QUESTION 1

Roadmap

What is the current extent of dryland salinity and its risk of spread?

- **Why is this question important?**
- **What did we know in 1998?**
  - NDSP Phase I (1993–1998)
    - Assessing the causes, impacts, costs and management of dryland salinity (Page 8)
    - Understanding dryland salinity (Page 9)
- **What advances have we made since?**
  - NLWRA (1997–2002)
    - Mapping dryland salinity hazard and risk (Page 9)
    - Building on the National Classification of Catchments (Page 17)
  - Groundwater flow systems
    - Developing the Groundwater Flow Systems Framework (Page 14)
    - Using groundwater flow systems to compile information on salinity risk (Page 17)
  - Data
    - Mapping methods for salinity (Page 21)
    - Knowing where the salt is stored (Page 21)
    - Assessing salinity hazard and risk at the State level (Page 22)
    - Assessing salinity in cropping areas (Page 24)
    - Accounting for climate variability (Page 25)
    - Understanding the status of groundwater (Page 25)
    - Scoping groundwater recharge in the rangelands (Page 28)
  - Modelling capability
    - Using the right model for the task (Page 28)
- **Where to from here?**

QUESTION 1

What is the current extent of dryland salinity and its risk of spread?

DEFINITIONS[1]**:**

Hazard – Anything that can potentially cause harm to an asset. The word 'threat' is often used interchangeably.

Risk – The chance that hazard will cause harm to an asset at some time in the future. Risk is typically defined as an impact multiplied by its likelihood of occurrence at some given time in the future.

WHY IS THIS QUESTION IMPORTANT?

To address dryland salinity and its impacts, including in-stream salinisation, it is necessary to first understand how much salinity we have, where it occurs in the landscape and its risk of expansion. This question considers dryland salinity extent and risk at the landscape rather than property or paddock level.

Mapping of the extent and risk of dryland salinity at an extensive scale is used for strategic planning. It enables comparison between States or between major catchments. Finer scale assessment and mapping enables comparison between sub-catchments within each major catchment.

This sort of mapping and its associated information provide a 'big picture' view of where the serious dryland salinity problems are. This facilitates good planning and policy-making by enabling the setting of sensible targets to protect valuable resources at risk from salinisation, including cultural assets, and the efficient allocation of limited resources for both research investigations and on-ground investments.

It is important to use our understanding of dryland salinity extent and risk to guide investment in planning and management. The problem in Australia is considerable, and protection and remediation of all parts of the landscape where dryland salinity is an issue is not viable. In this light, a surgical 'triage' approach of better targeting public investment to protect the highest value assets is needed. Measures also need to be put in place to help communities where living with salinity, including the productive use of saline resources, is the only viable option.

WHAT DID WE KNOW IN 1998?

In 1998, when NDSP reported on the outcomes of its first phase of research and activities, it wasn't possible to provide a comprehensive overview of the current extent and risks of dryland salinity and its risk of spread.

Chapter 2 in *Assessing the causes, impacts, costs and management of dryland salinity*[2] titled 'What are the options for mapping the current extent and risk of dryland salinity in my catchment?' focused on the available methods and tools for mapping salinity, rather than defining current extent and risk. While that chapter continues to be a relevant reference for understanding many of the methods and tools available for salinity mapping (albeit, with emphasis at property level), a more current user-friendly guide and associated technical report are described under 'Mapping methods for salinity' (section 1.3.1).

The following factors were considered:

- Defining the problem to be mapped
- Finding out what is already known
- Using visual observations
- Sampling your water and soil
- Checking out your water table

- Choosing suitable remote mapping techniques
  - Aerial photography
  - Satellite remote sensing
  - Airborne multi-spectral scanning (MSS)
  - Airborne geophysics
- Choosing ground-based mapping techniques
  - Electromagnetic techniques
  - Other ground-based methods
- Linking with groundwater information
- A case study of the Upper Kent River catchment in Western Australia.

While maps and databases were available to varying degrees across catchments and for individual States in 1998, data custodianship was uncoordinated, and access to information was difficult. Piecing information together at a State and National scale, understanding the gaps and deficiencies, and making data more readily available was a major task that lay ahead.

Some progress with establishing datasets for the Murray–Darling Basin to inform dryland salinity management was made by 1998 with the *Basin-wide vegetation datasets*[3] and *Murray–Darling Basin Soil Information Strategy*[4] projects; however both datasets have significant limitations. The *NSW Dryland salinity hazard*[5] project produced the first statewide dryland salinity map based on a 'weights of evidence' approach and GIS manipulation, and showed areas of major concern for more detailed investigations.

The importance of having a national perspective on dryland salinity to inform regional planning and management only emerged in the late 1990s. *Assessing the causes, impacts, costs and management of dryland salinity* discussed the notion of a 'National Catchment Categorisation System' or the 'National Classification of Catchments'[6] to 'readily extrapolate management results from those more intensively studied catchments to assess salinity risk and determine appropriate salinity management options in other catchments'. The National Classification of Catchments approach was similarly conveyed in *Understanding dryland salinity*.[7] This system became the building block for the *Groundwater Flow Systems Framework*[8] (highlighted in the Introduction) — an operational framework now in use for assessing dryland salinity risk.

The groundwater and farming systems models described in *Assessing the causes, impacts, costs and management of dryland salinity* — FLOWTUBE, HARSD, MODFLOW, PERFECT, APSIM, WAVES, TOPOG — are still used to assess risk and management options, although further refinements have taken place. Water balance models are described in detail in Question 4.

WHAT ADVANCES HAVE WE MADE SINCE?

1.1 National Land & Water Resources Audit (1997–2002)

1.1.1 Mapping dryland salinity hazard and risk

The estimates of shallow water tables and salinity hazard brought together by the Audit[9] presented the first comprehensive snapshot of extent and risk across Australia based on State studies. This was a great feat in combining data from a variety of sources, putting it on one map and providing a set of estimates for planners and policy-makers to work with. It highlighted the significance of dryland salinity as a natural resource management issue.

QUESTION 1

Salinity strategic planning and the development of action and investment plans at National, State and regional levels were given renewed importance by the findings of the Audit. In particular, this was reinforced by the National Action Plan (NAP) for Salinity and Water Quality launched in November 2000 by the Australian Government.

The Audit used regional-scale, dryland salinity risk or hazard assessments undertaken by State/Territory agencies drawing on:

- Information on groundwater levels and trends
- Known incidence of salinity
- Soil characteristics
- Topography.

Risk assessments were undertaken for New South Wales[10], Western Australia[11], South Australia[12] and Victoria[13] where sufficient data enabled an understanding of shallow water table behaviour. However, a consistent approach was not always applied in these assessments.

In Queensland[14] and Tasmania,[15] *hazard* assessments were undertaken as data on groundwater levels and trends were sparse, requiring greater reliance on knowledge of dryland salinity incidence and land features. For the Northern Territory,[16] the Audit used information from a hazard assessment of dryland salinity undertaken in 1994.

Areas considered to be of very low risk were not assessed, including most of the non-agricultural area in Western Australia, South Australia and western New South Wales.

Dryland salinity risk and hazard estimates for the year 2050 were compiled into a single map. It shows about 5.7 million hectares of agricultural and pastoral land with dryland salinity (through shallow water tables), increasing to 17 million hectares by 2050 in the absence of effective action (see Figure 1.1). Table 1.1 shows the breakdown of these estimates by States; however it should be noted that some States have undertaken finer resolution assessments since this time. These assessments are discussed in more detail in section 1.3.3.

The map shows large tracts in the Murray–Darling Basin in South Australia, Victoria and New South Wales at risk, together with the agricultural zone of south-west Western Australia. Over four million hectares of south-west Western Australia were assessed to be at risk. This area was predicted to double by 2050. These assessments were based on existing data held by States and constrained by financial resources and available time. Priorities for improving the groundwater data quality and coverage across States were exposed by the assessment process.

While confidence in different parts of the maps varies, it generally points to the need for land use change and management to address salinity, and where that change may need to take place. It is also helpful in targeting where more detailed assessments are needed. Confidence in the estimates is variable in southern Australia, but greater than in northern Australia where groundwater data is very sparse to non-existent.

Dryland salinity is an emerging problem in northern Australia. Water balance changes in catchments with high salt stores have the potential to mobilise salt. An estimated 3.1 million hectares in Queensland was assessed as facing a high hazard.

The specific definitions of 'Hazard' and 'Risk' used in the Audit assessments vary between States. For example, the following definitions have been established in NSW:

Dryland salinity hazard is the extent to which natural physical characteristics, excluding land cover, predispose a landscape to salinisation. Relevant characteristics include topography, soils, geology and climate.

Dryland salinity risk is a measure of the likelihood of salinity occurring as a result of land use and other activities and of the severity of the impacts (economic, social and environmental costs) caused by that salinity (Risk = likelihood x consequence).
A change in land use or management practice can either reduce or increase risk.

Figure 1.1

Forecasted areas containing land of high hazard or risk of dryland salinity in 2050

(Source: Commonwealth of Australia, 2001, *Dryland salinity in Australia: National Land & Water Resources Audit's Australian Dryland Salinity Assessment 2000 – Extent, impacts, processes and management options.* National Land & Water Resources Audit, Canberra ACT.)

Table 1.1

Areas at high risk from shallow water tables or with a high salinity hazard by State

(Source: Commonwealth of Australia, 2001, *Dryland salinity in Australia: National Land & Water Resources Audit's Australian Dryland Salinity Assessment 2000 – Extent, impacts, processes and management options.* National Land & Water Resources Audit, Canberra ACT.)

STATE*	**1998–2000# (ha)**	**2050# (ha)**
Western Australia	4,363,000	8,800,000
Victoria	670,000	3,110,000
South Australia	390,000	600,000
New South Wales	181,000	1,300,000
Tasmania	54,000	90,000
Queensland	not assessed	3,100,000
TOTAL	**5,658,000**	**17,000,000**

* The ACT and Northern Territory were excluded from the assessment on the basis of very minor salinity issues
# Finer resolution assessments have been made since this time and are discussed in section 1.3.3

The map-making facility provided on the Audit's web-site (www.nlwra.gov.au) can be used to generate dryland salinity maps of risk and hazard for individual States or catchments. An example for the midlands region of Tasmania is shown in Figure 1.2.

Figure 1.2

Predicted dryland salinity extent for the Midlands region of Tasmania in 1999–2000

(Source: www.nlwra.gov.au)

ACTION #1.1

Review data, information, reports and maps on the current extent of dryland salinity and its risk of spread compiled by the Audit relevant to your catchment, but with due consideration to work that has taken place since.

The key messages on dryland salinity risk and hazard arising from the Audit are:

- There is no quick fix — salinity can be managed by prevention, treating the cause, ameliorating the symptoms, living with it or a combination of these
- Salinity management requires knowledge about soil, salt, water and vegetation integrated with knowledge about groundwater flow systems
- Hazard assessment has confirmed that large areas of the tropics and sub-tropics have potential salinity problems if clearing occurs
- Broad-scale land clearing with little or no regard for the salinity hazard is a recipe to repeat the problems of temperate Australia
- Assessment of areas identified as having a hazard, particularly areas of extensive clearing in central and southern Queensland, is essential, and would underpin the development and implementation of vegetation management policies and guidelines
- Opportunity exists for a major national, well-focused investment in preventive action in northern Australia.

The availability of information on current extent and risk through the Audit has stimulated interest and debate around Australia about the importance of dryland salinity, the accuracy of data, the critical gaps in information and the need to more efficiently allocate resources. Water resources issues, such as The Living Murray Initiative (www.thelivingmurray.mdbc.gov.au) and the allocation of environmental flows, are also driving the need to better integrate dryland salinity management with other natural resource issues. While our understanding is still far from adequate, especially at the catchment planning level, managers and investors have a much better picture of where to focus their efforts and resources than in 1998.

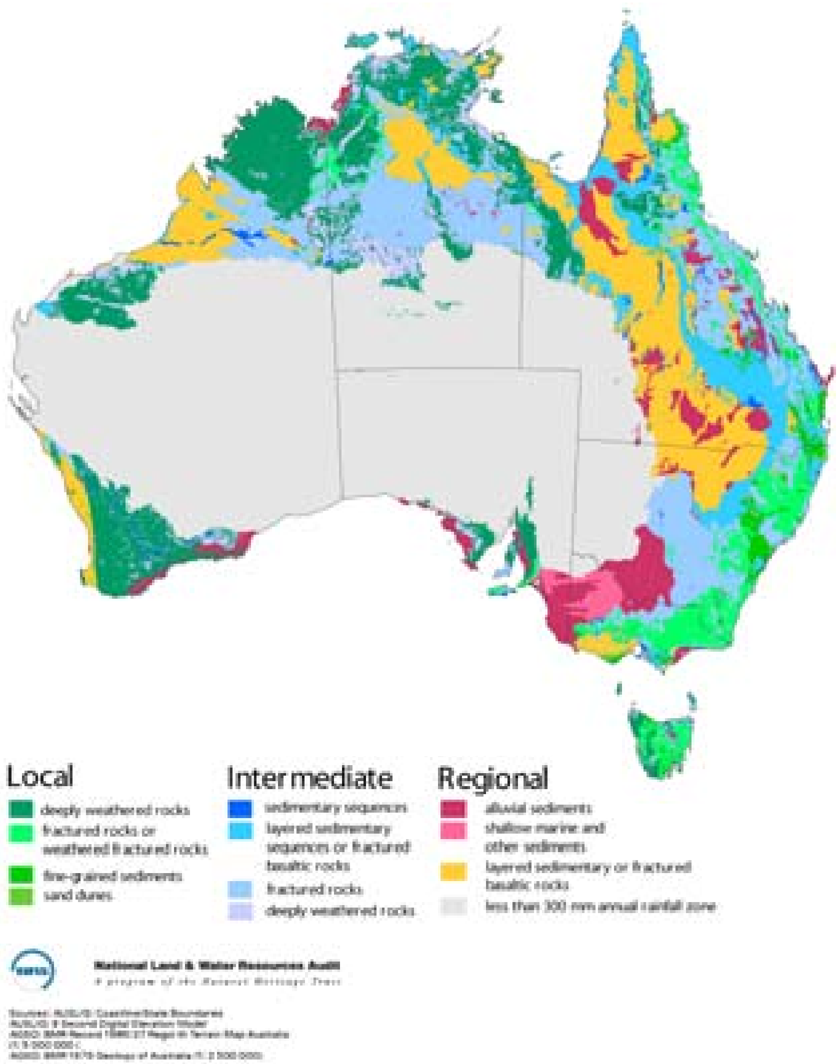
1.1.2 Building on the National Classification of Catchments

The Audit produced two 1:5,000,000 resolution maps of groundwater flow systems across Australia — the first representing the three major groundwater flow system types, and the second (see Figure 1.3) showing 12 sub-systems (3 of the 15 sub-systems described in the *National Classification of Catchments* could not be mapped at this scale). The three major groundwater flow systems are based on spatial extent and influence. A system with greater spatial extent has slower responsiveness to any changes in water balance and therefore presents a higher risk, as reversing the process is inherently more difficult.

Figure 1.3

Twelve major groundwater flow sub-systems in Australia at 1:5,000,000

(Source: Commonwealth of Australia, 2001, *Dryland salinity in Australia: National Land & Water Resources Audit's Australian Dryland Salinity Assessment 2000 – Extent, impacts, processes and management options.* National Land & Water Resources Audit, Canberra ACT.)



ACTION #1.2

Review data, information and reports on groundwater flow systems compiled by the Audit (www.nlwra.gov.au)

The mapping of groundwater flow systems embodies an understanding of the causes and processes of dryland salinity, as reflected in the five case study catchments outlined in Question 2 (section 2.1.2). The Audit describes the three major groundwater flow systems types accordingly:

- *Local groundwater flow systems* (<5 km in length) respond rapidly to increased groundwater recharge. Water tables rise rapidly and saline discharge typically occurs within 30 to 50 years of clearing native vegetation.
- *Intermediate groundwater flow systems* (5–50 km) have a greater storage capacity and generally higher permeability than local systems. They take longer to 'fill' following increased recharge. Increased discharge typically occurs within 50 to 100 years of clearing of native vegetation.
- *Regional groundwater flow systems* (>50 km) have an even higher storage capacity and permeability. They take much longer to develop increased groundwater discharge than local or intermediate flow systems – probably more than 100 years after clearing the native vegetation. The full extent of change may take thousands of years.

While a map of groundwater flow systems alone is not sufficient to assess dryland salinity risk or hazard, it provides an indication at the broadest level of potential exposure to risk from removing deep-rooted, perennial vegetation without further knowledge of catchment characteristics, such as the location of salt stores. Risk ratings can also be assigned to the various attributes that characterise a particular groundwater flow system (e.g. aquifer transmissivity, specific yield, catchment size), resulting in overall risk ratings for dryland salinisation, water salinity and salt load.

1.2 Groundwater flow systems

1.2.1 Developing the Groundwater Flow Systems Framework

Since the National Land & Water Resources Audit report on salinity, the 'Catchment Classification' project has produced a 1:1,000,000 resolution map of groundwater flow systems for the Murray–Darling Basin (see Figure 1.4) and drawn together and summarised the lessons from nine case study catchments across Australia (discussed in Question 2, sections 2.1.2 and 2.2.1) in the publication *Groundwater Flow Systems Framework – Essential tools for planning salinity management.*[17]

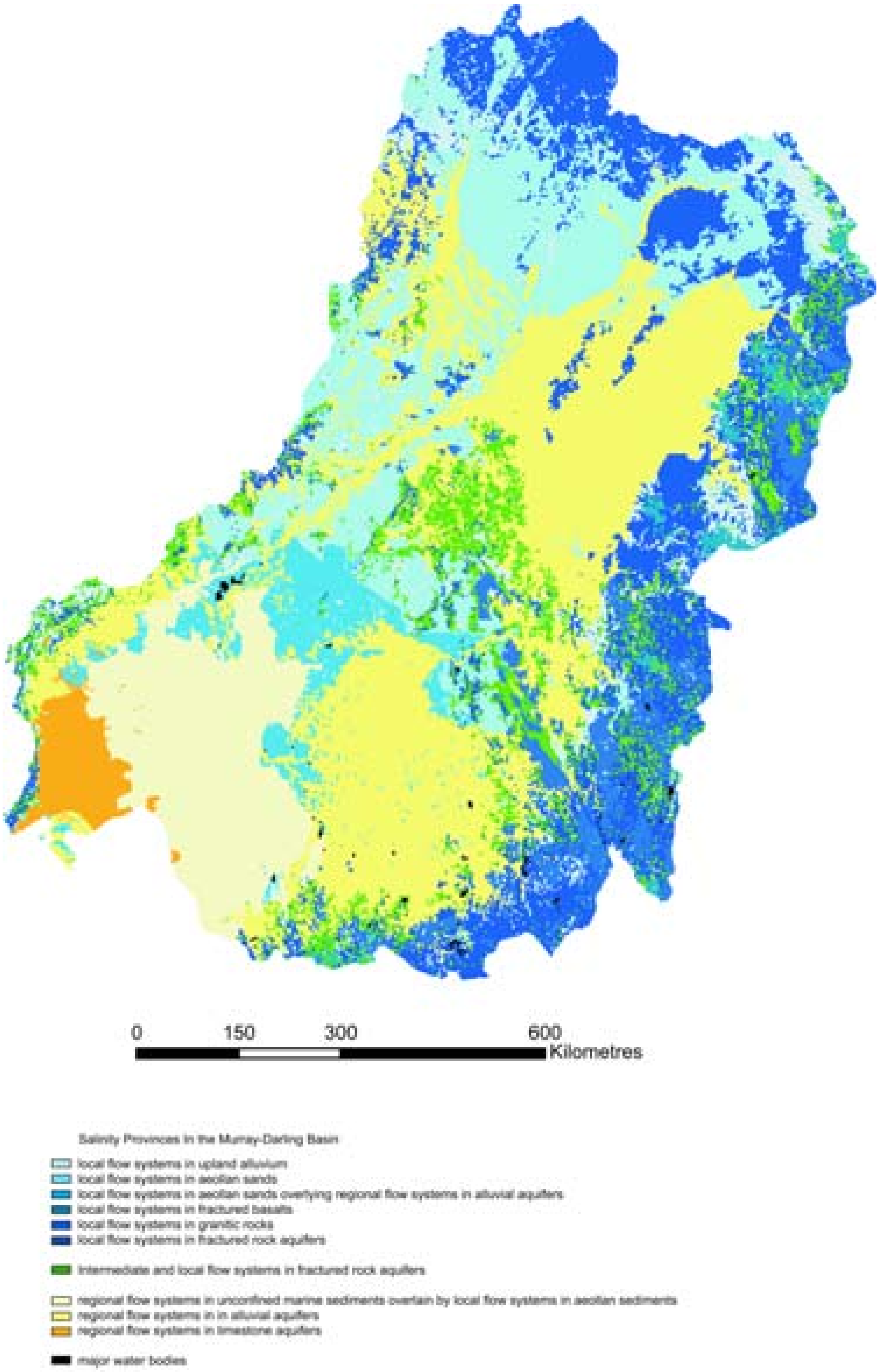
The framework provides all the key elements of a valuable and credible tool for salinity managers:

- An understanding of the causes of salinity – how groundwater recharges, mobilising salt, in response to changes in land use and management
- Conceptual models that describe groundwater processes leading to discharge
- Sound methodology for mapping the different groundwater flow systems
- Case studies where groundwater processes have been closely studied and model predictions tested and validated
- Groundwater and surface water data along with quantitative descriptions of hydro-geological features.

Figure 1.4

Murray–Darling Basin groundwater flow system map at 1:1,000,000 resolution

(Source: Walker G., Gilfedder M., Evans R., Dyson P., and Stauffacher M., 2003, *Groundwater flow systems framework: Essential tools for planning salinity management*, MDBC Publication 14/03, Murray–Darling Basin Commission, Canberra ACT.)



We now have a consistent method for mapping the landscape into distinct groundwater flow systems and associating these with conceptual models (see Figure 1.5). Importantly, we can describe in broad terms how groundwater functions in each part of the landscape. From this we can identify the typical processes leading to dryland salinity. In doing so, we can use the *Groundwater Flow Systems Framework* to prioritise catchments, propose options for managing them, and predict the most likely outcomes. These aspects of the framework are discussed in the chapters that follow.

The approach to using groundwater flow systems was modified in Western Australia to account for the dominance of salinity within local groundwater flow systems of similar geologic origin. Areas of like process, management action and risk have been grouped into 31 soil landscape zones[18]. These zones were used as the basis for assessing the impact of management options and quantifying the benefits of actions between zones (see further detail in section 5.2 — Salinity Investment Framework).

In catchments where there is a need and an established benefit, groundwater flow systems can be taken to paddock scale using airborne geophysics and associated systems of ground-based analysis[19]. Paddock-scaled resolution of soil, regolith, salt store and geology can be derived by use of these systems. Clear management objectives need to be established prior to planning for such levels of planning and action.

ACTION #1.3

Read the six-page summary of the Groundwater Flow Systems Framework, *and understand its strengths and limitations in guiding your salinity management planning.*

Groundwater flow systems may be 'nested'; for example, a local groundwater flow system may overlie a regional groundwater flow system, and these systems may or may not be connected. There are also very real limits to how reliably we can expect to transfer principles from one well-studied catchment to another that appears similar but is not well described.

This approach suggests that there is no 'one-size-fits-all' solution to dryland salinity. We should not be surprised to find, in such a vast and diverse landscape, that some catchments might not fit neatly into our catalogue of groundwater flow systems. But we now have a set of models that help us interpret and describe groundwater behaviour at a variety of scales.

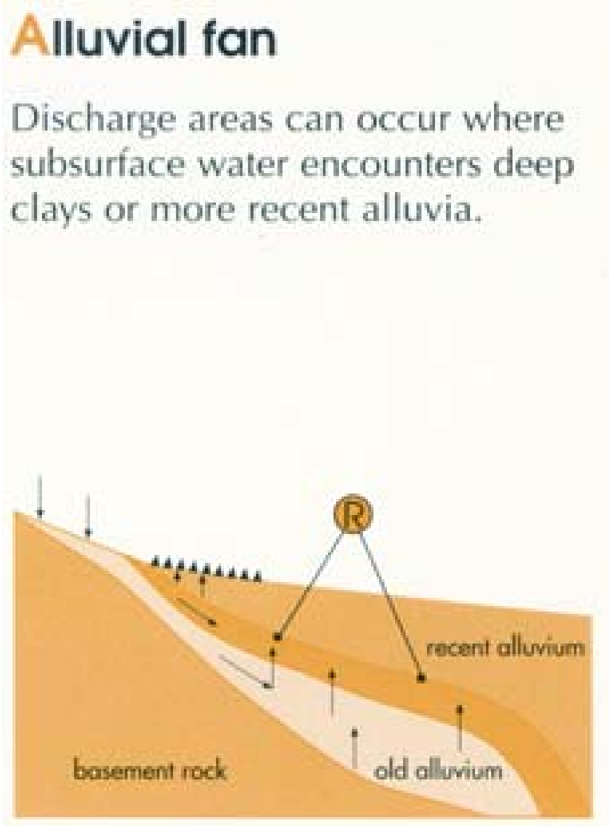
In some instances we might find that the variability within a groundwater flow system is actually greater than the variability between different systems, providing a significant challenge to our classification scheme. Whilst we could remedy this by describing further catchment sub-systems, it comes at a price. The increasing detail and complexity negates the multiplier benefits of extrapolating knowledge from a few catchments to many that should be similar.

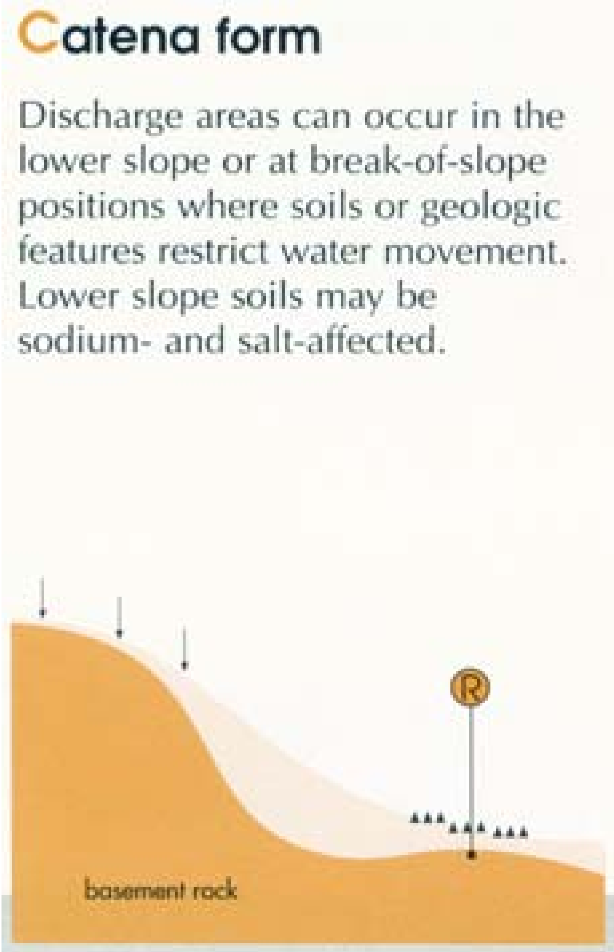
The current knowledge developed under the groundwater flow systems banner is a starting point that introduces the concept and places an approach in front of those charged with management. The classification of catchments allows for broad policy development and regional prioritisation of management options. However, we will require more complex tools as we focus in on key areas for more detailed assessment of options.

Figure 1.5

An example of local groundwater flow systems where the movement of water is often occurring within the upper 2–5 metres of the soil profile — 'Alluvial fan' and 'Catena form' salinity types

(Source: Department of Natural Resources Queensland, 1997, *Salinity management handbook.* Scientific Publishing, Resource Sciences Centre, Coorparoo QLD.)





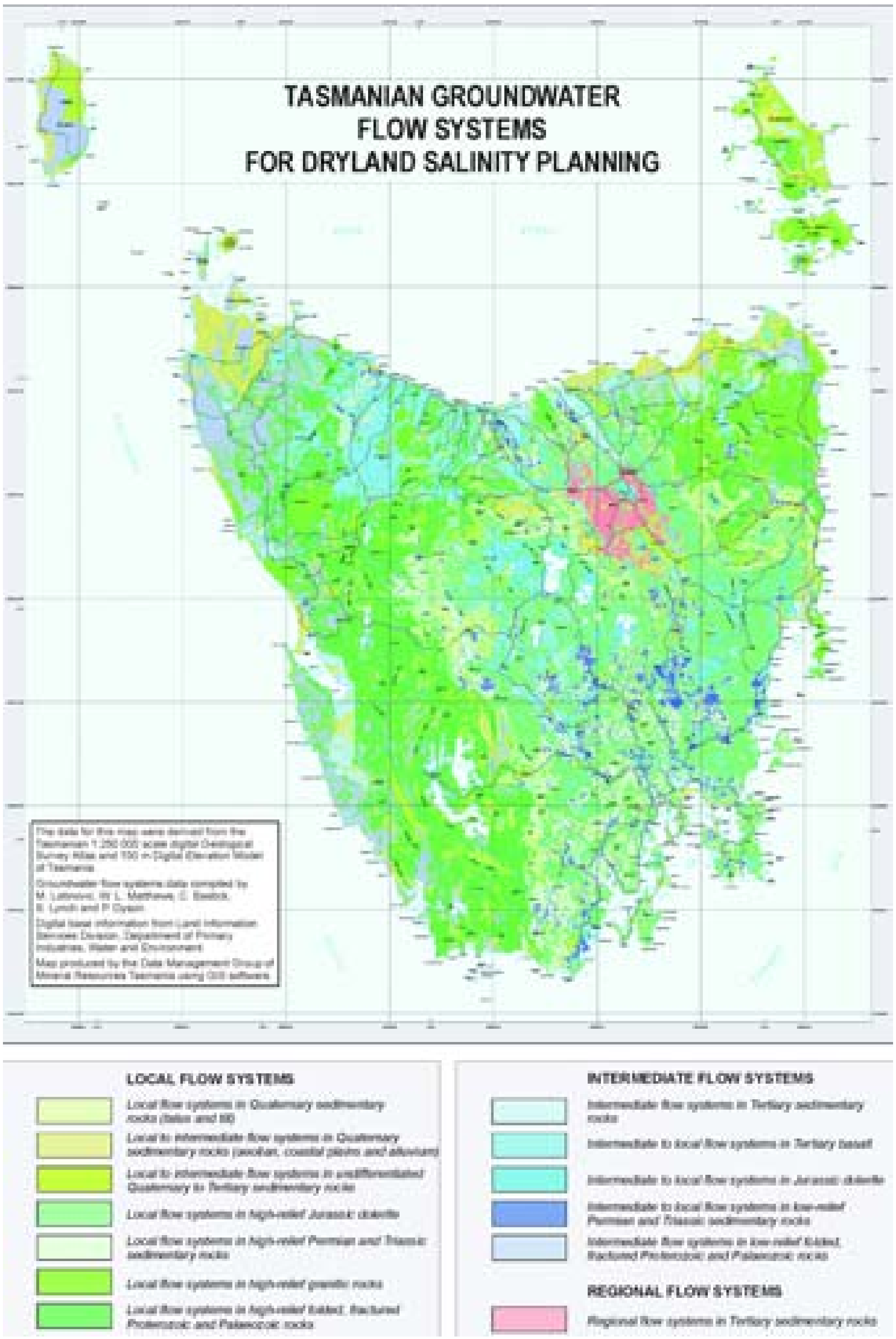
1.2.2 Using groundwater flow systems to compile information on salinity risk

Regional groundwater flow system maps at 1:250,000 resolution have been developed for the major catchments of the Murray–Darling Basin, with the exception of the rangelands (where their applicability is limited) and the Victorian and NSW Mallee. These maps were developed as a joint initiative of the *Catchment Classification* project and the *Tools*[20] project, a major communication and capacity-building initiative on planning and managing dryland salinity in the Murray–Darling Basin. Ongoing refinement of these maps continues, and some mapping at 1:100,000 resolution has also taken place in parts. Tasmania has just completed a 1:250,000 resolution map of groundwater flow systems for the State. Management options for the thirteen groundwater flow systems are described.[21]

Figure 1.6

Map of groundwater flow systems for Tasmania at 1:250,000

(Source: Latinovic M., Matthews W. L., Bastick C., Lynch S., Dyson P. and Humphries E., 2002, *Tasmanian Groundwater Flow Systems for Dryland Salinity Planning*, Mineral Resources Tasmania, Tasmanian Geological Survey Record 2003/02, Department of Infrastructure, Energy and Resources, TAS.)



The 'Tools' project used the *Groundwater Flow Systems Framework* to package information on salinity planning and management. The overarching *Salinity Information Package*[22] comprising 40 technical information sheets was described in the Introduction (page 1). Ten *Regional Information Packages*[23] for the major catchments of the Murray–Darling Basin use the *Groundwater Flow Systems Framework* to describe the extent of salinity and a relative rating for salinity risk for each major groundwater flow system (see Table 1.2). These regional packages are specific to particular regions in the Murray–Darling Basin and represent an important achievement. They can also be used as a model for developing information packages for any region in Australia.

Each 'Tools' regional package considers the following:

1. Background
    - Location
    - Climate
    - Natural resources
    - Population
    - Industry
    - Heritage
2. People and the land
    - Land use
    - Trends in agriculture
    - Implications for salinity management planning
3. Salinity
    - Aspects of salinity
    - Extent of salinity
    - Costs of salinity
    - Implications for salinity management planning
4. Hydrogeology and salinity management
    - Background
    - Management options for each major groundwater flow system
5. Best management options
6. Further reading and references
7. Useful contacts.

Regional Information Packages are available for the following regions of the Murray–Darling Basin (www.ndsp.gov.au):

- Qld Murray–Darling Basin
- Barwon, NSW
- Central West and Lachlan, NSW
- Murray, NSW (also see *Healthy Catchment guide*[24])
- Murrumbidgee, NSW
- Goulburn-Broken, Victoria
- North Central, Victoria
- North East, Victoria
- Wimmera, Victoria
- SA Murray–Darling Basin and the Victorian Mallee.

ACTION #1.4

Use the 'Tools' information packages. Rapid Catchment Appraisal *findings or* Catchment Management Handbook *for your region (or review them as a model for developing your own information) as a guide for assigning salinity risks to each of your major groundwater flow systems.*

ACTION #1.5

Access the best available groundwater flow systems map for your region, and consider investing in the development of smaller-scale maps at 1:250,000 and 1:100,000 for more detailed identification of risks.

Table 1.2

The Murray Regional Information Package provides an example of the decision-support table showing salinity risk categories

(Source: Murray–Darling Basin Commission, 2004, *Tools for improved management of dryland salinity in the Murray–Darling Basin – Murray regional information package*, Murray–Darling Basin Commission, Canberra, ACT.)

	Groundwater Flow System							
Attributes	**Local**				**Local & Intermed**	**Local, Intermed & Regional**	**Intermed & Regional**	**Regional**
	High Relief Fractured Rocks (Non-Granite)	High Relief Granites	Low Relief Granites	Fractured Sandstone & Surrounding Plains	Low Relief Fractured Rocks (Non Granite)	Upland Alluvium	Murray Basin Sediments (Shepparton Form)	Murray Basin Sediments (Calivil & Renmark Form)
	IV	V	VI	VII	I	III	II	VIII
Aquifer Transmissivity	20–50	<10	20–30	20–50	20–50	100–2,000	5–200	1500–2,500
Specific Yield	<5	10–15	10–15	<5	<5	15–20	15–20	15–20
Catchment Size (km^2)	<10	<10	<10	<20	100–200	500–1000	50	1,000
Annual Rainfall	650–1000	650–1000	450–650	600	450–550	450–700	350–450	350–500
Groundwater Salinity (dS/m)	0.2–3+	0.3–2+	1–20	1–3	1–10	0.4–12	0.5–60	0.4–50
Salinity Rating (soil)	S2	S2, S3	S2, S3	S2, S3	S2, S3	S2, S3	n/a	n/a
Temporal Distribution of Recharge	S	S	S, E	S	S, E	S	E	S
Spatial Distribution of Recharge	Hilltop	Slopes	Slopes	Slopes	General	General	General	Fan head
Type Areas	Holbrook Little Billabong	Mullengandra	Gerogery	Gerogery East	Lockhart	Upstream Corowa	Deniliquin	Deniliquin
Salinity Risk	L	L	L	L	M–H	L–M	M	L

Definitions of the relative ratings that apply to the characteristics of GFS (NLWRA 2001)

Aquifer Transmissivity	L	low (<2 m^2/day)	M	moderate (2–100 m^2/day)	H	high (>100 m^2/day)
Specific Yield	L	low (<5%)	M	moderate (5–15%)	H	high (>15%)
Catchment Size	S	small (<10 km^2; <1,000 ha)	M	moderate (10–500 km^2; 1,000–50,000 ha)	L	large (>500 km^2; >50,000 ha)
Annual Rainfall	L	low (<400 mm)	M	moderate (400–800 mm)	H	high (>800 mm)
Groundwater Salinity	L	low (<2,000 mg/L; <3 dS/m)	M	moderate (2,000–10,000 mg/L; 3–15 dS/m)	H	high (>10,000 mg/L; >15 dS/m)
Salinity Rating (soil)	S1	loss of production	S2	saline land covered with salt-tolerant species	S3	barren saline soils, typically eroded
Temporal Distribution of Recharge	E	episodic	S	seasonal		
Salinity Risk Ranking	L	low	M	moderate	H	high

Similar information in the Western Australian context is available through the *Rapid Catchment Appraisal* (http://agspsrv34.agric.wa.gov.au/environment) (RCA) program. As part of the Western Australian Salinity Strategy[25], RCA provides regional catchment and local government authorities with current estimates of extent and risk, analysis of the impact of management options, and direction for salinity management in their region. Extent and risk analysis is driven by assessments of satellite-based salinity mapping, while management option assessments use established modelling tools such as FLOWTUBE and AgET. Analysis and reporting from projects spanning approximately six million hectares of the agricultural area has been completed.

For north-eastern Australia, the *Salinity Management Handbook*[26] comprising three parts — understanding salinity, investigating salinity and managing salinity — provides a comprehensive and practical introduction to salinity using groundwater flow systems concepts. The three major types of salinity are described and practical information for planning and carrying out salinity investigations is provided. Vegetation, irrigation and engineering applications are outlined, together with the process of developing an integrated plan of management.

1.3 Data

1.3.1 Mapping methods for salinity

Salinity mapping in a landscape can mean different things to different people. This has led to a comprehensive review on 'Salinity mapping methods in the Australian context and their applicability for assessing salinity hazard and risk'. A user-friendly guide[27] has been produced, supplemented by a technical report[28] with more detailed descriptions of approaches to salinity mapping, prediction, monitoring and risk management.

ACTION #1.6

Consult the guide on salinity mapping methods to refine your thinking on future regional investments in salinity mapping, prediction, monitoring and risk management.

The guide looks at the information needs of three classes of user — at catchment, sub-catchment, and paddock levels. It explains the difference between hazard and risk, and briefly describes the origins of dryland salinity. It provides detailed information about methods to map dryland salinity, including the investment decisions that need to be made, the cost, skill level, applicability and limitations of each method. It is designed to help identify the optimal approaches that can be used to get more information about your salinity problem to help make better decisions about management options.

The review showed that tools such as air-photo interpretation, ground electromagnetics and satellite-based mapping systems could provide accurate maps of the current extent of existing dryland salinity. Acquiring these data require that they are first matched to the users landscape and their needs. All systems are only accurate if properly calibrated. Systems that are better equipped to assess hazard are tools such airborne electromagnetics, magnetics and radiometrics. These tools map the spatial distribution of soils, regolith and deep salt stores that affect future risk. They do not map dryland salinity.

1.3.2 Knowing where the salt is stored

Techniques are available to map catchment attributes (soils, geology, regolith and salt stores), such as satellite, multi-spectral, hyper-spectral, terrain, radiometric, magnetics and electromagnetic systems. There are others that can map the expression of dryland salinity (satellite, air-photo, ground electromagnetics). Combinations of these systems have been used in hazard mapping. However, what is crucial is that none of these approaches directly maps the

ACTION #1.7

Explore the various geophysical techniques (ground and airborne) available for locating catchment salt stores and undertake a cost-benefit analysis to guide effective investment in your region.

key parameters in salinity risk assessment, that is, land use and related changes to the catchment water balance.

Hazard maps require knowledge about the physical characteristics of the catchment, together with time trends in water and salt driven by climate and land use change. This approach drove the development of an assessment of current and predicted dryland salinity in Australia under the National Land & Water Resources Audit and, in part, the development of the groundwater flow systems approach. Since the Audit, various regions and States have taken differing approaches to resolve regionally-based assessment of hazard or risk by acquiring new datasets or assessing old datasets.

Salinity hazard maps have been produced for National Action Plan (NAP) catchments in Queensland. A state-wide salinity hazard dataset has been produced for New South Wales using a similar methodology to that used in Queensland. The overlay of three GIS datasets produces these maps: regolith salt store, recharge potential and discharge sensitivity. The resulting maps indicate the potential for salt to accumulate in a particular part of the landscape at sometime in the future.

If a finer resolution of risk and hazard is required, higher resolution datasets, such as airborne geophysics can be acquired. The *National Airborne Geophysics Project*[29] (NAGP) assessed the efficacy and application of airborne systems (SALTMAP, DIGHEM, TEMPEST) and interpreted products at five sites in four States. These products include salinity hazard, soil, groundwater target, salt store and geological maps.

The NAGP concluded that no others tools available provide the descriptive capacity for landscapes, or level of resolution available to assess salinity risk and hazard. However, it also concluded that the raw data was unusable by land managers and hence interpreted products were required. Assessments of those products showed that they could be significantly improved and that the major limitation to the technology was the lack of benefit developed from improvements in decision-making for land managers. The project also concluded that every dollar spent in the air should be matched by one on the ground (calibration and interpretation).

This conclusion was revisited in a further study that undertook analysis of the costs and benefits and adoption issues faced by land managers. They concluded that the majority of existing surveys had been poorly conceptualised and that only those who better understood the strengths of the technologies and needs of catchment managers would be valued[30]. Recent surveys completed in South Australia (Riverlands)[31] are evidence that the old logic of acquisition and testing (system trials) is giving way to products to test realistic applications and provide results.

1.3.3 Assessing salinity hazard and risk at the State level

The National Land & Water Resources Audit estimates of areas with shallow water tables and future hazard in Western Australia have been updated as part of the *Land Monitor*[32] project, which provides farm-scaled, satellite-based estimates of the area of salt-affected land. Interpreted satellite images showed that 1.047 million hectares of land was classed as severely salt-affected, compared to the earlier estimate of 4.363 million hectares under the Audit shown in Table 1.1. Of this revised area of 1.047 million hectares, 0.821 m ha is farmland and the remainder is public land (mainly native vegetation). The time trends in the rate of expansion of saline land were approximately 15,000 ha/yr. It is anticipated that satellite data will be continuously acquired on a 5–10 years timeline to update trends in salinity and native vegetation. The project also developed a surrogate system for assessing salinity risk into the future, after first failing to develop a system based on conventional groundwater data and modelling systems[33]. The final hazard assessment tool used terrain analysis and decision rules derived to identify valley hazards for subsequent analysis. Between 4.4 million hectares (private) and 5.4 million hectares (plus public land) was identified using this system.

South Australia has salinity risk maps[34] for catchment managers, based on GIS modelling from soils, landscape, topography and existing salinity databases.

A major project under the NSW Salinity Strategy[35] is developing a *NSW Salinity Hazard and Risk Data Set*. This modelling is based on a range of data layers and provides a high-level strategic product for Catchment Management Authorities (CMAs) and government agencies to plan salinity actions.

The NSW Coastal Salinity Audit (in draft)[36], together with the Hunter River Salinity Audit[37], completes Action 1.3 of the NSW Salinity Strategy: to audit salt-affected areas outside the Murray–Darling Basin (MDB). The coastal audit focuses on the North and South Coast, plus the Manning River, Karuah River and Lake Macquarie and Tuggerah Lake basins, which were not included in the Hunter audit. The MDB and Hunter River audits assessed the impact of dryland salinity on stream salinity and river basin salt loads, and predicted future stream salinity based on groundwater level trends. The audits did not address land salinisation. Likewise, the coastal audit focussed on stream salinity, however, there was insufficient groundwater data for coastal river basins, except for the Hunter, to be able to make salinity trend predictions.

The general findings of the coastal audit are that:

- Median salinity values for most coastal rivers and tributaries are low
- Stream salt loads are not currently a major threat in coastal regions
- Agricultural practices currently present a low risk for stream salinisation across the coastal basins
- Major salinity problems on the coast are associated with urban development.

Urban salinity in Western Sydney is the subject of separate projects, as a part of the Local Government Salinity Initiative and the Urban Salt Action Team work, also established under the NSW Salinity Strategy.

The study *Salinity predictions for NSW rivers within the Murray–Darling Basin*[38] looks at the primary question of how much salt will be carried in the Murray and Darling tributary rivers of NSW as a result of dryland salinisation processes and rising groundwater during the coming century. Secondary questions regarding the impacts of salinity changes on river water uses such as irrigation, urban water supply and wetland ecosystems are also broadly addressed. On a whole catchment basis, the study calculated the total salt delivery in a range of from 0.3 to 26 t/km^2/yr, with rates within catchments as high as 76 t/km^2/yr in some geological units.

The Queensland Government has released a series of hazard maps covering priority catchments in Queensland, that is, over 40 per cent of the State[39]. The maps use a composite index method in a GIS environment, developed from pilot studies of some seven million hectares in southern Queensland[40]. The method captures the current knowledge of landscape salinity processes to identify vulnerable landscapes; a similar approach has since been used in New South Wales

ACTION #1.8

Use the results from assessments on the extent and hazard of dryland salinity to inform your decision-making processes with due consideration to the level of confidence in the underlying data sources applicable to your area.

hazard mapping. These maps provide a broad-scale regional overview; more detailed guidelines[41] were developed for Queensland in 1997 for the identification, investigation and management of salinity based on site inspections and landscape observations. Broad-scale salinity risk mapping, salinity assessment tools and decision support tools are now being developed through the National Action Plan for Salinity and Water Quality and related activities.

1.3.4 Assessing salinity in cropping areas

The *Queensland cropping hazard*[42] project assessed the potential of salinity issues in grain growing regions, using GIS-based hazard mapping, on-ground investigations of soil conductivity, and modelling of drainage associated with selected cropping systems. It showed that 21 per cent of all cropping land in Queensland faces a high hazard over the next 50 years. This area represents 4.5 per cent of all land within the Queensland agro-ecological zones defined by the Grains Research and Development Corporation (GRDC) (see Figure 3.4). A simplistic analysis would suggest that targeted management is need within an area of approximately 1.6 million hectares to protect the 21 per cent of cropping land falling within the high hazard category (see Table 1.3). Although this study used the latest advances in understanding and managing salinity, Queensland has major gaps in both data and knowledge of groundwater flow systems outside traditional irrigation areas, and therefore we need to use the information in a manner that reflects limited confidence in the results.

Table 1.3

GRDC agro-ecological zones in Queensland facing 'high salinity hazard'

(Source: Moss J., Gordon I., and Pearce B., 2002, *A description of the GIS based risk assessment methodology for salinity hazard assessment modelling in the Queensland Murray–Darling Basin*, Department of Natural Resources, Indooroopilly QLD.)

GRDC agro-ecological zone	High salinity hazard (ha)	Total cropping area (ha)	% of total in high hazard	Contributing catchment area (ha)
Qld South-East	222,500	1,283,500	17	741,500
Atherton	2,300	7,300	31	7,500
Qld South-West	6,000	186,800	3	20,200
Burdekin	200	1,800	9	600
Central	259,200	812,000	32	864,000
TOTAL	**490,200**	**2,291,400**	**21**	**1,633,800**

The *Economic evaluation*[43] project overlaid salinity extent maps from the NLWRA with the GRDC agro-ecological zones to assess the areas within each zone being impacted by dryland salinity in 2000 and 2020. Table 1.4 shows the estimated current extent of salinity within each GRDC agro-ecological zone by 2020. Zones with expected large increases include the WA Sandplain, SA Vic Bordertown Wimmera, NSW Vic Slopes, WA Central and Vic High Rainfall. Over 60 per cent of the additional saline area forecast to develop from 2000 to 2020 will be in the Western Region. About 1.1 million additional hectares of farmland in the cropping regions of Australia are forecast to become saline by 2020.

ACTION #1.9

Consider the results of specific studies on the extent and hazard of dryland salinity in cropping areas to inform your decision-making processes with due consideration to the level of confidence in the underlying data sources applicable to your area.

Table 1.4

Estimated current extent of dryland salinity in each GRDC agro-ecological zone and the anticipated growth in salinity area in each zone by 2020

(Source: Kingwell R., 2003, *Economic evaluation of salinity management options in cropping regions of Australia*, Grains Research & Development Corporation, Canberra ACT.)

	Saline Area ('000 ha)		Area Increase	
GRDC zone	**2000**	**2020**	**('000 ha)**	**(x Area)**
NSW Central	4	32	28	7.4
NSW Northeast-Qld Southeast	38	88	50	1.3
NSW Northwest-Qld Southwest	2	6	5	2.9
NSW Vic Slopes	61	203	142	2.3
Qld Atherton	1	2	2	2.2
Qld Burdekin		1	1	180.3
Qld Central	32	71	39	1.2
SA & Vic Mallee	108	145	37	0.3
SA Mid-North Lower York Eyre	118	118		
SA Vic Bordertown Wimmera	277	488	211	0.8
Tas Grain	18	24	6	0.3
Vic High Rainfall	72	228	155	2.1
WA Central	961	1,142	181	0.2
WA Eastern	374	374		
WA Northern	280	280		
WA Sandplain	275	522	247	0.9
TOTAL*	**2,620**	**3,723**	**1,123**	**0.4**

* No significant areas of salinity are recorded for WA Mallee or the WA Ord zones.

1.3.5 Accounting for climate variability

A project[44] in cropping areas on the south-west slopes of NSW showed that the main driver for water table change over the past 50 years has been climatic variability (at >80 per cent, compared to land use change at <20 per cent) and water tables over the past 30 years generally do not show a rise and in many cases have shown a slight fall. This suggests, for these catchments, that there will be minimal increase in land salinity over the next 50 years.

The marked rise relative to the initial level may be due to historic clearing of vegetation, but may be a consequence of bore development during dry periods and subsequent monitoring during wet periods. However, in Western Australia it has been demonstrated that rise in water levels is largely explained by vegetation clearance and the consequent adjustment in the water balance. The HARTT[45] model was used to discern changes and lags in water table response to rainfall and land use activities. These studies allow us to assess future likely trends in water levels, and consequent changes in salinity-affected areas.

ACTION #1.10

Take into account climate variability (rainfall and evapotranspiration), where possible, when determining the risk of dryland salinity spread.

1.3.6 Understanding the status of groundwater

The *Groundwater Status Report* project builds on the 1996 report on the status of groundwater in 1992 entitled 'Murray–Darling Basin Groundwater — A resource for the future'[46] and adds significantly to the body of data and knowledge used to inform the production of dryland salinity extent and risk/hazard maps by the Audit.

A plain-English report *Murray–Darling Basin Groundwater Status 1990–2000: Summary report*[47] is being prepared that will provide a strategic overview of the status of groundwater across the Basin, for each State and an individual status report on each major catchment based on the *Groundwater Flow Systems Framework* — using the 1:1,000,000 resolution map of the Murray–Darling Basin. A supporting comprehensive technical reference provides a detailed review of each groundwater flow system, and will be used to inform the production of the *Groundwater Status Report* itself.

The groundwater attributes considered include:

- Water table elevation
- Depth to water table
- Elevation of potentiometric surface (of semi-confined aquifers)
- Maximum drawdown
- Groundwater salinity (where data is available)
- Groundwater use, allocation and yield (for each groundwater management area)
- Analysis of groundwater trends as identified from analysis of hydrographs
- Identification of areas where groundwater resources are at risk.

ACTION #1.11

Review the 'status report' for your region and State in the Groundwater Status Report for the Murray–Darling Basin (or as a model for developing your own in other parts of Australia) and use the CD-ROM to tailor your own regional maps.

ACTION #1.12

Consider the concept of representative bores and the associated hydrographs for each groundwater flow system, and use this approach to guide future investments in bore installation and monitoring.

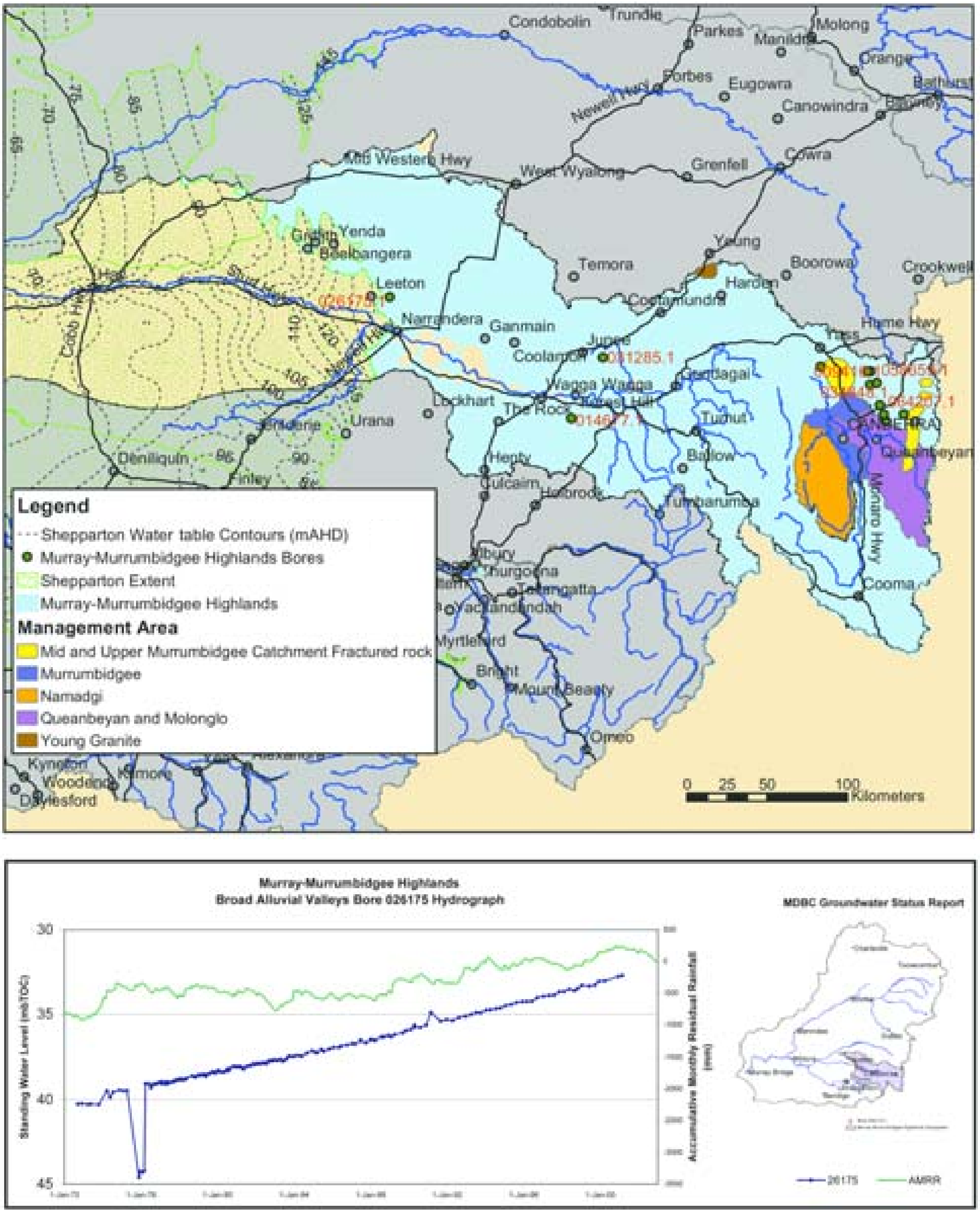
For Murray–Darling Basin catchments, the *Groundwater Status Report* will represent the most up-to-date information available that consistently and accurately presents the attributes listed above. It will supercede comparative information presented in both the NLWRA and 'The salinity audit of the Murray–Darling Basin — A 100-year perspective, 1999'[48] and its associated State reports. However, as the 'Groundwater Status Report' is focused on groundwater, data on historical stream salinity trends and catchment salt balances[49] used in the 1999 Salinity Audit remain relevant.

Information is also presented as a GIS product. The GIS has been developed in ArcGIS Publisher and is delivered as a series of digital maps linked by a web style interface. The product may be viewed through ArcReader, a free product that is distributed with the GIS. The product allows maps to be printed at the scale required, with the ability to turn layers on and off to allow the user to tailor map outputs to specific requirements in addition to having hyperlinks to show representative hydrographs and salinity graphs (see Figure 1.7).

Three complementary reports reviewing *Groundwater management and property rights,*[50] *The origin of fresh groundwater in the SW Murray Basin and its potential for salinisation*[51] and *Projections of groundwater extraction rates and implications for future demand and competition for surface water*[52] in the Murray–Darling Basin are also available. The first publication considers the national framework for groundwater management and the Council of Australian Governments Water Reforms. On a State-by-State basis, it reviews groundwater legislation, institutional arrangements, implementation of approaches and dissemination of information, implementation and infrastructure issues and significant management initiatives. The second publication looks at the potential for salinisation of the large fresh groundwater reservoir in the Mallee region of the Murray–Darling Basin, which was mostly recharged 20,000 years ago and is not being replenished. The resource is drawn on for domestic, livestock and irrigation, and its expected life will be dependent upon the rate of extraction, but with the most immediate concern of the possibility of groundwater salinisation resulting from saline soil-water being displaced into the groundwater. The third publication considers water extraction in relation to the Murray–Darling Basin 'CAP on diversions' and recommends investigating and quantifying the groundwater resources of the Murray–Darling Basin and supporting their sustainable land use.

Figure 1.7

Example of a map of the Murrumbidgee Highlands showing groundwater management areas, with an example hydrograph showing rising groundwater levels from a representative bore near Leeton. (Source: Murray–Darling Basin Commission – *Groundwater Status Report* project.)



ACTION #1.13

Investigate salinity risk in more detail before proceeding with conversion of native vegetation to pasture or irrigated agriculture in the rangelands of the Murray–Darling Basin, especially north of Wilcannia.

ACTION #1.14

Read the paper 'An overview of modelling techniques and decision support systems and their application for managing salinity in Australia', and consult the PRISM CD-ROM and 'Catchment Modelling Toolkit' (www.catchment.crc.org.au) to help refine existing information on the extent and risk of dryland salinity in your region.

1.3.7 Scoping groundwater recharge in the rangelands

The *Rangelands recharge*[53] project scoped the risk of land and water salinisation in the rangelands of the Murray–Darling Basin from increased deep drainage from converting native vegetation to pasture land. The purpose of the salinity assessment was to identify areas for more detailed work, rather than to provide accurate predictions. The study used other data to extrapolate deep drainage, as recharge data in the rangelands was scarce.

For the southern rangelands (south of Wilcannia), increases in deep drainage would be unlikely to lead to significant increases in aquifer recharge within 100 years. Over this time-frame, the development of dryland salinity is expected to be limited to relatively small areas. Salt loads to the Darling River between Wilcannia and Pooncarie would not be expected to increase significantly.

For the northern half of the rangelands, significant areas of dryland salinity would be expected within 100 years after the increase in drainage. On this basis, the areas around Bourke and south of Charleville are potentially most at risk, and might be considered highest priority.

More extensive soil and stream salinisation would be expected following large irrigation developments, in both the south and north of these rangelands.

Two of the uncertainties in this salinity hazard assessment are water table depths and groundwater salinities of the aquifer in the northern rangelands. While detailed hydro-geological mapping of the Murray Geological Basin has been undertaken, the Darling Basin remains poorly understood.

1.4 Modelling capability

1.4.1 Using the right model for the task

A wide range of models has been developed to support salinity planning and management. These models draw on the understanding of experts and often local knowledge about salinity causes and processes. Many of these models have an element of risk assessment, but also salinity impacts and options for management — the topics of chapters to follow. The CRC for Catchment Hydrology is developing an on-line *Catchment Modelling Toolkit* (www.catchment.crc.org.au) with software and documentation on catchment modelling, supported by a *Catchment Modelling School* for professional training in model use.

The paper *An overview of modelling techniques and decision support systems and their application for managing salinity in Australia*[54] summarises some of the key models used to estimate salinity extent and risk. Table 1.5 is adapted from this paper, and provides some examples of salinity hazard and trend models. A description of these models is also on the PRISM (Practical Index of Salinity Models)[55] CD-ROM — a review of salinity models to support the implementation of the National Action Plan for Salinity and Water Quality. Also refer to section 4.3 'Models, frameworks and decision support tools'.

Table 1.5

Examples of salinity hazard and trend models in Australia

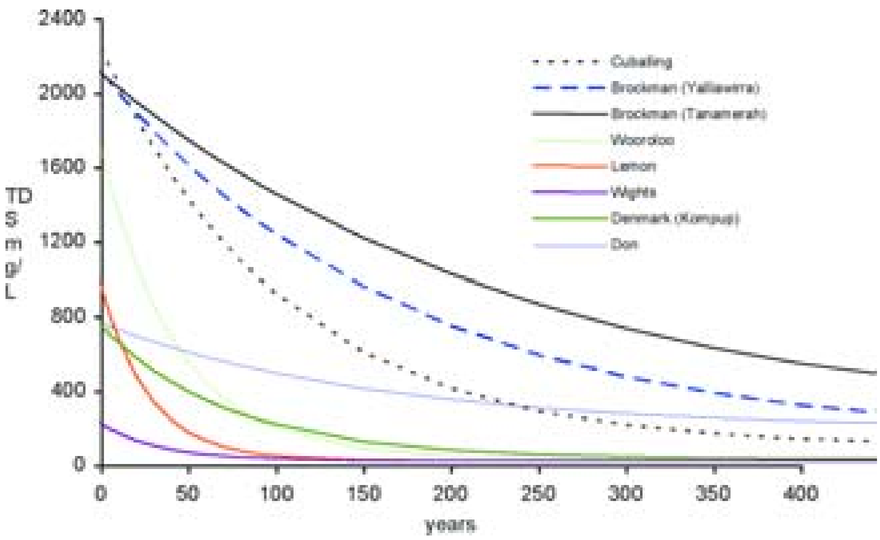
(Source: modified from Littleboy M., Vertessy R., and Lawrence P., 2003, *An overview of modelling techniques and decision support systems and their application for managing salinity in Australia*, PUR$L 2003, CRC for Catchment Hydrology, Melbourne VIC.)

Model Type	Jurisdiction	Area	Focus	Summary
Hazard	BRS	Australia	Landscape	Composite index of climate and soil properties.
	Queensland	Qld Murray–Darling Basin & other Qld NAP regions	Landscape	Composite index of recharge potential, discharge sensitivity and salt stores.
	Western Australia	Catchment to sub-catchment	Stream	Catchment salt-flushing model[56] — a simple storage and discharge model that estimates salt and water fluxes from catchments to estimate the time to reach a target salt load and flow concentration in a given stream, and the recovery of stream salinity to some useable level, as salt loads reduce over time. Eight catchments were modelled in south-west Western Australia under the 'Environmental Impacts'[57] project (see Figure 1.8).
Trend	MDBC	Murray–Darling Basin	Stream	Used in the MDBC Salinity Audit. Linked rising groundwater model with current stream salinity trend to predict future stream EC and salt loads.
	NLWRA	Australia	Landscape	Identified current and future areas of shallow water tables. Linked to impact assessment on agriculture, urban and infrastructure.

Figure 1.8

Modelled reduction in-stream salinity through time for eight catchments in south-west Western Australia

(Source: Hatton T.J., Silberstein R.P., and Salama R.B., 2001, *Catchment salt balances and the future of river salinisation in Australia*, CSIRO Land & Water, Wembley WA.)



WHERE TO FROM HERE?

National Land & Water Resources Audit

The State assessments undertaken for the Audit resulted in a comprehensive analysis of groundwater data while exposing many limitations in quality, information management and fitness for purpose with respect to dryland salinity management. Most States have further refined these assessments since.

Some clear directions can be drawn from the Audit on understanding the current extent of dryland salinity and its risk of spread. The hazard assessments undertaken for central and southern Queensland were based on limited data and on-going refinement is better guiding the development of vegetation management policies and guidelines. Well-focused investment in preventative action in northern Australia is still needed, and this should be guided by the best available information.

R & D TIP #1.1

Review the strategic plan for the National Land & Water Resources Audit Phase II (www.nlwra.gov.au) and/or speak with Audit staff to ascertain the extent to which the planned program of activities will meet your particular needs.

The Audit has provided a mechanism by which users can determine what information is adequate and what is deficient for their particular purpose. Priorities for further research identified were improved methods of developing groundwater surfaces with distributed groundwater data, and improved methods for estimation of water balance targets, recharge and deep drainage with explicit links to groundwater system response.

Data records are accessible to catchment managers and funders to inform their investment decision-making processes, and we need to make sure that we use and build on this capability. This is particularly important given that the National Action Plan for Salinity and Water Quality has devolved a high proportion of resources directly to the regional level. Catchment managers and decision-makers need to be aware of the wealth of information that exists and where their investment choices can best add value at the regional level, and within the broader context.

The value of sharing information has been made apparent through both the Audit and the development of the *Groundwater Flow Systems Framework*. The Audit has played an on-going role in maintaining and updating the national database and ensuring its availability and accessibility. It is important that data collected at the regional level by catchment managers and funders continue to be made available and retrievable through this mechanism.

Groundwater flow systems

R & D TIP #1.2

For information on further development of groundwater flow systems visit the NLWRA (www.nlwra.gov.au) and Bureau of Rural Sciences (www.brs.gov.au), and for the Murray–Darling Basin (www.mdbc.gov.au), as well as at individual State and regional levels.

Where information on the current extent of dryland salinity and its risk of spread is limited, the groundwater flow systems approach has helped to fill the knowledge gaps. Understanding the type of groundwater flow systems provides an indication of the nature and size of the problem, and where it is likely to express itself in the landscape. From this, it is possible to rank catchments according to the nature and scale of their salinity problem or potential problem.

At National, State and regional scales the *Groundwater Flow Systems Framework* is guiding policy and investment decisions by identifying local, intermediate and regional groundwater flow systems, helping to determine broadly where the salinity risk is greatest and where management activities are most likely to be rewarded. In the Murray–Darling Basin and south-west Western Australia more detailed mapping and assessment allows regional predictions of salinity risk, guiding policy decisions and identifying broad management options. Further regional and sub-catchment scale mapping and interpretation are needed throughout Australia to support strategic and design level investment.

Data

Studies in airborne geophysics indicate that specialised skills are required for salinity risk assessment and land management planning, and that targeted capture of airborne data is warranted in some circumstances. Realistic modelling of dryland salinity extent through time is achievable when combined with bore and climate data. Work needs to be expanded and explored further for different regions, where a cost-benefit analysis justifies the investment. There is also a need to collate metadata on existing datasets to maximise the benefits derived from multiple use of such data.

The *Groundwater Status Report for the Murray–Darling Basin* has used the *Groundwater Flow Systems Framework* to provide a statement on groundwater status for each system, major catchment, the Basin States, and the Basin as a whole. The approach used and the GIS tool are more broadly applicable and could be readily extended in other parts of Australia. Similarly, the identification of representative bores and hydrographs is an important step in rationalising data collection and reporting.

Plans are in progress for databases and associated information held by the Murray–Darling Basin Commission, including groundwater flow systems and those used in the *Groundwater Status Report*, to be made more readily available through an on-line GIS-based information facility. This system will complement the on-line NLWRA 'Atlas' facility and State-based web-sites.

Work on estimating recharge in the rangelands of the Murray–Darling Basin recommended that investigations be carried out in the north to provide more accurate data on water table depths, water table salinities and characteristics of the regolith, as well as field studies to better estimate rates of deep drainage beneath grazing land. It indicated that the monitoring network needs to be expanded, to ensure that rises in water tables of shallow aquifers beneath non-irrigated lands are detected. Particular attention should be paid to areas where time-lags between increases in deep drainage and increases in aquifer recharge are predicted to be relatively small.

Modelling capability

The tools, models and frameworks described in Table 1.5, on the PRISM CD-ROM and on the 'Catchment Modelling Toolkit' web-site provide very useful information for catchment managers. Furthermore, the 'Basin Salinity Management Strategy Operational Protocols' provide criteria for model assessment and review. However, tools, models and protocols are constantly under refinement, and it is difficult for potential users to keep abreast of such changes. Maintenance of these databases and information will require consideration. Investment in model and tool refinement should also consider the transferability of the model or tool between catchments and scales, and its data requirements. The overarching philosophy driving model and tool development should be that it is 'fit for purpose' (see section 4.3 for more details).

R & D TIP #1.3

Consider the National Airborne Geophysics project (www.affa.gov.au) to keep up-to-date with activities and advances in airborne geophysics mapping and research.

R & D TIP #1.4

The Groundwater Status Report for the Murray–Darling Basin is likely to be updated periodically, while accessibility of groundwater and other natural resource management information for the Basin will be progressively improved (www.mdbc.gov.au).

R & D TIP #1.5

Contact State agencies, NLWRA (www.nlwra.gov.au) or CSIRO Land & Water (www.csiro.au) for further information on development of programs or activities to collect data for salinity management in rangeland environments.

R & D TIP #1.6

Visit the CRC for Catchment Hydrology web-site (www.catchment.crc.org.au), which is developing a Catchment Modelling Toolkit *and consider the program of the* Catchment Modelling School *for training model users.*

Link back to Introduction

Link to Q.2 - Causes and Processes

Link to Q.3 - Impacts and Costs

Link to Q.4 - What can we do?

Link to Q.5 - Integrate with other NRM issues

Link to a checklist of actions

Link to - Where to get help

Link to Glossary and References