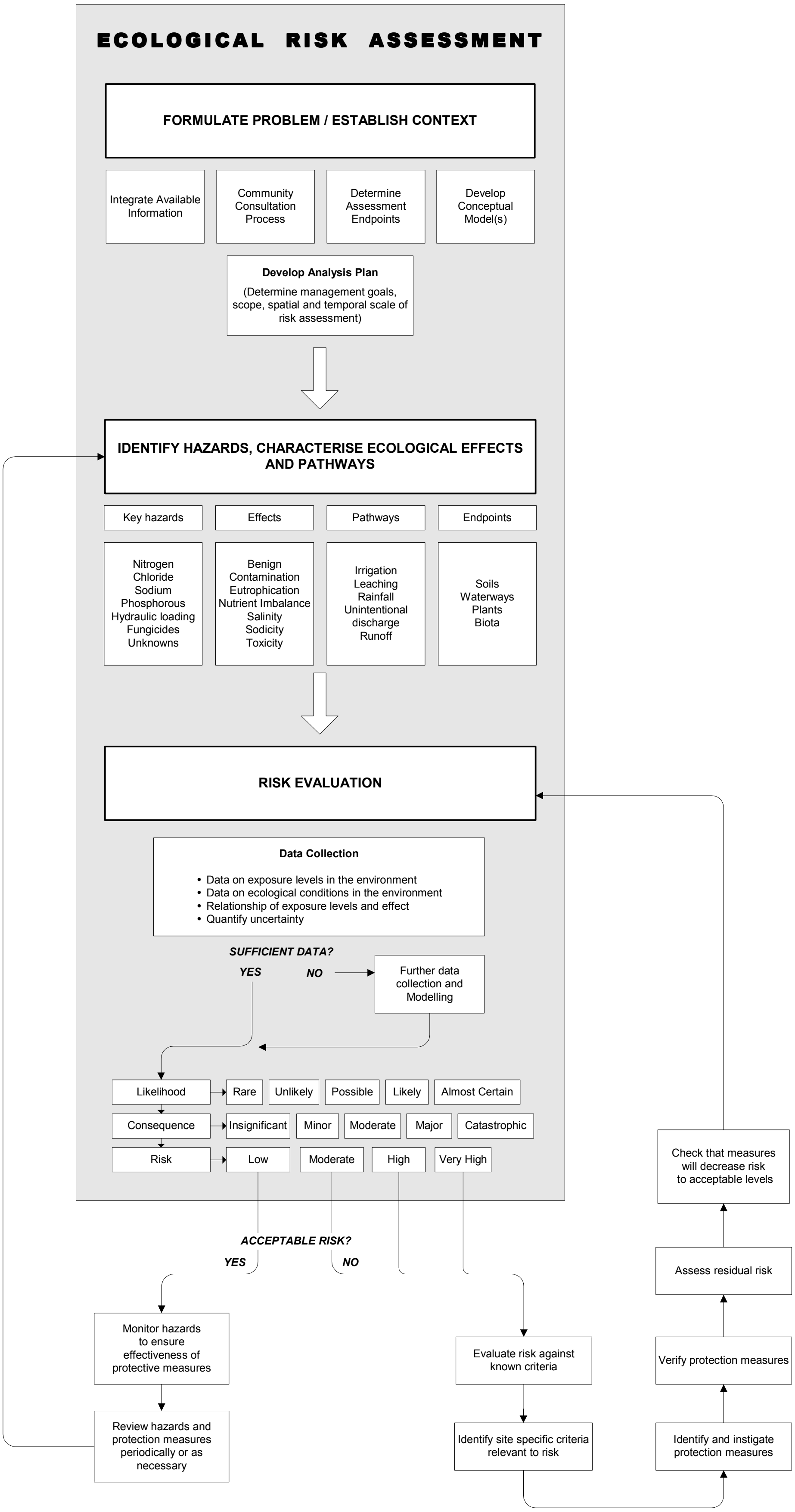

Figure 1. ERA process followed in this study, adapted from ERA process used in the National Guidelines for the use of Recycled Water (draft document) and the USEPA's ERA process in "Guidelines for Ecological Risk Assessments".

Methodology

The ERA process (Figure 2), as described by Hart *et al*. (2004), was used to develop a method to begin identifying and quantifying the risks associated with OH in the Mallee catchment area. This process highlights the cyclical nature of ERA and the approach based on continuous improvement (plan-do-check-review).

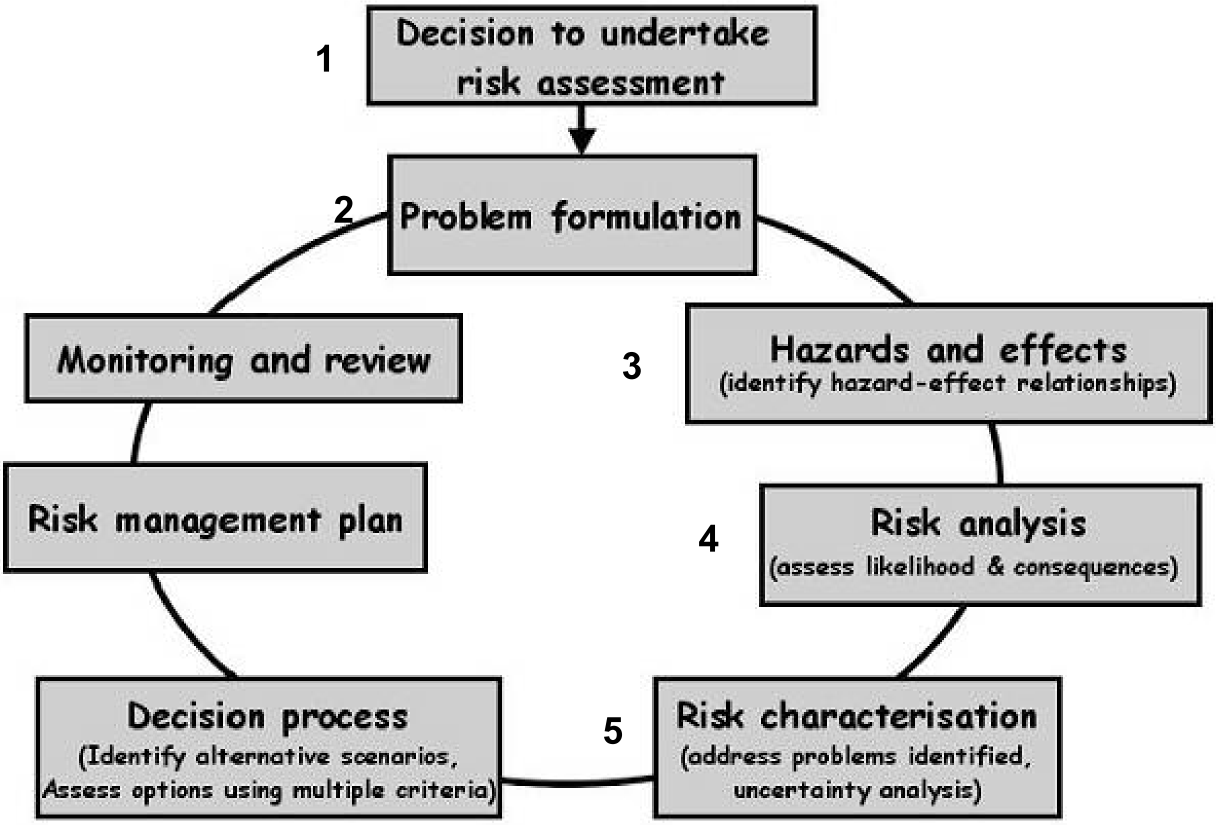

Figure 2. Risk assessment and management framework (Hart *et al.*, 2004)

1. Decision to undertake risk assessment

Land and Water Australia recognised that the growing popularity of OH necessitated a risk assessment to analyse its impact on sensitive ecosystems. A key component of Stage 1 of the project 'Open Hydroponics: Risks and Opportunities (LWA DAN22)' was the application of ERA to OH production systems and an overall assessment of the major environmental issues.

2. Problem Formulation phase

During Stage 1 of the project, a workshop on Ecological Risk Assessment was held (October 20th 2004) to explore the benefits of ERA to OH decision-making (in conjunction with Professor Barry Hart, Monash University and Dr Terry Walshe, the University of Western Australia). Workshop participants included natural resource managers, irrigation scientists, Catchment Management Authority (CMA) and viticulture and citrus industry representatives, as well as members of the community. Participants developed a generic conceptual diagram, in which an OH orchard was placed in a delicate catchment area (Figure 3). This diagram was used to facilitate the identification of 1) ecological values to be protected within affected catchments, and 2) direct and indirect effects of OH that have the potential to harm local ecosystems.

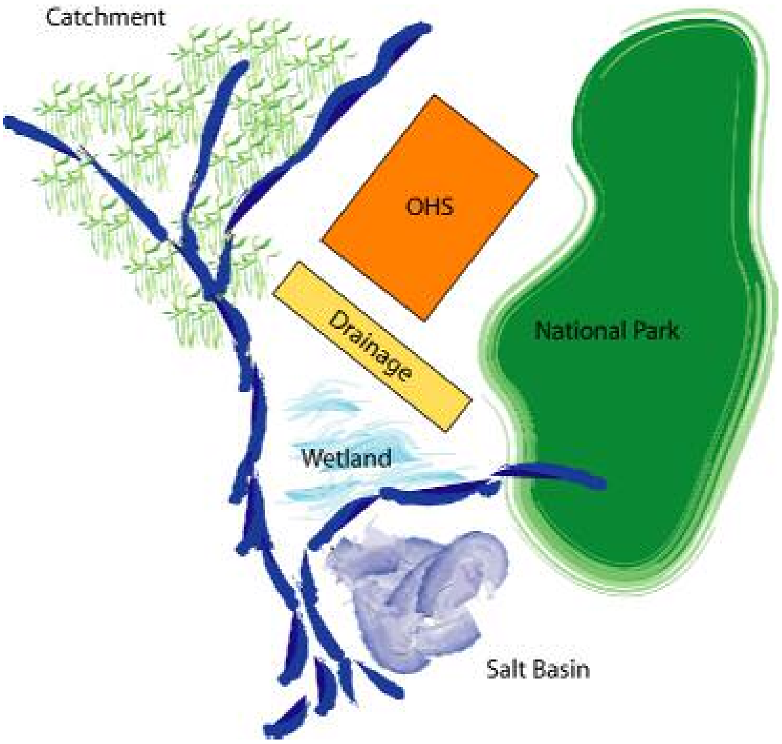

Figure 3. Conceptual diagram of OH in a generic catchment area with waterways, wetlands and a national park in the vicinity.

Although a number of ecological values were identified by the participants, a more comprehensive analysis of ecological values for the Mallee region was contained within the Mallee CMAs Regional Catchment Strategy. The Mallee CMAs primary goal is "To protect and improve the capability of land resources in the Mallee to support ecological processes, primary production and built infrastructure". Their outcomes and targets (or ecological values to be protected) are defined through the following:

1. The impact of salinity on locations and systems that are critical for conservation of biodiversity, agricultural production and community infrastructure is avoided or minimised.
2. Land management practices in place that prevent and manage land degradation (includes soil health).
3. The quality of the surface or ground water is maintained or enhanced.
4. Surface or groundwater allocated for consumptive use within the sustainable capacity of the resources.
5. Production systems (agricultural) developed that maintain or enhance water quality, and prevent and manage the impact of salinity on the water resources of the Murray River.
6. The extent, diversity and condition of aquatic riparian and floodplain ecosystems, and associated ecological processes, are protected and improved.
7. Use, development and harvesting of waterways, wetlands and floodplains managed on a sustainable basis.
8. Ecological processes restored to meet ecological needs.
9. Native vegetation on private land managed according to biodiversity outcomes.
10. The 'legacy of clearing' impacts on River Murray salinity minimised and a net reduction in other regional contributions to River Murray salinity.
11. Improved soil health.

These can be summarised into four major ecological values:

- healthy waterways (Murray River)
- healthy groundwater
- diversity of flora and fauna
- productive land.

The major ecological values (or endpoints), that could potentially be affected by OH in a delicate catchment are:

1. **Waterways,**
2. **Groundwater,**
3. **Flora and Fauna, and**
4. **Soil.**

3. Hazards and Effects

Using the conceptual diagram and the four key endpoints, the workshop participants identified a number of hazards posed by OH to an ecological system, as well as factors contributing to the risk of those hazards impacting on the system. A preliminary list of hazards was compiled:

- Fertilisers and other contaminants leaching into waterways
- Extraction of water from water courses and low river flows
- Sediment in surface water runoff and turbidity in waterways
- Salts leaching into soil and waterways leading to salinity and sodicity
- Episodic rainfall events exacerbating leaching and runoff
- Effects of contaminants on aquatic organisms
- Changes in biodiversity and parasite/disease problems
- Changes in competition/predation/interaction between flora and fauna
- Unknown components of the OH nutrient mix

The key hazards considered by the project team were:

1. **Nutrients (such as N, P and B)**
2. **Salts (Na, Cl)**
3. **Hydraulic loading**
4. **Unknowns**

These hazards pose a risk to sensitive catchments because of the potential for:

1) Leaching of nutrients into waterways (and thus eutrophication and toxicity to aquatic organisms), which could be exacerbated by increases in hydraulic loading.
2) Increased salinity and sodicity of soils from salt accumulation.

The hazards posed by the various ‘unknowns’ associated with irrigation, and particularly with OH, have been included to highlight the need for further investigation. In OH, disinfectants are used to flush out and clean irrigation lines and pesticides are sometimes used to control soil-borne pathogens. The various compounds making their way into the soil and aquatic environments must be identified so that they can be properly analysed for their potential to cause harm to the environment.

Also, while many common hazards and contributing factors were agreed upon at the workshop, other more disparate hazards were identified that were based on personal experience rather than scientific data. This served to highlight the difficulty in accurately identifying risks in an ecological system, and in evaluating the importance of uncertainties and assumptions when background data may be incomplete.

The information generated at the workshop was used to develop a series of conceptual models of the key ecological consequences of irrigation using OH. These models were combined to form a single conceptual model, which was further refined by the project team (Faggian, Boland, Goodwin) with the help of Prof Barry Hart and Dr Carmel Pollino at the Water Studies Centre, Monash University (Figure 4). The lack of data prevented the development of detailed conceptual models, but the generic model (Figure 4) served to provide context for assumptions of risk and to inform the ongoing ERA process.

The conceptual model demonstrates some of the pathways by which OH hazards may reach ecologically important endpoints (ecological values). For instance, the primary pathway for hazards is by application to soil and via water flows (surface, sub-surface and ground) to waterways. The risk of hazards reaching waterways is increased by episodic rainfall events, and could be compounded by the unintentional release of hazards through spills or waste disposal.

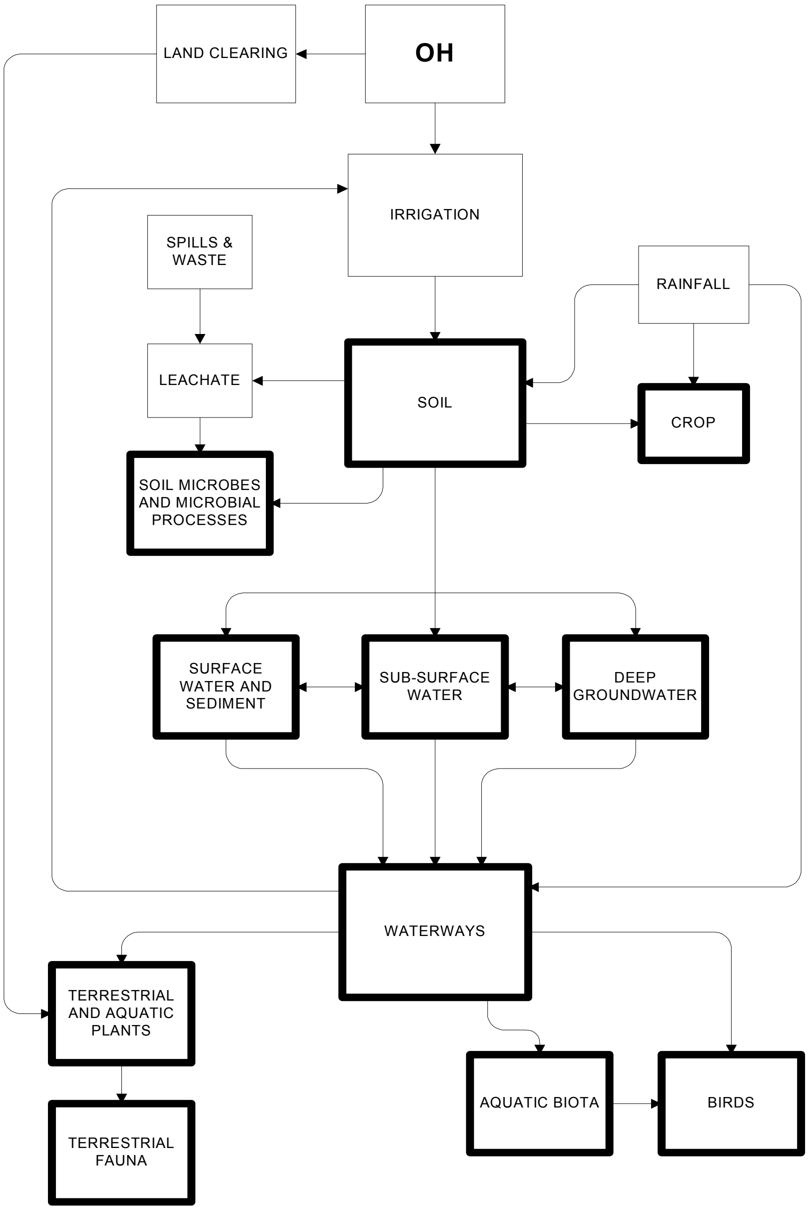

Figure 4. Conceptual model showing potential OH hazards and their pathways to ecologically important endpoints (bold).

4. Risk Analysis

The analysis of risk of individual hazards within an irrigation context has previously been conducted as part of the development of the National Guidelines for the use of ‘Environmental Risk Associated with Water Recycling”. Hazards were classified according to likelihood (rare through to certain) (Table 1a) and consequence (insignificant through to catastrophic) (Table 1b) and combined to produce a risk rating (Low, Moderate, High, Very High) (see Table 1c). Any risk rating above Low requires that remedial action or protection measures be taken to reduce the likelihood and consequences of a hazard such that a Low risk rating is achieved upon reappraisal.

Table 1a. Qualitative measures of likelihood.

Level	Descriptor	Alternatives
A	Almost Certain	Will occur in days or months
B	Likely	Will occur in years
C	Possible	Might occur in years
D	Unlikely	Could occur within 20 years
E	Rare	May occur in 100 years

Table 1b. Qualitative measures of consequence or impact.

Level	Descriptor	Alternatives
1	Insignificant	No impact or not detectable
2	Minor	Potentially harmful to local ecosystem
3	Moderate	Potentially harmful to regional ecosystem
4	High	Potentially lethal to local ecosystem
5	Very High	Potentially lethal to regional ecosystem or threatened species

Table 1c. Qualitative risk analysis matrix for determining the level of risk.

	CONSEQUENCES				
	1	**2**	**3**	**4**	**5**
Likelihood	**Insignificant**	**Minor**	**Moderate**	**Major**	**Catastrophic**
A (almost certain)	Low	Moderate	High	Very High	Very High
B (likely)	Low	Moderate	High	Very High	Very High
C (possible)	Low	Moderate	High	Very High	Very High
D (unlikely)	Low	Low	Moderate	High	Very High
E (rare)	Low	Low	Low	Low	High

As part of the ERA process the project team decided to test the application of the National Guidelines risk assessment framework. Since the National Guidelines framework has been developed with a high level of scientific rigour and refined using the available data, it provided the opportunity to analyse the hazards identified in this study. In short, for each hazard, a pathway, receiving environment, endpoint and effect is identified. The available quantitative scientific data on Likelihood and Consequence can then be applied on a case-by-case basis and fed through the ERA process to estimate risk. For instance, one of the key hazards identified in this study was salt, in the form of Sodium (Figure 5). When applied to soil with water, sodium can lead to sodicity. In this case, the **Pathway** within the OH context is irrigation (sodium-containing proprietary OHS nutrient solution added to soils via irrigation), the soil is the **Receiving Environment** and is also the **Endpoint** and the **Effect** is sodicity. According to the National Guidelines, the likelihood of this occurring can be estimated as **Possible** and the impact as **Minor,** resulting in a risk rating of **Moderate**. Given that any rating above low requires remedial action, the risk manager would need to ensure that a protection measure, such as a calcium soil amendment, was implemented before reassessing the risk.

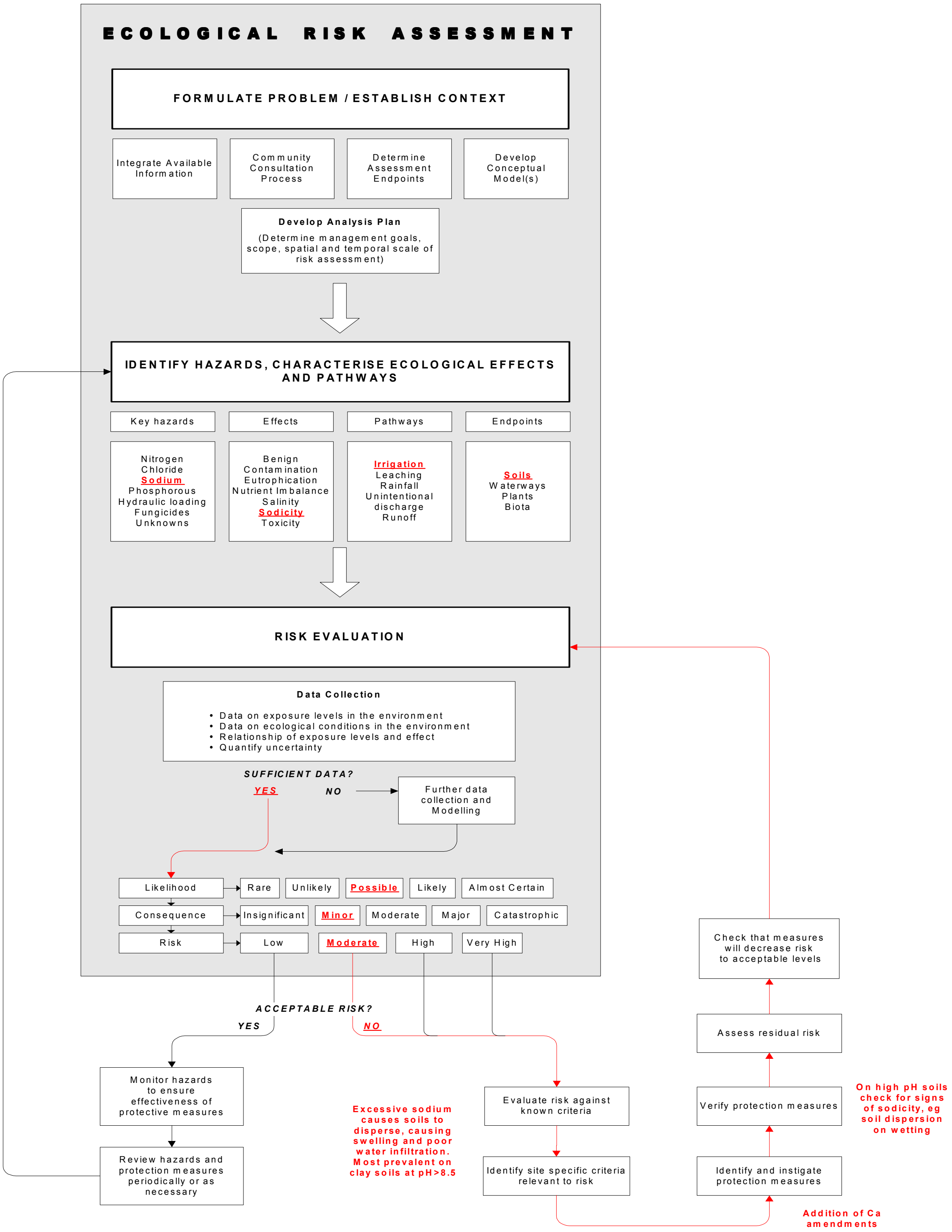

Figure 5. Risk analysis and risk characterisation using the National Guidelines approach, for sodium.

The assessment of risk using the national guidelines framework was undertaken for all major hazards previously identified (ie nutrients, salts, hydraulic loading and unknowns). The key hazards of irrigation of orchards are provided in detail (Table 2) and their likelihood, impact and risk rating is presented in Table 3 (taken from National Guidelines for Recycled Water with modifications).

Table 2. The key hazards associated with irrigation of orchards and their pathway to the receiving environment, endpoint and effect.

Hazard	Pathway	Receiving Environment	Endpoint	Effect	Comments
Boron	Irrigation	Soils	Plants	Toxicity	Boron in reclaimed water may accumulate in soils and become toxic to sensitive plants
	Irrigation & Unintentional release	Water body	Aquatic biota	Toxicity	Some aquatic organisms may be susceptible to B concentrations of 10 mg/L
Chloride	Irrigation	Soil	Plants	Toxicity	With repeated irrigations Cl may build up in the soil if not leached out. It then accumulates in plant leaves, causing toxicity. Is also a component of salinity.
	Irrigation	Water Body	Aquatic biota	Toxicity	Concentrations of chloride are unlikely to be high enough to cause direct toxicity?
Hydraulic loading	Irrigation	Soil	Plants	Water Logging	
			Water - ground	Salinity	Dependent on size of scheme and other inputs to regional groundwater
Nitrogen	Irrigation	Soil	Plants	Nutrient Imbalance	
		Water body	Water - ground	Contamination	
		Water body	Water - surface	Eutrophication	
	Unintentional release	Soil	Plants	Toxicity	Discharges on to locally significant natural ecosystems need to be minimised as nutrient enrichment may impact on values
	Unintentional release	Water body	Water - surface	Eutrophication	Run off from overflowing dams or burst pipes could result in nutrient enrichment of waterways
Phosphorous	Irrigation	Soil	Plants	Toxicity	In cases where excess P is applied, and pH is <7, excess P may precipitate Fe, resulting in Fe deficiency. Alternatively, many plants native to sandy soils in Australia are sensitive to P enriched environments
		Water body	Water - ground	Toxicity	In sandy soils phosphate may leached if provided in excess of soil phosphorus retention capacity
		Water body	Water - surface	Eutrophication	
	Unintentional release	Soils	Plants	Toxicity	Run off to native vegetation may result in nutrient enrichment and significant changes in growth and survival of native species and incursion of weeds

Table 2 continued.

		Water body	Water - surface	Eutrophication	Small changes in P concentrations in waterways can result in algal blooms, a major environmental problem
Salinity	Irrigation	Soils	Plants	Salinity	
Sodium	Irrigation	Soils	Soils	Sodicity	Excessive sodium causes soils to disperse, causing swelling and poor water infiltration. Most prevalent on clay soils at pH>8.5
Unknowns	Irrigation & Unintentional release	?	?	?	Information about the ingredients of the proprietary OHS nutrient mixes is not freely available and may contain harmful compounds (eg. pesticides)

Table 3. The key hazards associated with irrigation of orchards and their likelihood of occurring, consequence and risk rating.

Hazard	Pathway	Receiving Environment	Endpoint	Likelihood	Consequence	Risk
Boron	Irrigation	Soils	Plants	Possible	Moderate	High
	Irrigation & Unintentional release	Water body	Aquatic biota	Rare	Minor	Low
Chloride	Irrigation	Soil	Plants	Possible	Moderate	High
	Irrigation	Water Body	Aquatic biota	Rare	Minor	Low
Hydraulic loading	Irrigation	Soil	Plants	Possible	Minor	Moderate
			Water - ground	Possible	Moderate	High
Nitrogen	Irrigation	Soil	Plants	Possible	Minor	Moderate
		Water body	Water - ground	Possible	Moderate	High
		Water body	Water - surface	Unlikely	Moderate	Moderate
	Unintentional release	Soil	Plants	Rare	Insignificant	Low
	Unintentional release	Waterbody	Water - surface	Rare	Minor	Low
Phosphorous	Irrigation	Soil	Plants	Rare	Minor	Low
		Water body	Water - ground	Rare	Minor	Low
		Water body	Water - surface	Rare	Minor	Low
	Unintentional release	Soils	Plants	Possible	Moderate	High
		Water body	Water - surface	Possible	Moderate	High
Salinity	Irrigation	Soils	Plants	Likely	Moderate	High
Sodium	Irrigation	Soils	Soils	Possible	Minor	Moderate
Unknowns	Irrigation & Unintentional release	?	?	?	?	?

5. Risk Characterisation

Going through the risk assessment process allowed risks to be ranked (Table 4) for prioritisation and characterisation.

The major risks identified in this study to sensitive catchments from irrigation include:

1) Leaching of nutrients into waterways, resulting in eutrophication and toxicity to aquatic organisms. Leaching could be exacerbated by increases in hydraulic loading through irrigation management practices or episodic rainfall events.
2) Increased levels of boron in the soil.
3) Increased salinity and sodicity of soils from salt accumulation, which may be less of a problem in sandy soils, but could be a serious issue in heavier soils.
4) The various compounds often associated with irrigation/horticulture such as pesticides and cleaning agents, whose identity and pathways remain unknown.

Table 4. Hazards ranked as a 'high' risk to sensitive Mallee catchments, as well as unknowns hazards.

Hazard	Pathway	Receiving Environment	Endpoint	Likelihood	Impact	Risk
Boron	Irrigation	Soils	Plants	Possible	Moderate	High
Chloride	Irrigation	Soil	Plants	Possible	Moderate	High
Hydraulic loading	Irrigation	Soil	Water - ground	Possible	Moderate	High
Nitrogen	Irrigation	Water body	Water - ground	Possible	Moderate	High
Phosphorous	Unintentional release	Soils	Plants	Possible	Moderate	High
		Water body	Water - surface	Possible	Moderate	High
Salinity	Irrigation	Soils	Plants	Likely	Moderate	High
Unknowns	Irrigation & Unintentional release	?	?	?	?	?

OH versus Traditional Irrigation ?

It is difficult to compare OH and traditional irrigation practices, with respect to ERA or any other scientific study, without the appropriate data. Data from traditional irrigation is very limited and data from OH irrigation is not in the public domain. Broadly speaking however, the hazards posed by conventional irrigation and OH are similar. Leaching of nutrients, increased boron levels and salt levels in soil, and soil sodicity are concerns common to both irrigation practices. Unique to OH are the potential hazards posed by the various unknowns that may be components of individual systems, and the increased threat to virgin land from new OH developments (since OH reduces the function of soil to no more than a substrate to hold plants upright, it becomes feasible to establish OH orchards on land previously considered too marginal for citrus crops).

It is possible, however, to compare two OH irrigation scenarios using the information generated by mathematical modelling in the "Water, Nutrient and Salt Balance Simulations" section of this report. The 'fixed irrigation' scenario was defined as irrigation that is operated every day for a set duration and adjusted monthly according to average daily crop evapotranspiration (ET_c). Accurate estimates of average daily ET_c were required to avoid plant water stress. Nitrogen leakage was low when the amount of nitrogen applied matched crop requirement and sufficient salt leaching occurred. The 'flexible irrigation' scenario was defined as irrigation that was operated when the soil water content (SWC) declined to a set threshold. Flexible irrigation had the capacity to contain drainage and nutrients, but this increased the likelihood of nitrogen and salt accumulation in the wetted zone, and therefore also increased the likelihood of leaching during rainfall. Strategic leaching was recommended.

From an ecological risk point of view, flexible irrigation poses the greater risk. It requires sophisticated management skills to accurately monitor and respond to SWC and plant nitrogen uptake efficiency, and to carry out appropriate strategic leaching. Even in the event of good management, leaching of salts and nutrient is still more likely than not during rainfall events.

Conclusions

The ERA was a useful process to prioritise risks of irrigation of orchards within the context of sensitive Mallee ecosystems and enabled the identification of key information gaps and data requirements. The ERA process provides a systematic means of characterising a potential environmental hazard (ie irrigation) using a process of scientific and community consultation. The development of conceptual models quickly identifies real pathways where a hazard might reach sensitive ecological systems, and in the process eliminates emotive or anecdotal risks.

The risk analysis step is a rigorous method that relies on quantitative data to assess the likelihood and impact of hazards. In the case of ERA, qualitative and subjective data will always form a component of the data set due to the complex nature of ecological systems. This is dealt with by explicitly stating the uncertainties and assumptions made in all steps of the ERA. The approach taken for the draft national guidelines on recycled water proved to be useful for the application of risk assessment for irrigated horticulture.

Recommendations

1. ERA can provide rigorous assessment at a catchment scale. The process should be undertaken by natural resource managers with the appropriate expertise rather than individual businesses.

2. The ERA process provided clear identification of information gaps when considering the effects of OH. These information gaps should be addressed through appropriate monitoring programs.

3. It is expected that OH will decrease the likelihood of environmental impacts but could potentially increase the consequence (ie something going wrong could have a significant impact). The resultant risk will be dependant upon the skills of the manager and the adoption of sustainable management practices. To assess the severity of these risks it would be possible to conduct scenarios analysing management practices and validating this through monitoring.

4. Given the significant impact of management skills on environmental impacts it is critical that a program defining sustainable management be developed that includes specific management practices and monitoring requirements.

Next Stage

Stage 2 of the project should focus on a comparison of the risks of OH and conventional irrigation, using the full ERA approach. In order to carry out such a comparison, processes need to be established (i.e. secrecy/commercial agreements) that allow the collection of quantitative data from field sites or trial sites. In either case, significantly more information about the proprietary nutrient mixes used in the OH system must be released to the scientific community to enable the risks to be analysed fully. In some instances, data collection will be impossible or impractical, in which case theoretical modelling will provide a reliable alternative.

This assessment has used irrigation as the starting point. In the absence of any data it was not possible to compare an OH with traditional irrigation. The establishment of Bayesian networks to incorporate quantitative data would enable proper risk assessment. These preliminary results concur with Goodwin (this report) on potential problems of salinity, nutrient leakage and sodicity, which were based on the irrigation simulations using simple mathematical models. It would be possible to incorporate these simple models into a Bayesian network to provide semi-quantitative data and fill knowledge gaps.

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