DEVELOPMENT OF A REFERENCE MODE FOR CHARACTERISATION OF SALINITY PROBLEM IN THE MURRAY DARLING BASIN

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ABSTRACT

Reference modes are the patterns of dynamic behaviour produced by feedback structures linking variables considered key to a specific problem. Identifying reference modes can be a challenge when data is scanty or available from a variety of sources and presented at different levels of aggregation. Lack of unequivocal reference modes can lead to ambiguity and conflict among stakeholders. This paper describes an attempt to identify and specify reference modes for the problem of dryland salinity. The method suggested by Saeed (2002) was applied. Dryland salinity in the Murray Darling Basin of Australia is used as a case study. The extent of the salinity problem in the Murray Darling Basin is described. Sources and availability of data for key salinity parameters are then evaluated. Insights gained from application of Saeed's method are discussed. Shortcomings of the method can be reduced through extensive and close involvement of stakeholders right from earliest stages when attempting to identify the preliminary model boundary.

Keywords: System dynamics modelling, reference modes, problem articulation, dryland salinity, Murray Darling Basin, Australia

1.0 INTRODUCTION

Effective policy interventions deliver sustained and desirable changes to system of purposeful human activity. In problem solving approaches such as that proffered by Kepner and Tregoe (1981), problems are considered to be deviations from the pre-existing conditions. To improve our understanding of the reasons for deviation, problems need to be characterized. This characterization includes articulation of the problem according to the available modes of understanding. Problem articulation refers to initial characterization of the problem in terms of time horizon, stakeholders perceptions of the problem, observable symptoms, the perceived causes of the problem, and factors affecting it (Saeed 2001; 2002). Problem characterization is usually done through a combination of the discussions with the client team, archival research, data collection, interviews and direct observation or participation (Saeed 1998; Sterman 2000). Two of valuable processes in problem articulation are establishing reference modes and explicitly setting the time-horizon. Saeed (1998) suggests that half of the understanding about the problem is achieved through the learning processes involved in the development of the reference modes. Facilitating such understanding is fundamental to the system dynamics discipline.

In this research task, the concept of reference mode of behaviour as it applies to the dryland salinity was investigated. Reference modes were developed from the time series data as well as highly aggregated descriptive data. The 20 step method developed by Saeed (2001, 2002) for building reference mode was followed in an attempt to define reference modes for dryland salinity which has become a serious problem for farmers, local, State and Federal governments and environmental authorities. Such problems are present in numerous regions around the world including Sudan, Ethiopia, India and Pakistan. Available data was assessed in an attempt to build reference modes to guide subsequent development of the system dynamics models. Gaps in the quantitative and qualitative data were identified.

This paper presents the results of an investigation into development of reference modes for the dryland salinity. The description starts with revisiting of the concept of reference modes, its significance, usage and factors to be considered while developing reference modes. Then Saeed's method for developing reference mode is described that is followed by a discussion of the results of this application. Near the end, the insights gained from this research are summarised.

2.0 CONCEPT OF REFERENCE MODES REVISITED

In system dynamics, the term 'reference mode' is used to denote a pattern of graphs that present the idealised or actual behaviour of different variables over time. The other terms used include behaviour over time (BOT) graph, reference behaviour or reference conditions. These terms fundamentally refer to the same thing that is behaviour over time and specifying patterns that characterise those changes.

The concept of reference modes is not new being used in a variety of disciplines and for a variety of purposes. The disciplines in which it has been used include basic sciences, social sciences and management sciences. In chemistry laboratories equipments (atomic absorption spectrophotometers, colorimeters etc) are calibrated against standard solution concentrations. These standard solutions, with known concentrations, work as reference solutions for calibrating the equipment. In physics laboratories, instruments are calibrated against the standards provided by the Standards Institute. The measurements held at the Standards Institute act as the reference for calibration of equipment (weights and weighing balances, measuring devices etc). Within management sciences, widely used approaches for problem analysis (for example.Kepner and Tregoe (1981)) define a problem as a deviation from the "SHOULD BE" conditions. Here the "SHOULD BE" conditions provide the reference conditions for comparison of the present conditions and for characterization of the problems. In control theory, it is assumed that there exists a mathematical model describing the dynamical behaviour of the underlying process, which can be changed from existing to the desired behaviour (Ozbay 1999). In this case, the existing behaviour can act as reference behaviour to identify the desired behaviour.

Although different disciplines used the concept of reference mode, they use only the past or the known behaviour of a variable that depends upon observations made in the past. In System Dynamics modelling, the models are calibrated against the recent observed behaviour of the system. The behaviour is represented by a pattern arising from the combination and interaction of variables in sets of feedback structures.

The System Dynamics Modelling literature has made a marked contribution to the development of the reference modes concept. Whilst the processes of building reference modes start from time series data, the reference mode is more than a graph of the time series. Saeed (2002) termed it as an abstract concept that represents a fabric of trends and shows how different variables change with respect to each other over time. In particular, a time series graph simply represents correlation. The developer of the reference modes is presenting dynamic hypothesis(Helsinki School of Economics 1981; Oliva 1996; Maliapen 2000; Sterman 2000; Raimondi 2001) of the causality based on empirical data and local knowledge.

While developing reference modes a number of factors need to be considered:
- Time Scale relevant to the decision maker but sufficient to encompass longer term trends (for example, a balance between the reality of the 3 year election time cycle and the reality of the long term economic and environmental cycles);
- Logical boundaries (for example, are there 0% and 100% limits that will eventually bound observed local exponential growth)
- Valid scales of measurement for the parameter (that is, ordinal, interval scales, not nominal)
- Reference modes may be developed from:
    - Data-sets, particularly where the problem space is clearly bounded and data can be collected with high levels of the relilability and specificity.
    - Technical Characteristics for example error rates of machines increase as a result of wear over time such as suggested by Ford and Sterman (1998)
    - Expert knowledge
    - Inference based on the surrogate data sets, such as may be substituted for incomplete quantitative or qualitative data.

The reference modes are used for two purposes: first learning about the problem and its definition; and second for building confidence in the model through testing the hypothesised causality. Development of reference mode is a learning process that leads the effort of the modeller through to identification of model variables.

3.0 METHODOLOGY

To accomplish this research task, a methodology consisting of learning cycles approach has been adopted. This method provides a step-by-step approach towards development of reference modes. A brief review of methodology is given in the following paragraphs.

Over a decade, Saeed (2001; 2002; 2002) has developed a technique for 'problem slicing' and development of reference modes in a 20 step method (Figures 1,2 &3). His method is based on the Kolb's (1984)' model of experiential learning that includes learning cycle: feeling, watching, thinking and doing. Figure 1 shows the Broad framework of the Saeed(2002)'s method. This method describes a method involving five learning cycles. Each learning cycle consists of four steps. The method starts with the examination of available time series data. During the process, each learning cycle yields an intermediate product. The intermediate products of this learning process are domain boundary, preliminary system boundary, preliminary model boundary and model boundary. At the end of the learning cycle 5, a reference mode is produced. This reference mode consists of a graph showing a pattern of the past behaviour as well as likely future behaviour of the variables.

Each step of this method is described in the Figures 2 and 3 along-with the learning cycle it pertains to. The detailed method is illustrated in the section 5 while describing the results of the application of this methodology.

Data for identifying reference modes for the proposed dryland salinity model was acquired from a variety of sources. Datasets came in different formats having been prepared for
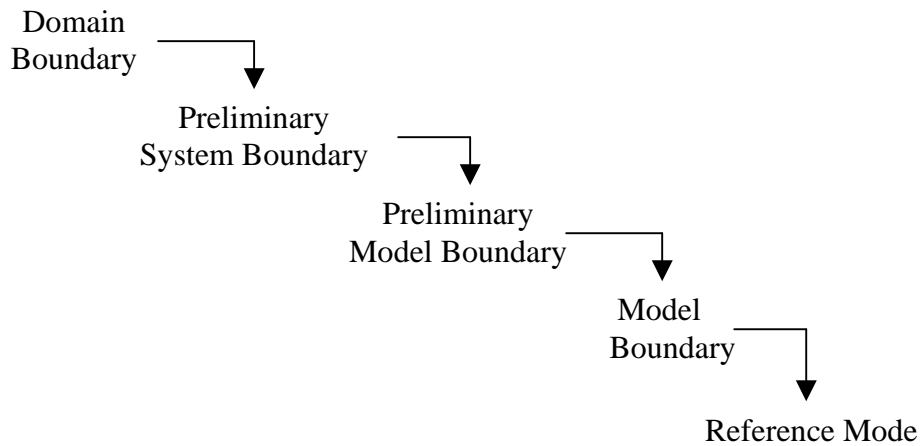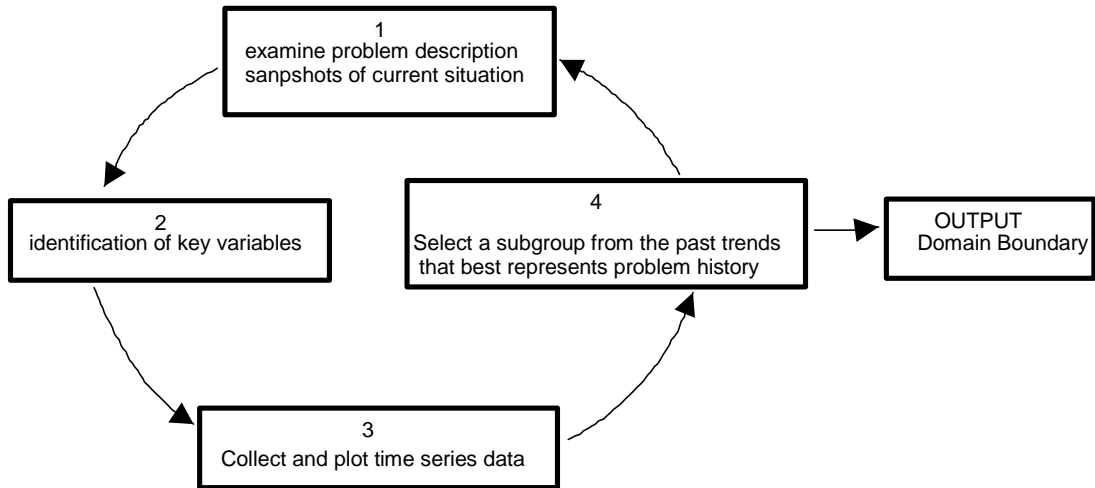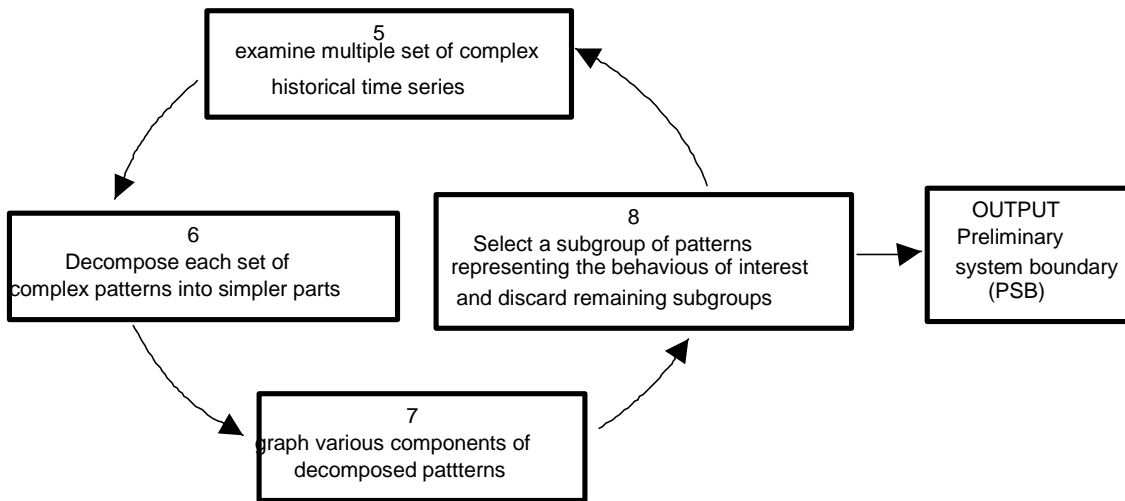
Domain
Boundary

Preliminary
System Boundary

Preliminary
Model Boundary

Model
Boundary

Reference Mode

Figure 1 Broad Framework of Saeed's Method

disparate customers for a variety of reasons, using different methods and at different times. The climate data was acquired from the Bureau of Meteorology, Australia. Temperature and rainfall data exists in the form of a time series data-set. Some of the data acquired was in the form of printed graphs. Data was generated from these graphs by using the software Grapher^{TM}. The water resources data was acquired from the different published material. Most of these were in hardcopy and an Excel^{TM} dataset was generated through Grapher^{TM}. The agricultural, land use and socio-economic data was acquired through the Agstat, a database in Microsoft^{TM} Access held by the Australian Bureau of Statistics. The gaps in data were addressed through direct contact with the local agencies. The land clearing data was acquired through the Australian Greenhouse Office. The quality of the data lies with the source of the data and integrity of the methods of collection. The original datasets have been aggregated at a variety of levels according to their original purpose. They also differ in their precision. None was collected specifically for this research activity. Alternate sources of data have not been discussed.

Learning Cycle 1

1
examine problem description
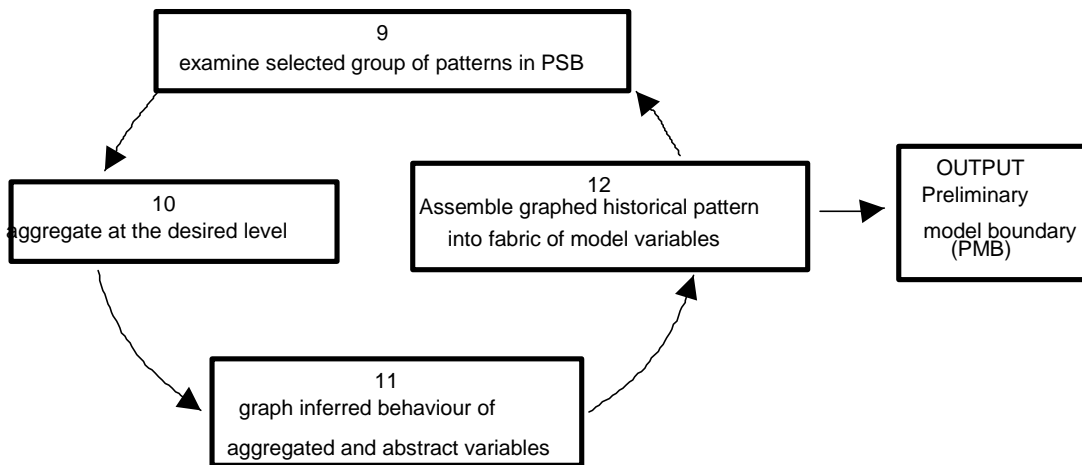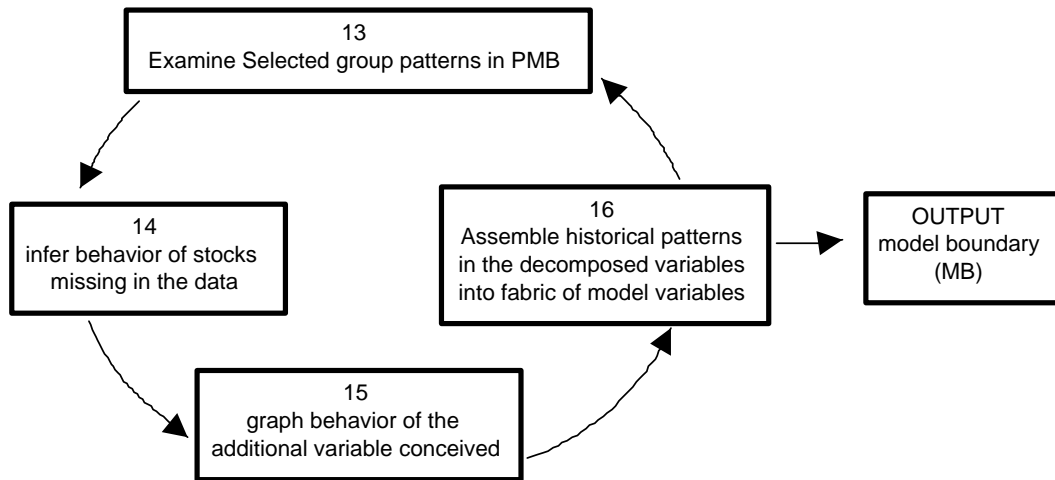sanpshots of current situation

2
identification of key variables

4
Select a subgroup from the past trends
that best represents problem history

3
Collect and plot time series data

OUTPUT
Domain Boundary

Learning Cycle 2

5
examine multiple set of complex
historical time series

6
Decompose each set of
complex patterns into simpler parts

8
Select a subgroup of patterns
representing the behavious of interest
and discard remaining subgroups

7
graph various components of
decomposed pattterns

OUTPUT
Preliminary
system boundary
(PSB)

Learning Cycle 3

9
examine selected group of patterns in PSB

10
aggregate at the desired level

12
Assemble graphed historical pattern
into fabric of model variables

11
graph inferred behaviour of
aggregated and abstract variables

OUTPUT
Preliminary
model boundary
(PMB)

**Figure 2 Method for Development of Reference Modes (Saeed 2001, 2002),
Cycles 1-3**

Learning Cycle 4

```
                    ┌─────────────────────────────────┐
                    │              13                  │
                    │  Examine Selected group          │
                    │  patterns in PMB                 │
                    └─────────────────────────────────┘

   ┌──────────────────────┐   ┌──────────────────────────┐   ┌──────────────────┐
   │          14          │   │            16            │   │     OUTPUT       │
   │  infer behavior of   │   │  Assemble historical     │   │  model boundary  │
   │  stocks missing in   │   │  patterns in the         │   │      (MB)        │
   │  the data            │   │  decomposed variables    │   │                  │
   └──────────────────────┘   │  into fabric of model    │   └──────────────────┘
                              │  variables               │
           ┌──────────────────────────┐  └────────────────┘
           │            15            │
           │  graph behavior of the   │
           │  additional variable     │
           │  conceived               │
           └──────────────────────────┘
```

Learning Cycle 5

```
                    ┌─────────────────────────────────┐
                    │              17                  │
                    │  Examine past behavior of        │
                    │  variables in the extended       │
                    │  model boundary                  │
                    └─────────────────────────────────┘

   ┌──────────────────────┐   ┌──────────────────────────┐   ┌──────────────────┐
   │          18          │   │            20            │   │     OUTPUT       │
   │  make intelligent    │   │  review past and         │   │  Reference Mode  │
   │  projections of the  │   │  inferred future trends  │   │                  │
   │  future behaviour of │   │  of the model and policy │   └──────────────────┘
   │  model variables in  │   │  variables as a fabric   │
   │  the extended        │   │  and ensure logical      │
   │  boundary            │   │  consistency             │
   └──────────────────────┘   └──────────────────────────┘

           ┌──────────────────────────────────────────┐
           │                   19                      │
           │  Graph inferred future trends for the     │
           │  variables in the extended model boundary │
           └──────────────────────────────────────────┘
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Figure 3 Method for Development of Reference Modes (Saeed 2002, 2001), Cycles 4 & 5

4.0 MURRAY DARLING BASIN: A BRIEF INTRODUCTION

Murray Darling Basin (MDB) is situated in the southeast of Australia. It covers 1,061 km^2 and consists of the tributaries of the Murray and Darling Rivers. The greater portion of the Basin is formed of extensive plains and low undulating areas mostly below 200m above sea level. It has range of climatic conditions and natural environments from the rainforests of the cool and humid eastern uplands to the temperate Mallee country of the southeast, the inland subtropical areas of the far north to the hot, dry semi-arid and arid areas of the far western plains. It extends through three states. Figure 4 shows the extent of the Murray Darling Basin.

1.9 million people live in the Basin. Agriculture is the dominant activity of the Basin. Agriculture is practiced both on the irrigated areas as well as dryland areas. The total area of the crops and pastures irrigated in the MDB is 1,472,241 ha. Agricultural land use consists of crops, pastures and grasses. The total area devoted to crops is 7,137,303 ha. The main crops grown include wheat, barley, rice, oilseeds, cotton and number of horticultural commodities. Commercial agriculture is undertaken on the 51,672 farms. Dryland salinity is a major issue that is threatening productivity, livelihood and infrastructure. The other major environmental issues (MDBC 2004) in the basin include sustainable communities, effective management,
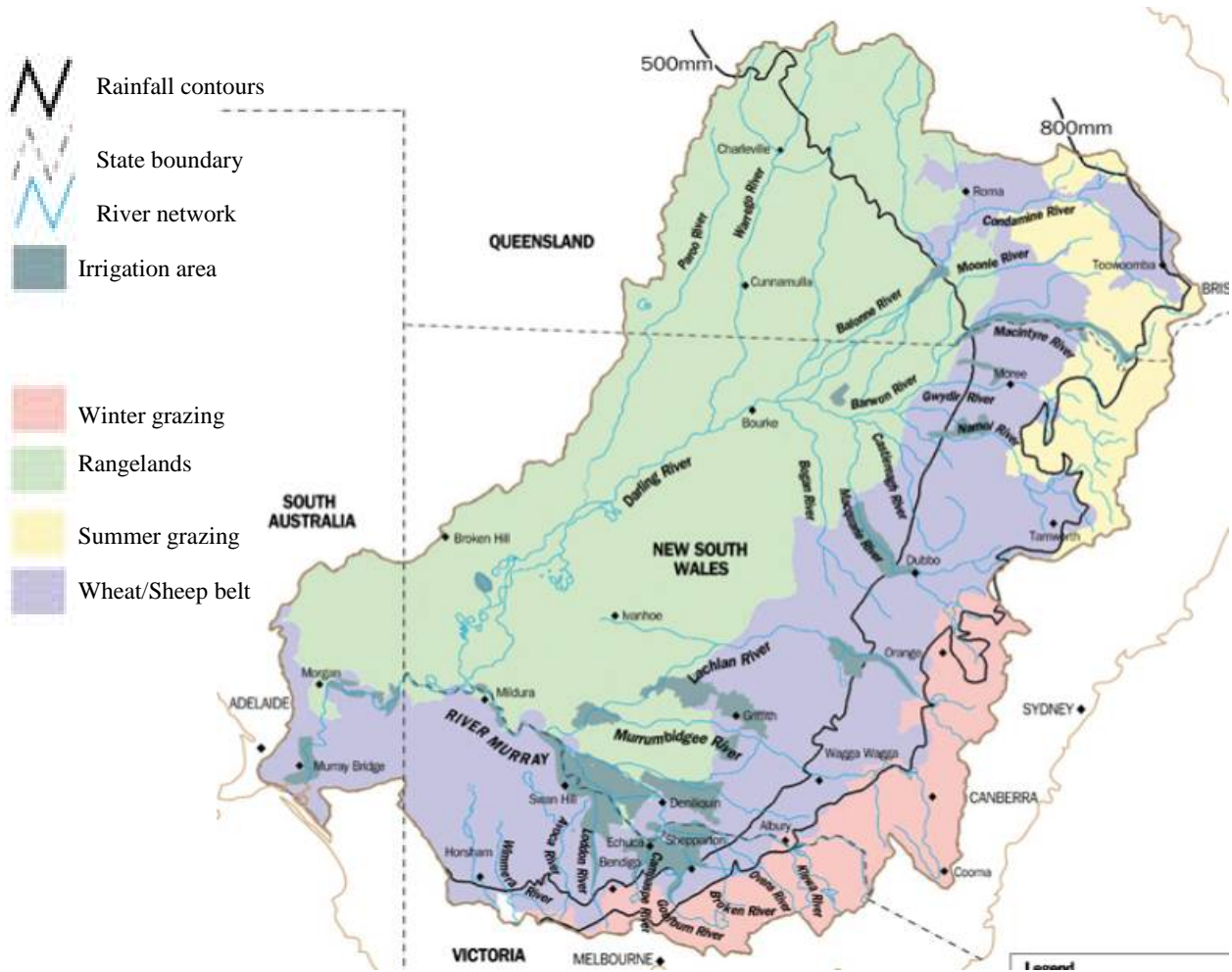
Figure 4 Key Features of the Murray Darling Basin (MDBC 2002)

communication, conflicting values, land capacity, nutrient and sediment export, water allocation, competing demands for water, changed water-flow patterns, using water efficiently and water reliability.

5.0 RESULTS AND DISCUSSION

5.1 Learning Cycle –1

This learning cycle consists of four steps and results in delineation of the domain boundary of the salinity problem. Each step is described below:

5.1.1 Step-1 Problem Description: Snapshots of Current Situation

In the following paragraphs, different snapshots of salinity in the Murray Darling Basin are described as cited in the literature. The term 'snapshot' has been used consistent with its dictionary meaning. In dictionary sense the term refers to:

- "A short description of a small amount of information that gives you an idea of what something is like". (online Oxford English dictionary)
- An isolated *observation.(Houghton 2000)*
- An impression or view of something brief or transitory (Merrium-Webster 2003)

The snapshots described below include the past and current status of salinity in the basin and the literature perceived causes of salinity. These snapshots have been described as an isolated observation and may or may not have relationships with the previous or the next snapshot.

5.1.1.1 Salinity Data snapshots

There are several concerns about the data. These concerns include that a) the trends that data shows are based on the risk associated with the rise of the water-table (NLWRA 2001) rather than actual salinity, b) the new advancement in data collection methods has identified the salt affected lands that actually existed before but were not identified due to the limitations of the methods used for data collection at that time. Other than implementation, the paucity of data can also restrict identification of the appropriate remediation measures. The initiative of salinity and land use mapping is quite recent and there are expected considerable delays in generation of consolidated data-sets. The following excerpts from literature depict the status and the quality of existing salinity data.

- "The paucity of data available to accurately characterize the state of degradation of Australia's irrigated and dryland areas is a major restriction on the implementation of appropriate and priority remediation programs" (Evans, Newman et al. 1996)

- "Even where the data is available (e.g., in Victoria, Southwest Australia), the forecasted groundwater levels to 2020 and 2050 are based on straight-line projection of recent trends in groundwater level. Due to inadequacies in current methods, accurate groundwater surfaces cannot be developed with the existing distributed data" (NLWRA 2000)

5.1.1.2 History of Salinization in the Murray Darling Basin

Land salinity in the MDB has a long history. When Sturt encountered Darling River in 1829, the flow was low and the water was too salty to drink (Crabb 1997). Salinity was perceived as a threat to the profitability of production systems when recharge from large scale irrigated production system caused water-table to rise and reach within two meters of the land surface.

The problem first emerged in the South Australian Murray, then in the Murrumbidgee, Curlwaa, Wakool Irrigation areas (Figure 5) and reach dryland areas (Crabb 1997). And currently, it is considered a risk to the sustainability of agricultural production systems (both dryland land as well as irrigated), river health, water quality, biodiversity and urban infrastructure.

5.1.1.3 Extent of Salinity in the Murray Darling Basin

In the Murray Darling Basin's salt affected lands include 300,000 hectares of dryland and 96000 hectares of irrigated land. 560,000 hectares of irrigated land has watertable within 2 meters of land surface (MDBMC 1999). Around five million tonnes of salts are mobilised every year. Out of this, two million tonnes are transported to sea through rivers while three million tonnes are retained in the land and redistributed to other areas (MDBC 1999). The prediction has been made that within the Murray Darling Drainage Division, the area affected by the dryland salinization will in areas from 2000 (in 1998) square kilometers to 10,000 Square Kilometers by the year 2010 (MDBC 1997). The following excerpts from literature also demonstrate the extent of salinity in the Basin:

- "In NSW, between 120,000 and 174,000 hectares of land are estimated to be affected by dryland salinity" (Prime Minister's Science, Engineering and Innovation Council - PMSEIC 1999; MDBC 1997).

- "Highly saline watertable are rising by half a meter a year in Wagga Wagga"(Standing Committee on Environment and Heritage, 2000)
- "If we continue to use our land the way we do now, by 2050 the area of affected land
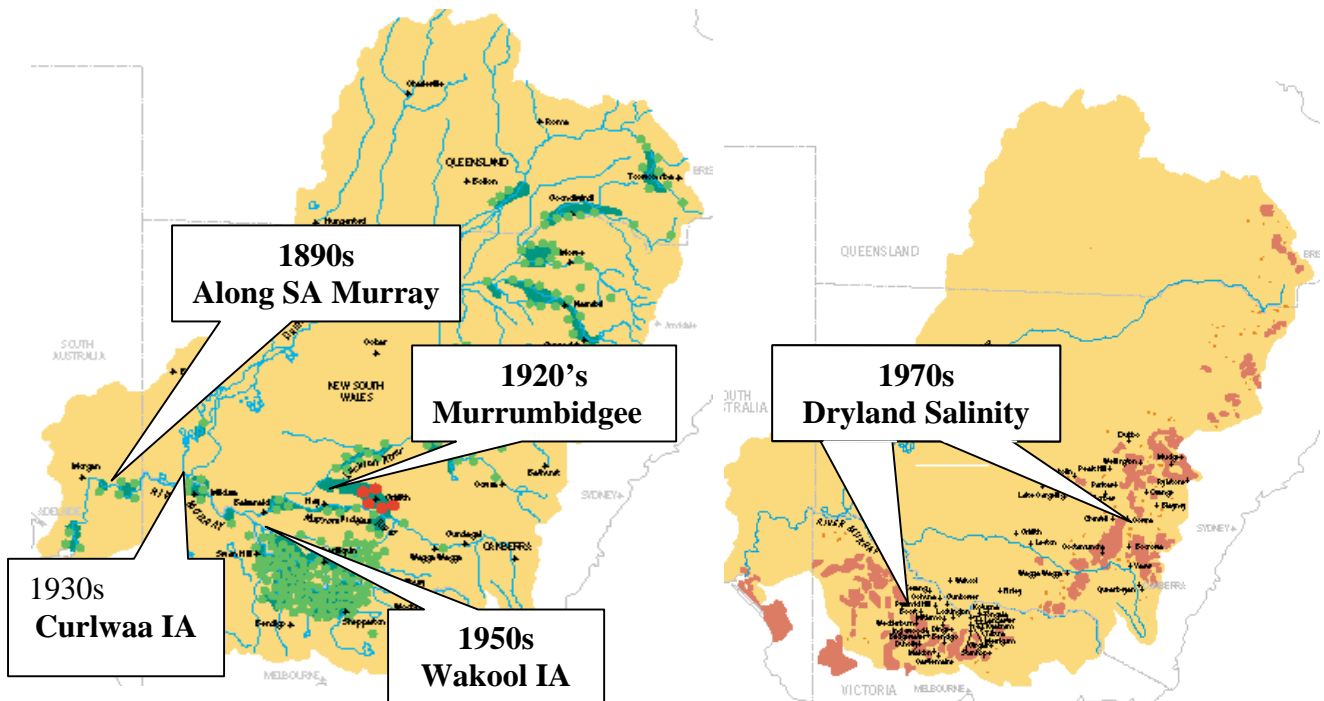
Figure 5 Chronological occurrence of Salinity (left) and dryland salinity (right) shown in brown patches in the Murray Darling Basin of Australia

in the NSW part of the Murray-Darling Basin could increase to 2-4 million hectares. Irrigation salinity is estimated to affect 320,000 ha, or 15% of irrigated land. About 70-80% of irrigated land in NSW is threatened by rising watertables and associated salinity problems" (EPA, 1997).

- "By 2040, 1.3 million hectares of irrigated land in the Murray Darling Basin are expected to be salinized or water logged- due to rising water tables" (Murray Darling Basin Groundwater Working Group, 1996).

- "For salinization to occur, it is necessary to have both an increase in water reaching the groundwater system and a source of salt to remobilize to ground surface. Basin suffers massive imbalances between rainfall and evaporation resulting in concentration of salt in the landscape. Through its geological history, the sediments of the Basin accumulated hundreds of millions of tonnes of salts. Most of these salts lie below the surface. The upward movement of the watertable brings the salt that lie below the surface to the surface" (Evans, Newman et al. 1996)

Salinity is increasing exponentially and it is affecting other areas and production systems like dryland and urban areas. In irrigated areas, the greatest rate of rise is occurring in the Murrumbidgee Irrigation Area, Coleambally Irrigation Area, Berriquin-Denimean-Deniboota Irrigation Area and Goulburn Murray Irrigation Area where Watertables are rising at about 10-50 cm/year (BRS 1999). In Shepparton area the watertable has reached within one meter below the ground surface. Keyworth (1996) expects all irrigated areas in the southern Murray Darling Basin to have watertable within two meters of the land surface by the year 2010.

5.1.1.4 Climate

Climate affects salinity in multiple ways. First, fluctuations in rainfall can affect the recharge and discharge of ground water. An increase in evapo-transpiration from soil surface can enhance the transport of salts towards surface and ultimate formation of the salt crust. Climate change can impact water resources in the MDB in two ways:

- Significant reductions in stream flow in the MDB,
    - 0 to 20% reduction by 2030 (Jones et al. cited in (Howden, Hartle et al. 2003)and
    - 10 to 35% reduction by 2050 (Arnell 1999 cited in (Howden, Hartle et al. 2003).
- "increase in water demand due to increased evaporation rates, lower rainfall. Frequency of general and high security water allocations for environmental flows not being met will increase"(Howden, Hartle et al. 2003)

Based on their analysis, Howden, Hartle et al. (2003) stressed on finding ways to integrate the effects of the climate change into policies and practices.

5.1.1.5 land use

The landscape in the Murray Darling Basin has been changing and will continue to change. The major human induced impacts had been settlement and land clearing for agricultural urban and industrial uses. Agriculture is one of the major sectors for land use change. (Crabb 1997).

- In Australia 20% of the total land area is under forest. The major ecosystems are shrubland, savanna and grasslands. It covers the 88% of the ecosystems in Australia. The cropland and crop/ natural vegetation mosaic covers 6% of the area. A major expansion in agricultural development during 1950s to 1980 had been due to extensive clearing and increase in cultivated area. (World Resources Institute 2003)

- Land clearing started in Australia many years ago and it is still continuing. The term land clearing refers to removal of the natural cover (e.g. forest) from the land for alternative uses. Within various studies conducted by the Australian government, different terms have been used for land clearing. In the "Land Clearing a Social History" (AGO 2000), the term land clearing is used with the above meaning but in the "Carbon Accounting System" (AGO 2000) the terms land conversion and re-clearing have been used. Land conversion refers to the first time clearing of the forest while re-clearing refers to the clearing of the re-growth and conversion to an alternate landuse. The current motivators for land clearing include land availability, clearing controls, environmental and social influences, financial and Institutional incentives, agricultural research and development, and market forces (AGO 2000).

- Graetz, Wilson et al. (1995) assessed that 1,029,640 sq km have been thinned and cleared within intensive landuse zones and most of this is in the Murray Darling Basin. One of the causes of land clearing was conditional purchases. For example from 1860's to 1960's leases and conditional purchases were issued on the proviso that a certain percentage of tree cover was to be removed each year (BRS 2000).

- "The native vegetation regimes evolved to make the best use of available rainfall while avoiding the salts. All vegetation pumps water from the soils and transpire a component to the atmosphere (through the evapo-transpiration process). Any change in vegetation density or type (e.g., a change in vegetation's water pumping capabilities) will alter the volume of water reaching the saturated zone below. Clearing of native vegetation disturbed the current balance." (Evans, Newman et al. 1996)

5.1.1.6 River Water Diversions and Salt Carrying Capacity of Rivers

The diversions from the Murray Darling River have increased. The amount of water presently taken from rivers is not ecologically sustainable and a new balance between the environmental requirements and the consumptive use will have to be struck (Toyne 1995 cited in Crabb 1997:53) These river extraction have increase multi-fold over the last five decades. For example, In 1960 the diversions from the Barwon Darling and the New South Wales and the Queensland tributaries were 50,000 ML while in 1990-91 they were 1.4 million ML. Moreover, the increase in diversion has been primarily due of the cotton industry and the use by the growers of large on farm water storages (Crabb 1997). The following excerpts from literature depict the picture:

"The continuing saga of the extraction of massive amounts of irrigation water from inland rivers to satisfy the escalating demands of the irrigation industry is Australia's most serious, and ultimately most disastrous water related issue" (White 2000).

"The impacts of land clearing and management of the Murray Darling Basin Waters by construction of dams and canals have lessened the variations in flow and salinity. However, the exploitation of the waters has reduced the capacity of the rivers to carry salt to the sea without prejudice to water users in the downstream reaches and has delivered a far higher salt load to the river systems. This has occurred through saline water drainage directly to the rivers and through increased groundwater flows".(Evans, Newman et al. 1996)

5.1.1.6 Delays

Delays in the groundwater system's response to disturbances exacerbate our understanding of the dynamics mechanisms and exactly how they contribute to dryland salinity as it is evident from the following excerpt:

"the groundwater system responded very slowly to these massive disturbances, so the full consequences of the human impacts have begun to be felt only after decades, or even a century. In fact, we know that the incipient degradation processes will often continue for centuries to come. We have now released a time-bomb with slow fuse" (Evans, Newman et al. 1996)

5.1.2 Step-2 Key Variables

In this learning cycle, the following variables have been identified from the problem description described above:
- Agricultural land (hectares).
- Land clearing (hectares).
- Climate:
- Rainfall (mm/year).
- Evapo-transpiration (mm/year).
- Temperature.
- Stream-flow (mean annual stream flow).
- Stream salinity.
- Salt affected Rivers.
- Value of Agricultural production.

5.1.3 Step-3 Collect and plot time series data

In this step, the data was acquired from different secondary sources that include Bureau of Meteorology, the Murray darling Basin Commission, National Land and Water Resources Audit, Green house office, Australian Statistical Bureau and published literature., the data about important variables is presented below in the form of graphs:
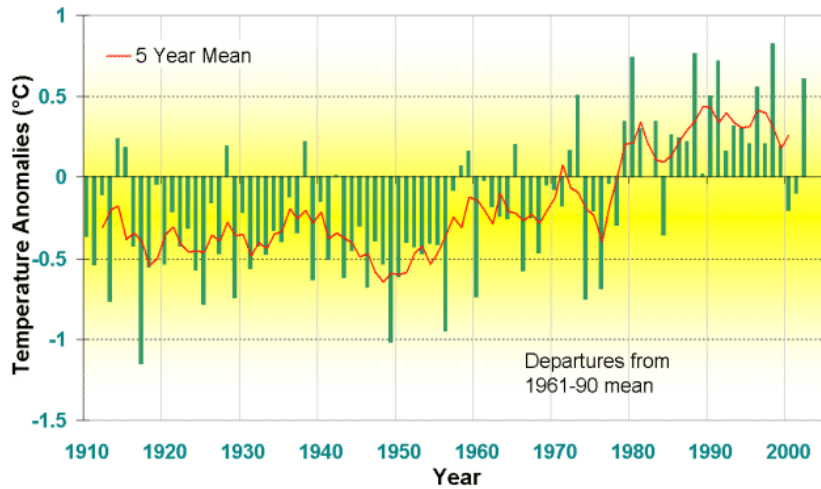
Figure 6 Mean Annual Temperature Anomalies for Australia (BOM 2003)

Figure 8 Annual Rainfall for Australia (BOM 2003)

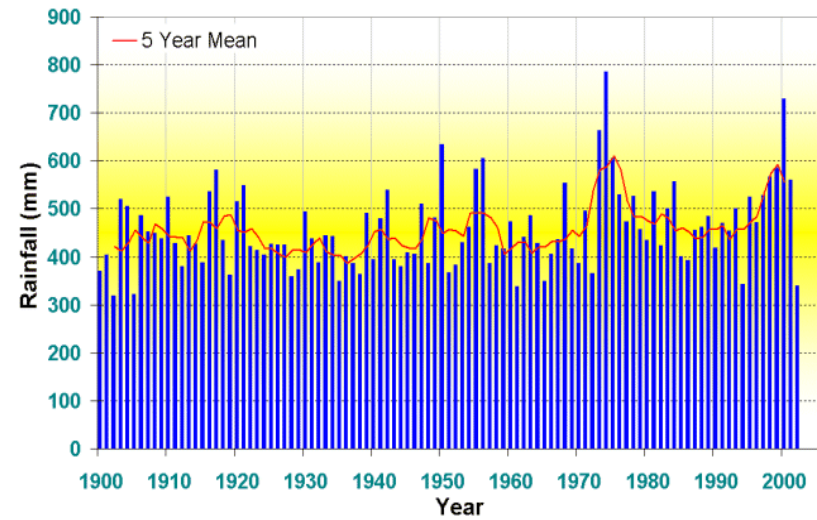**Figure 7 Annual Maximum and Minimum temperature anomalies (base 1961 to 1990) for the Southeast Australia (BOM 2003)**
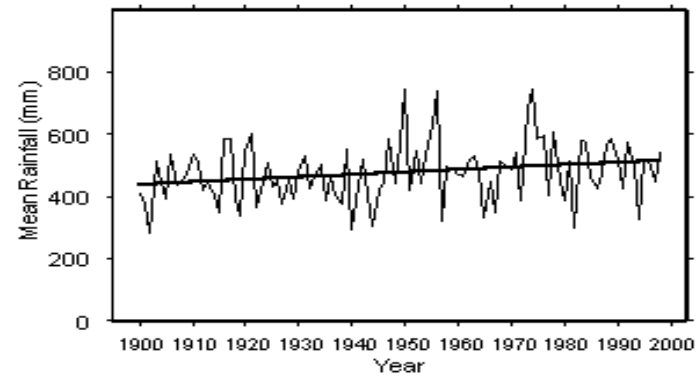

Figure 9 Mean Annual Rainfall in the South East Australia (BOM 2003)
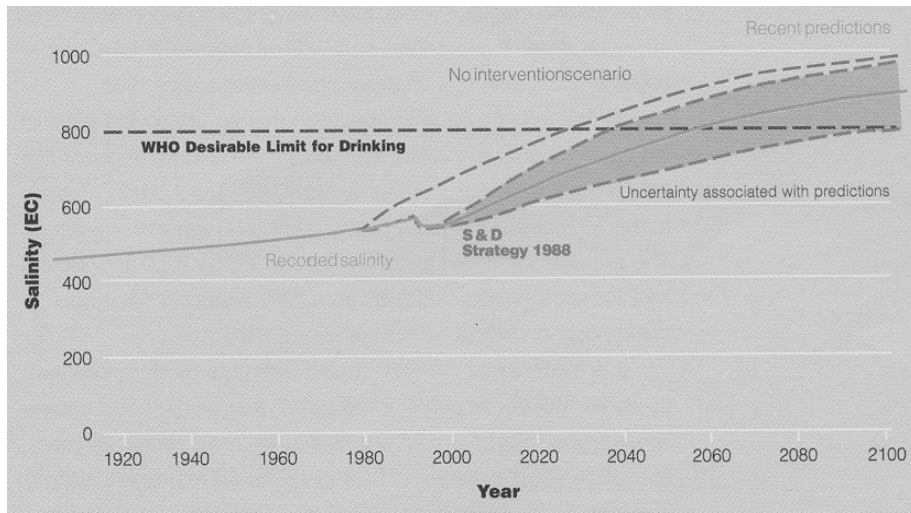
Figure 10 River Salinity at Morgan (MDBC 1999)
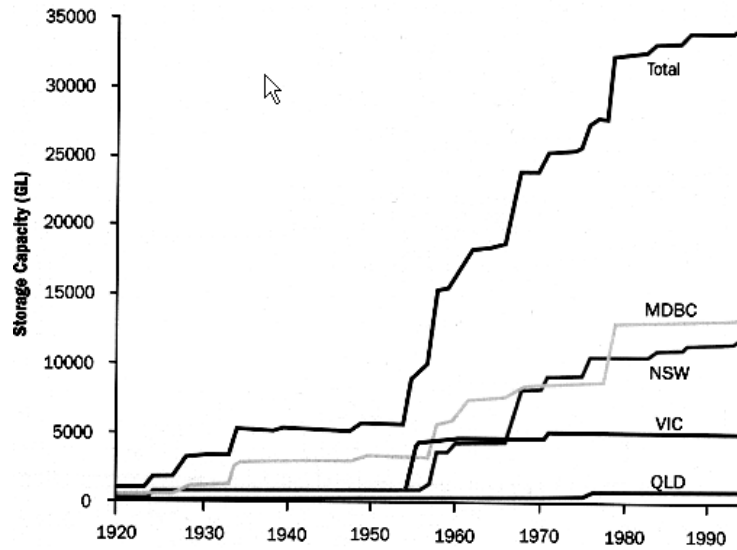

Figure 12 River Salinity in the NSW (MDBC 1999)

Figure 11 Storage Capacity in the Murray Darling Basin (Crabb 1997)
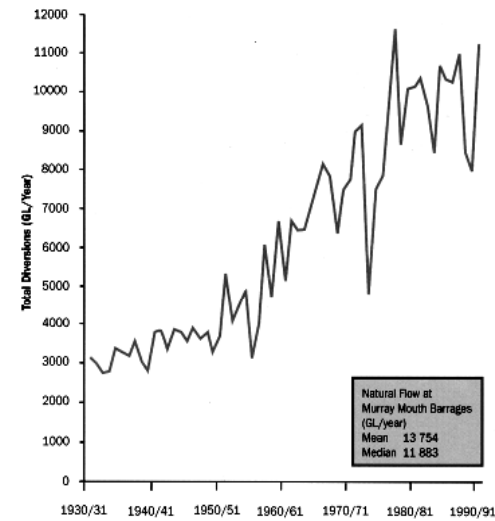
Figure 13 Total Diversions in the Murray Darling Basin (excluding Queensland) Source: (Crabb 1997)
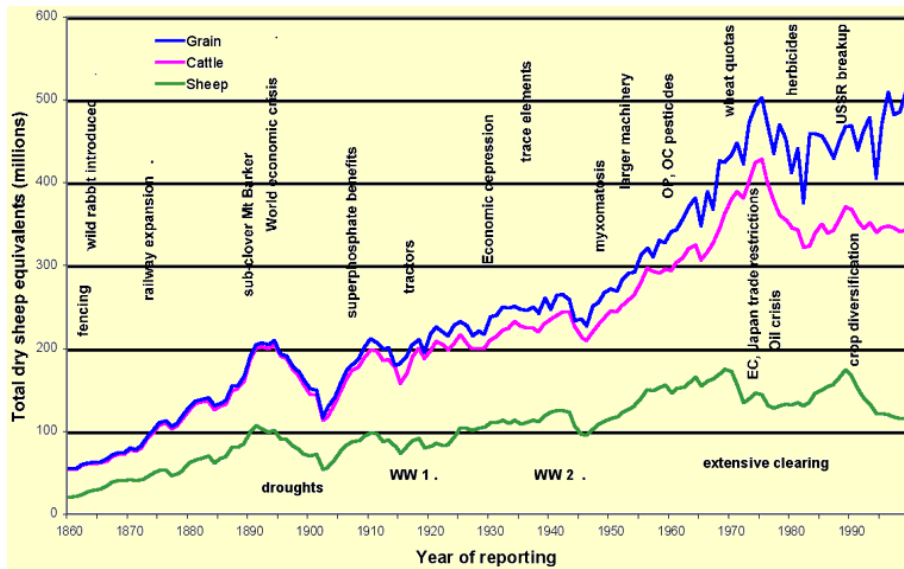
Figure 14 Historical trends of agricultural industry development, converted to dry sheep equivalents (DSE) with major influences (NLWRA 2001)
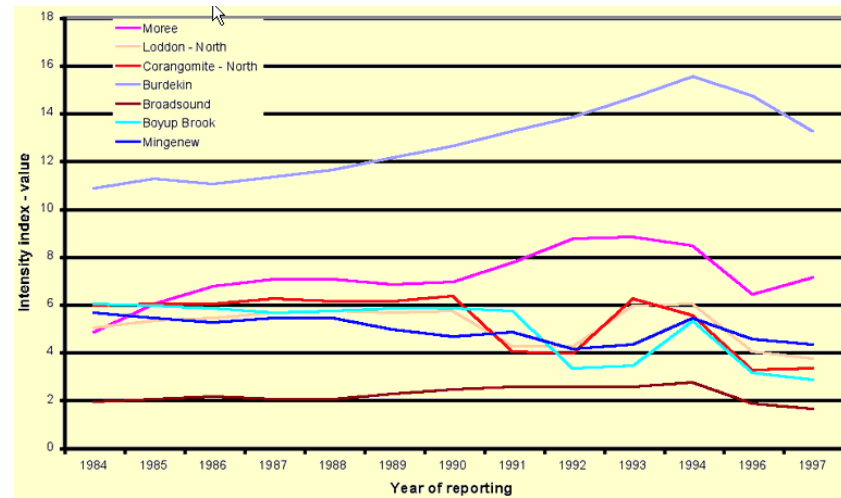

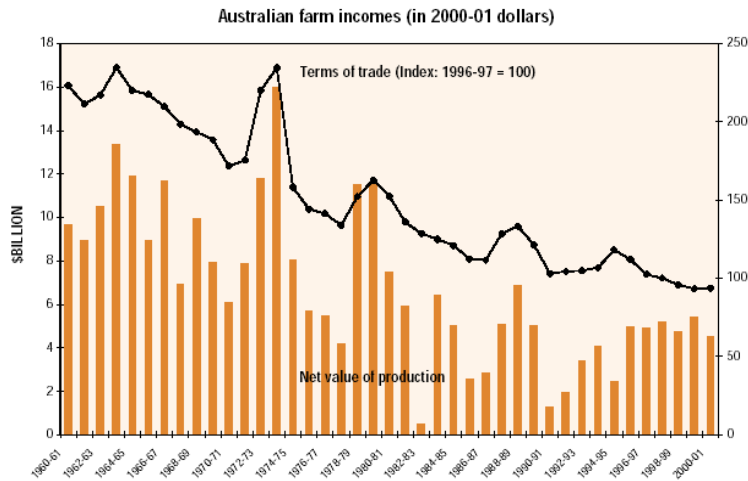**Figure 16 Examples of change in landuse intensity index (NLWRA 2001)**
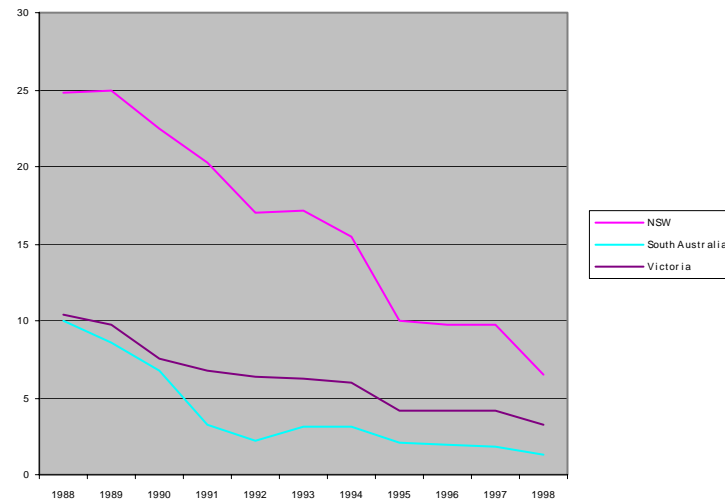

Figure 15 Australian Farm Incomes (AGO 2000)

Figure 17 Time-graph of the land clearing (x 1`ooo' hectares) from 1988 to 1998 (AGO 2002)

5.1.4 STEP 4 Domain Boundary

All the variables identified in the step-2 and plotted in the step three are considered important and have been retained within the problem domain. At this stage the following variable are included in the problem domain:

- Agricultural land (hectares).
- Land clearing (hectares).
- Climate:
    - Rainfall (mm/year).
    - Evapo-transpiration (mm/year).
    - Temperature.
- Stream-flow (mean annual stream flow).
- Stream salinity.
- Salt affected Rivers.
- Value of Agricultural production.

5.2 LEARNING CYCLE-2

In this learning cycle, the changing patterns of the variables identified in the preceding learning cycle are analysed. Complexities of the patterns have been further simplified to aid analysis. This learning cycle consists of four steps. First, the variables identified in the learning cycle-1 have been re-examined from the perspective of their relationship with salinity. The nature of the most data suggests that the further decomposition of the patterns into simpler patterns through Fourier series analysis is difficult. However the general trends amongst the data have been simplified visually and plotted against time for comparison with each other. The output of this learning cycle is the preliminary system boundary.

5.2.1 STEP 5-Examination of Variables

The variables identified in the Section 5.1.4 have direct logical links with salinity. In the following paragraphs, these relationships are discussed.

Climate is the main driver that determines the water fluxes between atmosphere and the land. The parameters considered here are i) temperature, ii) rainfall/precipitation, and iii) evapo-transpiration. Temperature affects the wether and seasonal patterns. It affects both the evapo-transpiration and precipitation. Water provides medium for the movement of salt through the biosphere. Under the forces of evaporation, salts in the groundwater move upwards through soil capillaries towards the soil surface. At the soil/ground surface, water evaporates and leaves the salt crust. Climate is very important model variable and must be included in the model.

Land clearing replaces the vegetation with clear land and affects the net evapo-transpiration and ultimate water balance in the region. Land clearing had been a very significant event in the Murray Darling Basin and must be included in the model. Generally land clearing has been done for the purpose of agricultural development.

Agricultural land hereby refers to land under crops or kept for agricultural purposes like grazing/animal husbandry. It provides a base for the growth of plants/crops. The root system, nutrient use pattern and root-shoot ratio determines the water-uptake by crops. Moreover,

crops vary in their tolerance to salts. This is a variable that cannot be left out from a viable model of salinity.

Stream salinity is an indicator of catchment health, that is, how much salts are leaking or being exported from the land to the water. Moreover, water taken from streams for irrigation purpose depends upon the salinity of streams. It can be included in the model as an indicator of catchment health.

Value of agricultural production/farm incomes indicates the economic viability of agricultural land. Salinity affects the land productivity and hence crop yields and it provides a good indicator of land problems.

5.2.2 STEPS 6 and 7

Steps 6 and 7 have been combined, as the processes of simplification and the processes of graphing are not different in this case. The graphed patterns are shown in the Figure 16 below.
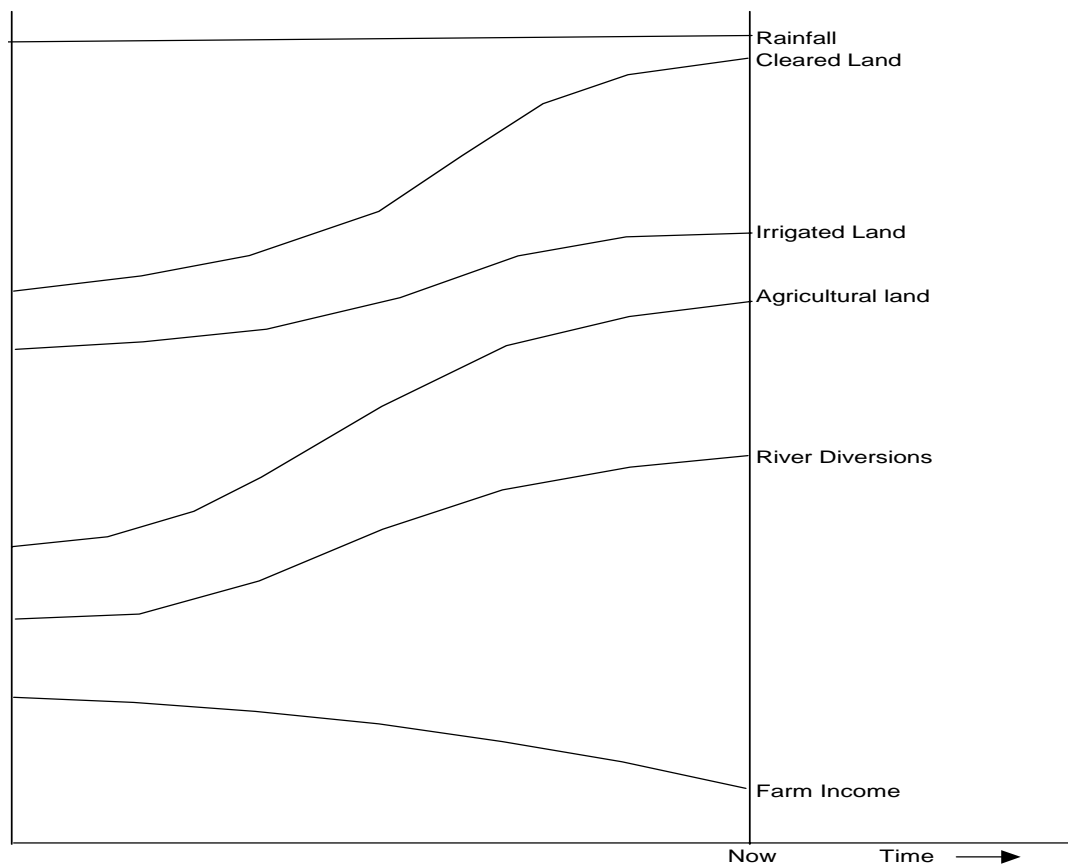

Figure 18 Pattern of Behaviour of Different Variables Overtime

5.2.3 STEP-8

In This learning cycle, data about different variables was simplified and graphed. Time series data about the evapo-transpiration over the Basin was not available and will be addressed in the following learning cycles. The temperature is indirectly reflected in the evapo-

transpiration, therefore, it has not been included in the system boundary. However upon analysis, the following variables have been found to constitute the system boundary:

- Rainfall,
- Evapo-transpiration,
- Agricultural land,
- Cleared Land,
- Irrigated land,
- River diversions, and
- Farm income

5.3 LEARNING CYCLE 3

5.3.1 STEP-9 Examine selected group of patterns

Data presented in the learning cycle 1 and 2 has been collected form the secondary sources and represents state of those parameters at different geographical levels. For example Figures 6 to 9 present climatic data at the national level as well as at the eastern Australia level. The Figures 7 and 9 present temperature anomalies and mean annual rainfall at the regional level. Some information is at the Basin scale for example Figure 10 presents salinity at Morgan that represents the salts collected in water at the downstream of the Basin. In Figure 12, average salinity forecasts are also on the individual river Basin scale but these rivers represent a major part of the Murray Darling Basin. Time graphs shown in the Figure 17, land clearing are at the state level. Storage capacities represented in the Figure 11 are at the state level. River diversions shown in the Figure 13 is summed up at the Basin level while Queensland has been excluded.

The problem of data collection at the basin level is in reported studies for example Australian Bureau of Statistics do not take Murray Darling Basin as one category, therefore, there are problems in the aggregation of data.

5.3.2 STEP-10 Aggregate at the desired level

The concept of aggregation has been used in two perspectives. First it is used for combining the data from different geographical regions. Second, it is used for combining different variables to create new variables at a different level of system. In the following paragraphs, first the problems in geographical aggregation are discussed and thereafter follow the problems in variables aggregation.

At the Basin level, parts of all the four states (not the whole state) are involved. To work at the Basin level, data from all states will be required but the state figures cannot be used as none the whole state is part of the Basin.

Climate information represents three geographical focuses, i) at the national scale and ii) at the regional scale. The climate change phenomenon is occurring over the whole continent and it is no different from the Murray Darling Basin. Therefore the trends shown over the eastern Australia have been adopted. Agricultural production figures presented in the Learning cycle-1 represents the national figures. Over last 100 years the major development of agriculture had been in the Murray Darling Basin. Major Water reservoirs have been built and more land had been brought under cultivation as well as the area under irrigation has increased. Therefore the agricultural development curve may be relatively steeper in the Murray Darling

Basin than the overall Australia figures. Landuse intensity shown in Figure-16 is at the catchment scale. Multiple landuse intensity curves have been shown in different areas of the MDB, however, these don't represent the whole MDB figure. However, these figures indicate an increasing trend in the landuse intensity. The only results available are from the studies for specific projects. Therefore, these are the figures that will have to be taken into account while looking at the landuse intensity. Multiple time series shown in the Figure 17 for land clearing provide data at the state level. Figure 11 shows already aggregated data of water storages.

The three variables, irrigated land, agricultural land, and cleared land are the types of the landuses instead types of land. Land remains same but uses change. Therefore the three variables are aggregated to give to constitute a variable, total land. All those transformation of landuses remain within the total land.

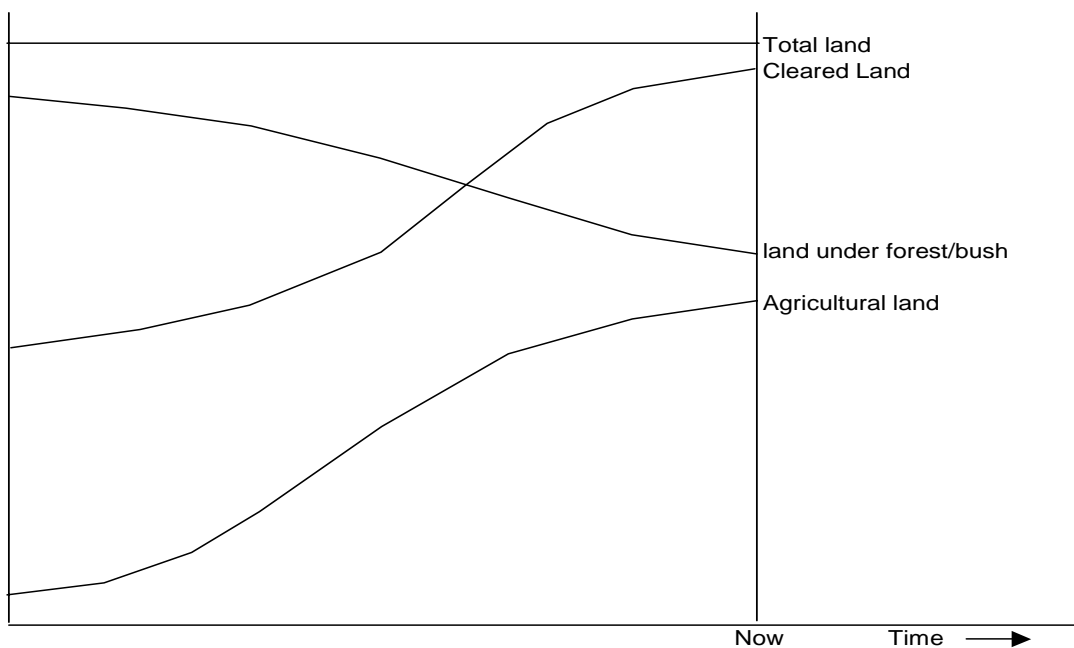### 5.3.3 STEP-11 Graph inferred behaviour of the aggregated and abstract variables

Figure 19 Aggregated Total land

5.3.4 STEP-12 Assemble graphed historical pattern into fabric of model variables

So far the following variables have been identified to be in model

- Total Land
  - o Land under forest/bush
  - o Cleared land
  - o Agricultural land
- Rainfall
- Evapo-transpiration
- River Diversions

5.4 LEARNING CYCLE 4

In this learning cycle, the variables selected in the learning cycle –5 have been examined. On the basis of this examination, variables missing in the examined data have been identified. The graphs presented in the following sections represent our hypothesis about the overtime behaviour of the missing variables. Our hypothesis is based on the ancillary data. The output of this learning cycle is the boundary of salinity model.

5.4.1 STEP-13 Examine selected group patterns

The patterns expressed in the above learning cycles indicate that land clearing is increasing while the total land is constant. River diversions have increased and farm incomes have a general decreasing trend throughout Australia. However these variables present a partial picture. The problem in focus is salinity and the data only does not lead to develop a mode of behaviour for salinity problem. In the following sections, such variables that are missing in data are identified and described.

5.4.2 STEP-14 infer stocks missing in the data

The following stocks seem missing in the data examined above. The term salinity refers to the amount of salts in water. In other words it is a ratio of salts to water in a solution. Therefore the variables describing the physical stocks need to be included in the list of main variables:

Stock of salts: Salt stock is the main important variables as the slats are naturally a part of the earth crust. The movement of water moves salts through different phases of the soil and water and plants, e.g., Stock of Salts in Soil, Stock of Salts in Groundwater, Stock of Salts in rainwater.

Stock of Water: In water cycle, water moves through atmosphere, it passes through land into groundwater, rivers or sea. The snapshots described in the section-xxx indicate that overtime the watertable has come up and has brought salts with it. It indicates an increasing trend in the stock of the groundwater.

Depth to watertable, the generic model that explains salinity states that rise in the watertable provides the medium for salts solubility and brings salts to the soil surface. Any model of salinity should examine the depth of the watertable or the elevation of watertable. When the watertable becomes within 2 meters from the soil surface, the yields of the crops start to decrease depending upon the salt tolerance of the crop.

Other than that, the rates of profit, rates of gross and net rent will need to be included in the specific modules concerning profitability of the farming enterprise. There exists a correlation between the worsening terms of trade and declining value of production

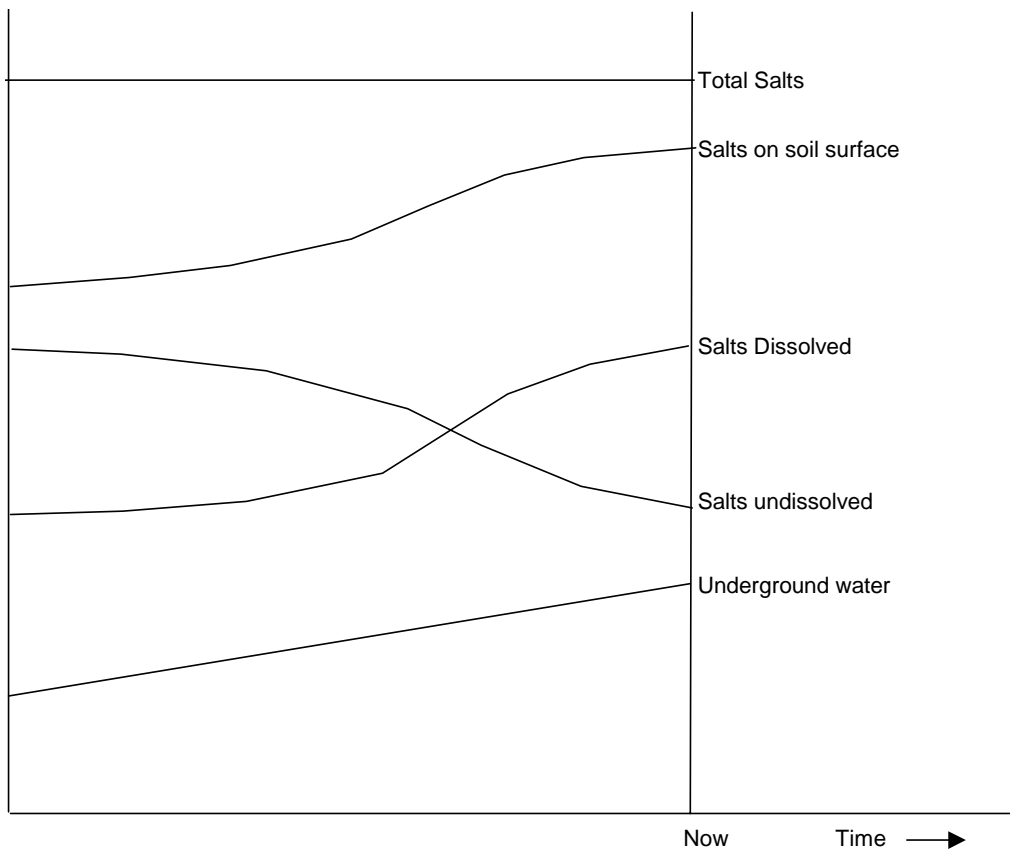### 5.4.3 STEP-15 graph behaviour of the additional stocks missing in data

Figure 20 Behaviour of Missing Stocks

5.4.4 STEP-16 Assemble historical patterns in the decomposed variables into fabric of model variables

At this level, the following variables have been suggested to be included in the model boundary:

- Climate
    - Rainfall
    - Evapotranspiration
- Total land
- Land under forest/bush
- Cleared land
    - Agricultural land
- Salts
- Land surface salts
- Undissolved salts
- River Salts

5.5 LEARNING CYCLE 5

In this learning cycle, the past behaviour of the output of the learning cycle 4 has been examined. Projections have been made into future based on logical relationships. Graphs of

this behaviour are presented. The output of this analysis becomes the reference mode. It contains the variables identified through data, variables missing in data (abstract) and the future trend of the variables.

5.5.1 STEP 17 Examine past behaviour of the variables in the

The past behaviour of the variables has already been discussed. Here only the past behaviour of the missing variables is discussed. The salt stock in land has not changed, the only difference has been that its location has been changed. And its location has been influenced by the stock of water. An increase in recharge has increased the ground water that has resulted in elevation of watertable.

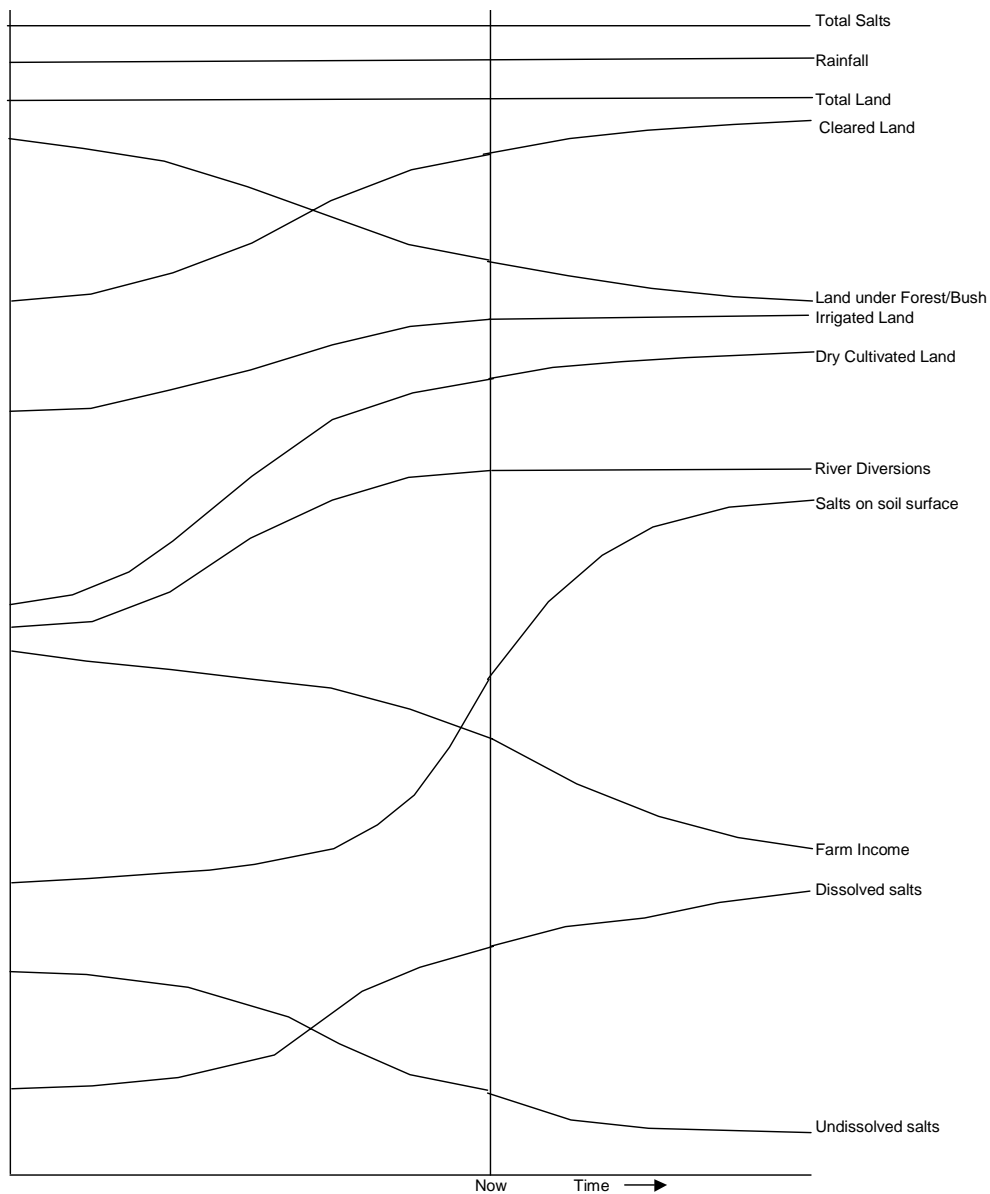## 5.5.2 STEP-18 & 19 projections into future

Figure 21 A Reference Mode for Salinity Problem

5.5.3 STEP 20 Ensure logical consistency

The behaviour shown in the Figure 21 draws its logic from the salinity processes described in literature (Section 5.1). These processes provide a basis for examining logical consistency and may include:

- due to rise in the watertable, the salts in the subsoil become dissolved in the water and move towards soil surface. At the soil surface, the water evaporates and leaves the salt crust. Overtime, due to increase in groundwater recharge due to land clearing, the watertable has increased its elevation and it is still rising at the 0.5 meters/year in Waga Waga. With the overland flow of the rainwater, these salts wash out to the rivers. Diversions from river for human consumption decrease the quantity of available water downstream for dilution of these slats. Graph in Figure show an increase in river diversion.

- River diversions are likely to maintain their current status as shown in Figure 21. It is because of two main reasons i) the awareness about salinity problem has increased. It has inturn increased public pressure for environmental flows. Environmental groups are major stakeholders, ii) the major irrigation schemes have already been built and area has brought under irrigation. There are no planned irrigation schemes.

- The future projections shown in Figure 21 indicate an increase and then smoothening in land clearing. The increase is based on the current status of land clearing. Land clearing is still continuing in the Queensland and on the margins of the wheat-belt in the New South Wales.

- The total salts content, available land and the climatic variables have been considered constant. Although the climate change is happening, it is a very long term process of change. According o the Australian Bureau of Meteorology, there is a slight upward trend in the rainfall but some authors have accrued it to the difference in measurement and analysis techniques. For the purpose of this model, the rainfall trend has been considered as the current.

6.0 INSIGHTS FROM APPLICATION OF SAEED'S METHOD

The application of Saeed (2001)'s method for characterisation of the salinity problem provides several insights about the potential and limitations of this method. The method provides a valuable means for focusing analysts' attention to the main issues. The question of starting "from where" in the fuzzy complex system is a prime one and Saeed's method provides a starting point. However, difficulties were encountered in the use of this method for the salinity problem. These difficulties and the suggested ways to overcome these difficulties are summarised in the following paragraphs. First the overall issues in application of this method are described. Then the issues arising from the structure of the method are discussed.

6.1 Issues in overall process of developing reference modes
6.1.1 Sources of data

Saeed's method relies on the published statistical data as the primary source of information to start with and proceeds to final development of the reference modes. Use of other sources of data are not envisaged in his framework. In situations where, the published statistical data is not available, sources other than such numerical data will typically need to be considered.

These sources may include the knowledge within the mental models of the systems expert/players of day to day systems functioning or written descriptions (Forrester 1994; Ford and Sterman 1998; Sterman 2000).

The method's application, described in the preceding pages, was strongly constrained by the lack of consistent numerical data. Saeed's approach would seem to imply a belief that the system dynamics models can be derived from statistical time series data. Forrester has consistently emphasized that key dynamical properties find their origin in system structure and the policies that guide decisions (e.g., Forrester 1995). In general, Such information is not amenable to statistical collection and must come from the alternative sources of information, for example the mental models of the key role players.

6.1.2 Stakeholders involvement

The involvement of stakeholders in the problem articulation stage is important not only because the stakeholders are:
 i) a part of the problem space as they influence the current system's behaviour through their decisions,
ii) an integral part of learning cycles and
iii) knowledgeable people essential to activities directed at identifying missing variables, missing data or explaining variations in quality of data..

The process of stakeholder involvement in the problem articulation stage also is important in developing the foundation for the subsequent validation process. Ford and Sterman (1997) stressed the inclusion of process knowledge of experts into system dynamics models. Without their involvement, the procedure of problem articulation will remain incomplete. Without their involvement in characterizing the modes of the problem behaviour the identification of reference modes from patchy deficient statistical data becomes a painful process of looking into a magic bowl. The shortcomings identified in this instance might be reduced through extensive and close involvement of stakeholders right from the earliest stages when attempting to identify the preliminary model boundary.

6.1.2 Aggregation of data

Saeed's method has some limitations in its application to the salinity problem. These limitations arise first because of the nature of the salinity problem and second because of the nature of available statistical data. First the available statistical data is not enough to characterize the modes of salinity behaviour based just on the time series data. The data that is available is not classified according to the catchment. It is collected and classified according to administrative boundaries (statistical units). Second, the concept of catchment has different connotations. The surface water catchment does not necessarily coincide with the groundwater catchments. The social catchment, that is the areas influencing, the adoption of resource use practices does not coincide with these either. In those situations, the aggregation of secondary data may not represent the reference behaviour of salinity problem. Available statistical data is from localised studies in different periods in time. Consolidated time series data is not available. Even the Australian Bureau of Statistics' Agstats provides data only from 1984 to 1997 with some parameters or data missing. In such situations alternatives to the aggregate data may also be highlighted.

6.1.2 All variables in reference mode or a few?

From Saeed's paper it appears that all the variables in the model must be represented in the reference mode as the process of model development and development of reference modes is not different. Literature presents a different picture. Ford (1999:185) used only one variable (Deer population) as a reference mode in his Kebab Deer herd while he used only a descriptive reference mode (Ford 1999:226) while his models contained more than one variables. In the company profit problem, Albin (1997) used only two variables (profit and inventory) to designate reference modes of the problem while his model contained more than two variables. He also used four variables to designate reference mode while his model contained more than four variables in the Heroine crime system. This raises the question that instead of having all variables in data, Would not be the only main variables enough to give a reliable reference mode?

6.2 Structural issues
6.2.1 Main framework of the method

The learning cycle approach provides a phased approach for advancement in understanding complex situations. This approach is in line with the reductionist problem solving approaches (i.e., breaking problems into smaller and smaller sub-problems (Joel 2002)). At each stage some data is discarded. The domain is reduced to preliminary system, the preliminary system, in turn is reduced to preliminary model and reference mode (Figure 1). During the whole process, both the model and the reference modes are the product of the same process and same sources of data. Only addition of likely future pattern differentiates a reference mode from the model. Each learning cycle leads to a next level of hierarchy in learning. The diagram representing the methodology (Figure 2 &3) does not explicitly show the linkages between the output of each learning cycle and its place in the entire learning process. Moreover, the process of developing reference needs to be further articulated. This 20 Step 5 stage learning cycle is NOT the articulation process. Articulation process is the agenda one follows and the methods or tools one employs, in e.g., steps 2/3/4. This process should be designed to foster learning.

6.2.2 Duplication

Step by step following methodology uncovers that there may exist some duplication, for example, in step 5, the examination of domain boundary (STEP-4) is suggested. Domain boundary consists of the graphs. The task of examination will involve referring (time and again) to the graph of step-4. The examination of domain boundary can better be performed at Step-4. This will result in unifying steps 4 and 5. The same is the case of steps 4 and 5, steps 8 and 9, steps 12 and 13 and steps 16 and 17. It will reduce the steps from 20 to 16 and will further clarify the approach by removing duplication and without losing logical progression from domain to Reference Mode.

6.2.3 All Steps in series or transition to alternate steps possible

As presented in the method, it appears to be that all steps must be followed to reach a reference mode. In some situations where the available data or the information provided may require the use of alternate steps. Arrangements may be specified for smooth transition from one learning cycle to next when (as presented the methodology looks like a series circuit where every step must be followed) some steps cannot be performed due to the nature of available information or available tools of analysis.

6.2.3 Missing procedures

Some of the steps will need to be further elaborated that how these steps can be performed. A methodology must show how the specified steps are to be performed (Jayaratna 1994). For some steps it is mentioned in detail that how these steps can be performed like step 6 (learning cycle 2) but for some steps for example step5,9,13 and 17 such procedures are not mentioned. The review of these steps from the view of implementation/ practicality can lead towards ease in implementation and natural flow of the methodology.

7.0 CONCLUSION

The study indicates that the Saeed's method is a valuable starting point when identifying variables that might be incorporated into the model. The method helps in identifying data shortcomings. It helps keep the modeller well focused on the problem being addressed. However, difficulties were encountered in application of this method. In part, the difficulties stem from Saeed's expectation that a sound statistical database will be available for key variables. This was not the case in this problem nor, it is suggested, in the generality of dynamic based problems. Variations in the level of aggregation of available data proved problematic, as did a lack of involvement of the many opposite stakeholders in defining the problem space. Whilst most appropriate when consistently aggregated data is available for a specific problem space, Saeed's method was found lacking here. The shortcomings in this instance might be reduced through extensive and close involvement of stakeholders right from the earliest stages when attempting to identify the preliminary model boundary. It is based on the beliefs that stakeholders are i) a part of the problem space as they influence the current system's behaviour through their decisions, ii) an integral part of learning cycles and iii) knowledgeable people essential to activities directed at identifying missing variables, missing data or explaining variations in quality of data. By addressing these issues, a template can be prepared based on the Saeed's method that may help the modellers in problem articulation and development of reference modes.

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