2.0 REVIEW OF LITERATURE AND DEVELOPMENT OF A SYSTEMS ANALYSIS

2.1 Significance and characteristics of the mulga zone

The mulga zone of Queensland occupies an estimated 22 million hectares in the semi-arid to arid south-west region of the state (Figure 2.1). It is characterised by the dominance of mulga (*Acacia aneura* F. Muell. ex. Benth.) associations defined by Perry (1970) as Acacia Low Woodland. The combination of climate, soils and vegetation makes it a unique area, and as a result, it is likely to require specialised management.

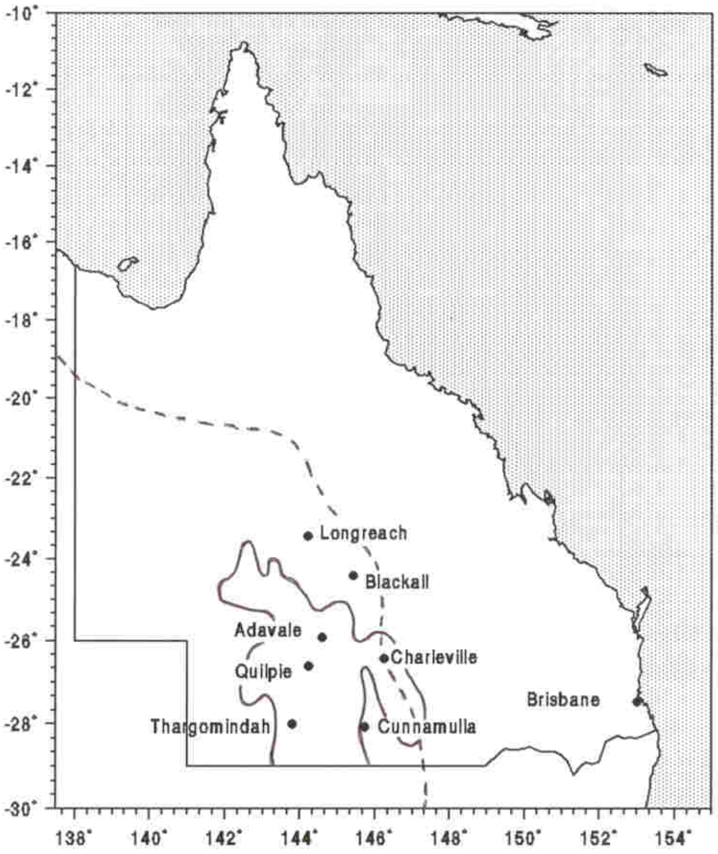

Figure 2.1 Location of the semi-arid zone (dashed line represents the 500 mm average annual rainfall isohyet) and the mulga lands in Queensland (solid line).

2.1.1 Current Land Use and Productivity

Prior to European settlement in the 1860's the region supported a number of aboriginal tribes who were thought to have been in the area for at least 20,000 years (Blake 1979). Since European settlement, the extensive grazing of sheep, cattle and horses has been the major industry. This industry has brought changes to the management and condition of the land and pastoral resources of the region. Continuous grazing and improvements such as fencing and improved water facilities are the major management changes to have taken place.

Proceeds from wool and sheep (average $109M from 1988/89 to 1993/94) and beef cattle (average $106M from 1988/89 to 1993/94) form the major source of income for the region (ABS data). Approximately thirty-six percent of Queensland's wool is produced in the region and 7% of the state's total beef production is derived from the region. In the mulga zone, small cattle herds are generally run in conjunction with predominantly sheep enterprises. To the west of the mulga zone and the dingo barrier fence, cattle grazing is the main enterprise. Grazing properties in the mulga zone range in size from 10,000 ha to more than 120,000 ha and carry 4,000 to 12,000 sheep and 100 to 300 head of cattle (Sullivan *et al.* 1986). Passmore (1990) reports an average property size of 33,000 ha for the mulga region carrying an average 7,000 sheep and 380 head of cattle. When converted to approximate dry sheep equivalents (DSE) (1 dry beast = 8 DSE) this equates to 10040 DSE or 30 DSE/km^2 which is 20% lower than the average of the long-term (1890-1989) livestock numbers from the Murweh and Paroo shires (38 DSE/km^2) reported by Mills and Purdie (1990).

Productivity of grazing enterprises varies widely within the region as a consequence of seasonal conditions, differences in animal husbandry, property management and inherent differences in soils and vegetation among properties and districts. Annual wool production averages 4.5 kg/head and lambing percentages range from 40 to 70%. Steer growth rates vary from 30 to 160 kg/head/year depending on seasonal conditions and brandings average 50% (Sullivan *et al.* 1986). Prior to the decline in wool prices in February 1991, Passmore (1990) reported return on capital, "adjusted to full equity", averaged $34,000 per property or $1.13/ha or $2.66/ DSE.

Concern at the decline in production (pastures and livestock products) from the region has been expressed by a number of authors e.g., Ratcliffe (1937), Burrows and Beale (1969), Pressland (1976, 1984), Mills (1986), WGA (1988), Mills *et al.* (1989) Miles (1989), Passmore and Brown (1992) and Anon (1993). Reliance on feed from browse trees and maintenance of inappropriate stocking rates at critical times have caused pasture degradation and production losses in the region. In the mulga zone, a lack of ground cover, accompanied by increases in sheet erosion and woody shrub cover, are the most common forms of degradation. The processes and extent of degradation have been documented by Burrows (1973), Brown (1981), Beale (1986), Pressland and Cowan (1987), Mills (1986), Mills *et al.* (1989), and Miles (1993). Mills (1989) estimated the gross value of wool production from the "Paroo" mulga area (3 M ha bounded by Charleville, Quilpie, Thargomindah and Cunnamulla) had been reduced by $4.4 M (4.2%) per annum by the effects of erosion and woody shrub cover.

To address these concerns a need to review "carrying capacities" / "stocking rates" was suggested by the Warrego Graziers Association (1988), Mills *et al.* (1989), Miles (1989) and Anon. (1993). This review is currently (July 1996) a component of an integrated regional adjustment and recovery program for south-west Queensland termed “The South West Strategy” (Williams 1995). This thesis develops an approach to address the determination of appropriate grazing capacities for use in strategic (20-30 year) decisions on livestock numbers as a central issue for the natural resource management component of the South West Strategy initiative. If appropriate grazing capacities can be estimated and adopted, a closer examination of methods to better estimate tactical (seasonal-annual) stocking rates could then be made. While recognising the linkage between short term stocking rates and longer term grazing capacities this thesis focuses on the establishment of “safe” grazing capacities as a starting point for sustainable grazing land management. Once these are established, mechanisms to examine short term stocking rates could then be developed. This thesis does not aim to explore the examination of short term stocking rates.

In south-west Queensland the grazing capacity issue is not confined to sheep and cattle. Kangaroos, feral goats, rabbits, termites and locusts do graze the same pastures as sheep and cattle though the relative densities of species varies across the landscape and over time. The term "total grazing pressure" accounts for the total level of pasture utilisation resulting from domestic, feral and native animals. Due to the nomadic nature of feral and native grazers it is difficult and sometimes controversial to quantify the pressure exerted by these animals on the pasture resource. The contribution to total grazing pressure and degradation from these animals is only now being determined quantitatively (Wilson 1991, Norbury *et al.* 1993, Hacker *et al.* 1995 and Landsberg *et al.* 1996).

In semi-arid areas it is often difficult to determine whether observed degradation is the result of year to year variation (reversible), or a long-term rundown in resource condition. This is due to the difficulty both graziers and land administrators have in separating the effects of management from year to year variation. Within the mulga zone, pasture biomass can fluctuate from less than 100 kg/ha to 1200-1500 kg/ha in a decade (Mills 1986). In addition, animal productivity is not always a good indicator of pasture condition as animal production can be maintained for some time after pasture deterioration has occurred (Beale *et al.* 1984). A long-term approach to managing livestock in the region is therefore required. Similarly, a long-term approach to monitoring regional productivity is also required. Despite the lag between a decline in livestock productivity and a decline in pasture productivity, Abel and Blaikie (1989) suggest that ‘the rate at which the land yields livestock products’ is still a valuable indicator of degradation for pastoralism within rangeland systems, and that livestock productivity should be monitored. In recognising these complexities, a systems analysis using computer modelling with historical climate, livestock and financial records potentially offers an approach to separate the effects of management from the effects of year to year climatic and economic variability. This thesis develops this approach.

2.1.2 Significance of native pastures

Native pastures have contributed significantly to the rural industry and economy of Queensland for the last 145 years.

Queensland has the largest area of native pasture (151 M ha or 87% of total area) of all the Australian states (Lloyd and Burrows 1988). In addition, the proportion of the state's total native pasture area used as natural grazing land is greater than any other state in Australia or any other country in the world. The mulga zone represents 14.5% of the State's native pastures.

Most of Queensland's cattle and virtually all of its sheep graze native pastures, indicating approximately one third of Queensland's primary producers substantially depend on these pastures for their income (Lloyd and Burrows 1988). The gross contribution to the State's economy of production from native pastures is estimated at $1125 M annually (1983-84 data) (Lloyd and Burrows 1988).

Much of Queensland's native pastures lie in semi-arid, sub-tropical and tropical environments where climatic conditions and soil factors limit the potential for cropping and improved pasture development. The mulga zone fits this description with only limited areas successfully developed with improved pastures (predominantly Buffel grass - *Cenchrus ciliaris*).

Thus the better management of native pastures is likely to be of greater importance in the mulga region than further development with introduced species (Smith and Silcock 1986).

2.1.3 Climate

The climate of the mulga zone is characterised by a low and unreliable rainfall, high evaporation rates and extremes of temperature. Meigs (1953) described the climate of the zone as semi-arid with hot summers, cold winters and rain at any season. Climatic data for Charleville are presented in Table 2.1.

On average, summer months have a greater mean rainfall, higher intensity rainfall, and higher evaporation rates than winter months. Rainfall variability is high throughout the year, but is highest in summer months. Droughts or floods can occur at any time. Drought frequency and indices of rainfall variability for Charleville are compared with those for Gayndah and Hughenden (two centres located outside south-west Queensland) (Table 2.2). Drought frequency for nine south-west Queensland shires, as defined by the Queensland State Government (annual rainfall less than 60% of average) is illustrated in Figure 2.2. By this definition "droughts" are frequent. An alternative analysis by Clarkson and Owens (1991) indicates the frequency is slightly less.

Table 2.1 Monthly climatic data for Charleville (26° 25'S 146°16'E elevation 306 m) (Bureau of Meteorology)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Rainfall (mm)													
Mean	68	67	61	33	32	28	21	20	21	35	41	57	493
Median	47	50	30	19	22	21	16	10	8	22	25	45	468
Lowest	3	0	0	0	0	0	0	0	0	0	1	1	203
Highest	308	400	382	248	199	128	220	125	127	188	190	235	1202
Temperature (°C)													
Mean max.	34.6	34.0	31.7	28.4	22.9	20.1	19.5	21.7	25.7	29.8	33.0	34.5	28.0
Mean min.	21.5	21.2	18.5	13.8	8.6	5.1	3.5	5.5	9.4	14.3	17.7	20.0	13.3
Pan Evaporation (mm/day)	11.2	9.8	7.9	6.3	4.1	3.4	3.7	4.7	6.5	8.7	11.4	12.2	2730
Vapour Pressure Deficit (hPa)	31.3	27.0	21.1	16.1	9.3	7.2	8.1	11.1	16.9	23.6	31.8	34.2	19.8
Rainfall / Evaporation	0.20	0.24	0.25	0.17	0.25	0.27	0.18	0.14	0.11	0.13	0.12	0.15	0.18

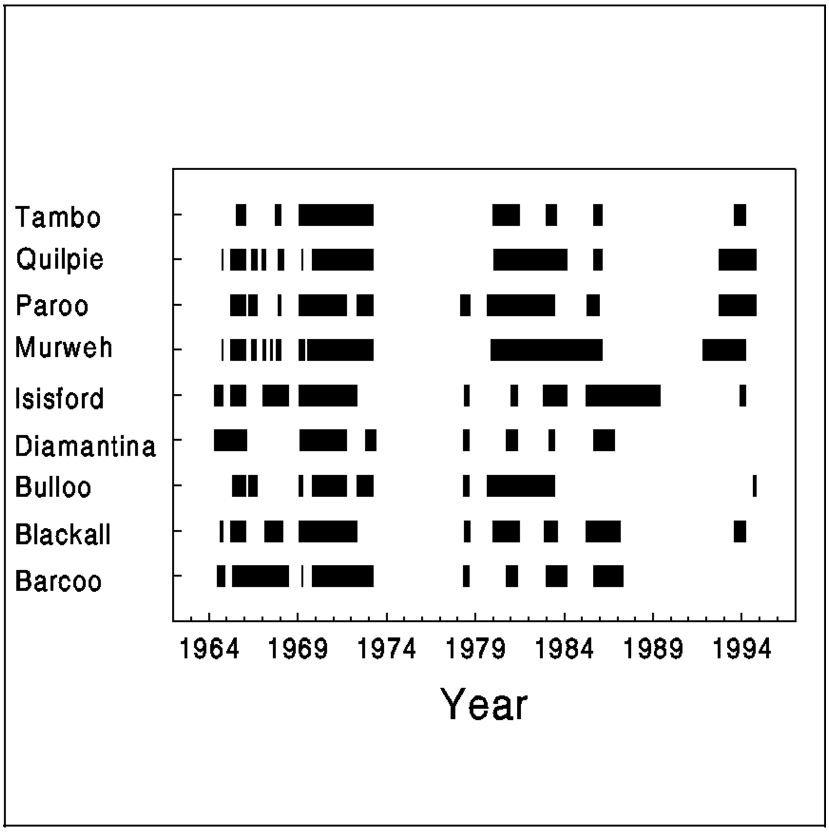

Figure 2.2 Declared drought periods for nine south-west Queensland shires from 1964 to 1994 (Queensland Department of Primary Industries).

Evaporation rates are high and vary from 2100 mm to 3000 mm annually at Charleville (four to five times the annual rainfall). December has the greatest evaporation (280 mm) and July the lowest (75 mm). The ratio of rainfall to evaporation does not exceed 0.3 for any month of the year indicating the high potential for moisture to limit plant growth (Table 2.1). This is supported by Fitzpatrick and Nix's (1970) average moisture index for Charleville not exceeding 0.4 throughout the year (Table 2.2).

Extremes of temperature are common. At Charleville, the hottest month is January with mean maximum and minimum temperatures of 34.6°C and 21.5°C respectively. In the coldest month, July, mean maximum and minimum temperatures are 19.5°C and 3.5°C respectively. Frosts are common in much of the region with Charleville averaging 50 to 100 frosts annually, occurring from mid-June to mid-August.

The mean monthly vapour pressure deficit at Charleville ranges from a maximum 34.2 hPa in December to a minimum of 7.2 hPa in June. The vapour pressure deficit, a measure of the dryness of the air, influences plant growth. Plant water use is less efficient when the vapour pressure deficit is high (Tanner and Sinclair 1983).

Failure to recognise the seasonal variability and potential interactions with economic variability may lead to land, livestock and financial management problems for grazing enterprises in this region.

Table 2.2 Comparison of indices for drought and climatic variability for three locations in Queensland.

Index*	Charleville	Gayndah	Hughenden	Reference
1.	2 - 3 in 10	1 in 10	1 -2 in 10	Daly and Dudgeon (1987)
2.	2.0 in 10	1.7 in 10	1.7 in 10	Clarkson and Owens (1991)
3.	1.8 in 10	1.4 in 10	1.3 in 10	Clarkson and Owens (1991)
4.	55	57	37	Clarkson and Owens (1991)
5.	1.09	0.71	1.07	
6.	0.95	1.03	0.99	
7.	0.42	0.27	0.42	
8.	0.2 - 0.4	0.6 - 0.8	0.2 - 0.4	Fitzpatrick and Nix (1970)
9.	0.2 - 0.4	0.4 - 0.6	< 0.2	Fitzpatrick and Nix (1970)
10.	< 0.2	0.2 - 0.4	< 0.1	Fitzpatrick and Nix (1970)
11.	0.18	0.37	0.17	

* Key to indices;

1. Drought frequency expressed as the number of drought years expected in every ten years. (Drought = Annual rainfall less than 60% of average, the index used by the Queensland Treasury Department).
2. Drought frequency expressed as the number of drought years expected in every ten years. (Drought = Driest 10% of calendar years).
3. Severe drought frequency expressed as the number of severe drought years expected in every ten years. (Severe drought = Driest 5% of calendar years).
4. Average proportion of time each drought spends as a severe drought (driest 5% of calendar years).
5. Index of rainfall variability (Decile 9 - Decile 1)/mean annual rain.
6. Index of rainfall variability (Median annual rain/Mean annual rain).
7. Index of rainfall variability (SD mean annual rain/Mean annual rain).
8. Soil moisture index, Summer (October - March).
9. Soil moisture index, Winter (April - September).
10. Soil moisture index, driest sixteen week period.
11. Ratio of Annual mean rainfall to Annual mean pan evaporation (Total).

2.1.4 Soils

The soils of the mulga zone are diverse, and have been described by Northcote *et al.* (1968), Dawson and Ahern (1973, 1974), Walker and Fogarty (1986) and Ahern and Mills (1990). Red earths predominate. These include loamy red earths (Gn2.11, Um1.43), sandy red earths (Uc1.23, Um5.51), earthy sands (Gn2.12), siliceous sands (Uc1.22) and lithosols (Uc1.43) (Ahern and Mills (1990)). Intermixed with the red soils are alluvial clay soils (Ug5.24), cracking clay soils (Ug5.34) and texture contrast soils (Dr2.53). These soils are mainly confined to water courses, and while only small in area, contribute significantly to the livestock production of the region.

The red earths, sands and lithosols of the mulga zone are structureless and prone to surface sealing and erosion by wind and water. Water holding capacity is low, with soil water held at field capacity ranging from 8 to 18% (mean 13%) and at wilting point ranging from 4 to 11% (mean 7%) (Dawson and Ahern 1973). Infiltration rates are variable and depend on the level of surface sealing. Levels of available phosphorus, total nitrogen and organic matter are low and decrease rapidly with depth. Greater than 95% of available soil nutrients are held within the surface 15mm of soil (Pressland and Cowan 1987). Soil depth varies considerably ranging from only a few centimetres on the lithosols, to several metres on the earthy sands. The soils are acidic in reaction, with iron and aluminium oxides responsible for the red colouring.

In contrast, the clay and texture contrast soils are alkaline to neutral in reaction, have greater water holding capacity and nutrient levels. The cracking clay soils are typically blocky with crumb, granular, platy or blocky structure. The texture contrast soils have predominantly a massive surface soil over-lying a more structured subsoil (Dawson and Ahern 1974). Calcium is present in many cracking clay soils and texture contrast soils. It is present as concretionary or soft lime and in some instances gypsum.

The diversity of soils in the region contribute to the complexity and variability of the environment with which management must contend.

2.1.5 Vegetation

The vegetation of the mulga zone has been described by several authors: Blake (1938), Beadle (1948), Everist (1949), Perry (1970), Specht (1981), Johnson and Burrows (1981), Boyland (1984) and Neldner (1984 and 1986). Trees and shrubs of the *Acacia* genus characterise much of the area. Mulga (*Acacia aneura*) is the most common species. Other tree species growing in association with mulga include *Eucalyptus populnea* (Poplar Box), *E. terminalis* (Western Bloodwood), *E. cambageana* (Blackbutt), *E. melanophloia* (Silver-leafed Ironbark), *E. thozetiana* (Mountain Yapunyah), *Grevillea striata* (Beefwood), *Atalaya hemiglauca* (Whitewood), *Hakea ivoryi* (Corkwood), *Geijera parviflora* (Wilga), *Alstonia constricta* (Bitter bark) and *Flindersia maculosa* (Leopardwood). Associated shrubs include *Cassia* spp., *Dodonaea* spp., and *Eremophila* spp..

Depending on the seasonality and amount of rainfall, mulga pastures can support a wide variety of herbage species. Grasses usually predominate after summer rainfall, and a range of forb species after winter rainfall (Purdie and McDonald 1990). Over half the total species in the area are ephemerals or short lived perennials, their presence determined by specific seasonal conditions.

Perennial grasses include *Amphipogon caricinis* (grey beard grass), *Aristida* spp. (wire grasses), *Chloris* spp., *Digitaria* spp., *Enneapogon* spp. (bottle washer grasses), *Eragrostis* spp. (love grasses), *Eriachne* spp. (Wanderrie grasses), *Monachather paradoxa* (mulga oats), *Panicum* spp., *Sporobolus* spp., *Thyridolepis mitchelliana* (mulga mitchell) and *Triodia* spp. (spinifex).

Under suitable seasonal conditions annual grasses such as *Dactyloctenium radulans* (button grass), *Paspalidium* spp., and *Tripogon lolliformis* (five-minute grass) proliferate. Annual forbs include *Ptilotus* spp. (foxtails), *Trachymene* spp., *Calotis* spp. (daisy burrs), *Helichrysum* spp. (everlastings), *Helipterum* spp. (paper daisies), *Atriplex* spp. (annual saltbushes), *Maireana* spp. (bluebushes), *Sida* spp., *Abutilon* spp. and *Velia* spp..

The variability in composition, quantity and quality of vegetation in the region needs to be acknowledged when managing for sustainable pasture and animal production. The challenge addressed in this thesis is how to manage with this variability to achieve sustainable grazing land management.

2.2 Grazing management, stocking theory and pasture utilisation

There is considerable debate in the literature over the definition, derivation, use and relevance of grazing capacity values (Bartels *et al.* 1993). Nevertheless, graziers, land administrators and financiers need to make strategic decisions on grazing capacity (20-30 years) and tactical decisions regarding stocking rate (seasonally or annually). While stocking rate theory (e.g. Jones and Sandland 1974, Hart 1978, 1986, Danckwerts 1984, White 1987, Turner and Tainton 1989, Vallentine 1990, Heitschmidt and Taylor 1991, Abel 1992, Behnke and Scoones 1993 and Holechek *et al.* 1995) and the impact of stocking rates on rangelands (Ash and Stafford Smith 1996) has been examined worldwide, there are few practical tools available to guide the estimation and implementation of sustainable grazing capacities. Most rely on ‘gut’ feeling, local knowledge and experience in determining appropriate livestock numbers despite the volume of science and theory directed at the issue. A similar conclusion was drawn by Holechek (1988) for rangelands in the USA. In contrast, Bartels *et al.* (1993) questions the validity of the carrying capacity concept in the communal rangelands in sub-Saharan Africa and recommends its application be stopped. In this thesis the carrying capacity concept as it applies to Western range management, where livestock are mostly confined by fences and the land owned or leased by individuals, is discussed.

Before continuing, some definitions of terms related to grazing land management are reviewed briefly.

2.2.1 Definitions

Grazing capacity (DSE/ha) is the number of animals that produces the greatest return without damage to the physical resources and in concert with other values received from the land (Heady 1975). In general terms it is the average number of animals that a particular pasture will sustain over time and in most cases is the figure determining the dollar value of properties being bought and sold (Holechek *et al.* 1995).

Carrying capacity (DSE/ha) is defined by The Macquarie Dictionary (1981) as the capacity of land or pasture to support livestock. It is also used synonymously with grazing capacity. However, it can be differentiated from grazing capacity to include harvested forages and other materials used in conjunction with grazing (Vallentine 1990a). It is therefore a means of summarising total property capacity. Heady (1975) stresses carrying capacity should not be confused with grazing capacity. He describes carrying capacity as the greatest return of combined products without damage to the physical resources. However, more recently Heady and Child (1994) equate carrying capacity with grazing capacity.

Stocking rate (DSE/ha) is the number of animals of a specified class, or animal units, per unit area of land over a specified period of time (Heitschmidt and Taylor 1991). Different classes of stock are converted to standard units or animal equivalents for comparison across classes. In this thesis, dry sheep equivalents (DSE) as defined by Anon. (1977) are used, and the stocking rate is expressed as DSE/ha or DSE/km^2.

Actual stocking rates may vary considerably between years due to fluctuating forage conditions. An average of the stocking rates possible year after year without damage to the land resource can define a carrying or grazing capacity (Holechek *et al.* 1995).

Grazing pressure is defined by Vallentine (1990b) as the animal demand for forage per unit weight of forage at any time. Cumulative or total grazing pressure relates the total animal demand (including feral and native animals) for forage to the amount of forage available. Grazing pressure fluctuates widely over time and space as a result of variations in forage quality and quantity caused by environmental factors such as rainfall, soil fertility, slope and aspect, and management factors, but chiefly stocking rate decisions (Heitschmidt and Taylor 1991).

Utilisation refers to the percentage of the current year's forage production that is consumed and/or destroyed by herbivores (Holechek *et al.* 1995 from Society for Range Management 1989). Quantitatively it is expressed as;

Utilisation % = [(Forage eaten + Forage trampled) / Forage grown] * 100

Utilisation measurements have many uses in grazing management. The most important are in assessing and adjusting stocking rates. The links between utilisation and stocking rates are explored later in this section.

The term "forage" has been used above to describe plant material consumed and destroyed by grazing animals. In section 2.3 the term "forage" and techniques for estimating forage production are described. From a practical point of view the quantity of material "trampled" is difficult to quantify whilst the amount "eaten" can at least be measured in pen studies. In this thesis the term utilisation will refer to the percentage of material eaten of what has grown unless otherwise specified. I.e.

Utilisation % = (Forage eaten) / (Forage grown) * 100

For semi-arid environments there are a number of limitations to these definitions:

1. They assume a single equilibrium is attainable between rainfall, forage growth and land condition on the one hand and the stocking and intake rates on the other. In semi-arid environments characterised by variable rainfall, non-equilibrium systems and multiple states are more applicable (Westoby *et al.* 1989). The attainment of one equilibrium (if any) is unlikely under these conditions.
2. They assume there is a threshold density of animals or level of forage utilisation above which degradation occurs and below which it does not.
3. The definitions do not clarify the "return", nor do they define the type or level of degradation resulting from grazing; and,
4. In south-west Queensland domestic livestock may only represent a portion of the total number of herbivores in the system. Other herbivores include kangaroos, feral goats and pigs, rabbits and insects. Studies in western New South Wales (Hacker *et al.* 1995 and Landsberg *et al.* 1996) and in south-west Queensland (L. Pahl, pers. comm.) have found that kangaroos and feral goats can contribute more than half the total grazing pressure.

The need for definitions relevant to semi-arid grazing lands is highlighted. Heady and Child (1994) recommend a careful choice of words when describing grazing capacities for specific situations. To avoid confusion definitions need to be quantitative and reflect non-equilibrium conditions.

In this thesis a temporal distinction is made between grazing capacity and stocking rate. Grazing capacity refers to livestock numbers in a long-term, strategic (20-30 year) time frame and stocking rate refers to a shorter term, or tactical (seasonal-annual) time frame.

2.2.2 Stocking theory

Determination of the appropriate stocking rate is the most important of all grazing management decisions from the standpoint of vegetation, livestock, wildlife and economic return (Holechek *et al.* 1989). Grazing pressure is the principal force, together with fire and cultivation, controlling species composition and forage production which the manager can manipulate (Heady 1975). The choice of stocking rate and the resulting grazing pressure also have a profound effect on both the immediate and the long-term animal productivity of the range. The immediate effect arises from changes in the quality and quantity of available forage at different levels of utilisation. The long-term effect on productivity arises from changes in the density and composition of the natural pasture community (Wilson *et al.* 1990).

The complex and highly variable relationships between stocking rate, production per animal, and unit of land have been reviewed by Jones and Sandland (1974), Hart (1978, 1986), Danckwerts (1984), White (1987), Holechek *et al.* (1989), Turner and Tainton (1989), Vallentine (1990b), Heitschmidt and Taylor (1991), Abel (1992), Behnke and Scoones (1993) and Holechek *et al.* (1995).

In general terms, at low stocking rates, individual animal performance is maximised as grazing pressure is low and forage quality is high. However, animal production per unit area is low as the number of animals per unit area is low. As stocking rate is increased individual animal performance declines because of restrictions imposed on nutrient intake by reductions in either quantity and quality of forage on offer, or increased energy use by animals. The stocking rate at which this decline begins is referred to as the critical stocking rate (Hart 1978). Production per unit area, however, continues to increase as stocking rate increases because of the increase in the number of animals. This increase continues to some maximum as stocking rate is increased, but eventually it too decreases as nutrient intake becomes progressively more restrictive (Heitschmidt and Taylor 1991).

Thus, for sustainable production from native pastures the links between grazing capacity and pasture utilisation are most important and will be explored here. However, animal productivity is not always a good indicator of pasture condition as animal production can be maintained for some time after pasture deterioration has occurred (Beale *et al.* 1984). Ash and McIvor (1995) indicate that diet quality may be higher (significant increase in in-vitro digestibility and nitrogen concentration) from pastures on land in poor condition. However, these authors warn that the large decrease in pasture productivity associated with declining land condition may more than offset the apparent improvement in feed quality. The role of supplements also distorts the links between animal production and pasture condition by enabling livestock to survive and produce on pastures in 'poor' condition (Gardener *et al.* 1990)

Hence, there is a need to balance the optimum stocking rate and resulting utilisation, with the grazing capacity of the pasture. Where animal production ($/ha) is maximised at a stocking rate lighter than the grazing capacity, over utilisation (overgrazing) and subsequent damage to the pasture resource is unlikely. Where the stocking rate for maximum animal production exceeds the grazing capacity the likelihood of overgrazing and pasture degradation increase. There is also a need to determine whether the grazing ‘thresholds’ thus established are biologically and/or socially acceptable.

This thesis does not aim to explore any further the relationships between stocking rate and animal production. However, at this point it is worth noting Abel's (1992) criticism of the conventional use of the terms overgrazing and degradation. He indicates successional theory describes degradation as a series of undesirable changes in land condition. Alternatively, Abel (1992) considers change in the net value of production as an indicator of degradation. Abel (1992) therefore adopts the definition of "overgrazing" as the result of a stocking density which causes a reversible decline in the net value of production, and "degradation" as an irreversible decline in the net value of production.

This is based on Abel and Blaikie's (1989) definition of range degradation as: "an effectively permanent decline in the rate at which land yields livestock products under a given system of management. In effect this means that natural processes will not rehabilitate the land within a time scale relevant to humans, and that capital or labour invested in rehabilitation are not justified. This definition excludes reversible vegetation changes even if these lead to temporary declines in secondary productivity. It includes irreversible changes in both soils and vegetation."

Determination of the grazing capacity of grazing lands and development of an understanding of the consequences are the most difficult tasks in grazing management (Vallentine 1990a). Several approaches are available for determining grazing capacity and appropriate stocking rates. Most are based on experience of "average" properties in "average" years (Wilson *et al.* 1990), and trial and error coupled with regular adjustments. Due to the variability in climate and base resources in south-west Queensland, the use of "district averages" is unlikely to yield appropriate grazing capacities for individual properties. Despite this, decisions on grazing capacity must be made, and Vallentine (1990a) lists seven methods for this. Briefly these are:

1. Initial stocking rate tables for various land and pasture types such as those reported by Mills and Purdie (1990) for south-west Queensland.
2. Known stocking rates adjusted for pasture condition and trend information. This is comparable to Condon *et al.* (1969) where known grazing capacity was corrected for factors such as precipitation, soil fertility, plant community type and topography.
3. Assessment of standing forage yield and calculation of stock numbers to use an appropriate quantity of that forage.
4. Percentage utilisation method where actual estimates of forage use or forage remaining are compared with appropriate levels of use or levels of residue for that forage.
5. Pasture comparison methods in which the grazing land under question is compared to a mental ideal or standard for that pasture.
6. Energy based methods requiring detailed quantification and matching of the energy content of pastures and requirements of grazing animals.
7. Forage density methods requiring estimates of forage density and quality to develop indices for appropriate stocking rates.

A number of these approaches require subjective judgment and some prior level of experience regarding the pastures in question. To remove this limitation a quantified approach to determining grazing capacity is required. Several authors propose the adoption of a utilisation approach in estimating grazing capacity. Heady (1975) and Vallentine (1990a) propose that estimates of forage production and utilisation will provide the basis for determining the correct amount of grazing, and the basis for further adjustments in stocking rates as the grazing season progresses. Holechek *et al.* (1989) indicates that most information regarding critical grazing intensities involves utilisation data, and these data can readily be used in stocking rate decisions. They add that a reasonable estimate of average forage production can be combined with the level of utilisation to estimate sustainable grazing capacities. Heady and Child (1994) generally support the utilisation approach in estimating grazing capacity but question whether the proportion of forage utilised or proportion remaining is the appropriate component to examine. They suggest the portion remaining can be measured directly while the portion utilised is only measurable by indirect methods. Scanlan *et al.* (1994) based their examination of "safe" carrying capacities for properties in the extensive cattle grazing region of north-eastern Australia on the portion utilised. This can be represented as:

“safe” grazing capacity(DSE/land system) = (**amount of forage which can be safely eaten** (kg/ha/year) / **amount eaten per dry sheep** (kg/DSE/year)) * **area of the land system** (ha)

where:

amount of forage which can be safely eaten (kg/ha/year) = (**“safe” level of forage utilisation** (%) / 100) * **average annual forage grown** (kg/ha/year)

An estimate of average forage production in semi-arid rangelands is not easy to determine. Forage production varies widely from year to year and from place to place. Up to four-fold variation in pasture yield was observed by Johnston and Carter (1986) from year to year. Consequently grazing pressure and utilisation will also vary. Regional statistics show up to two-fold variation in stock numbers among years (Mills and Lee 1990), which is a smaller variation than for pasture yield (Wilson and Harrington 1990). Vallentine (1990a) reported similar variations in forage production for semi-arid regions of the United States.

In the above discussion the term ‘forage’ has been used in its broadest sense to describe the vegetation within a system. As described in Section 2.1.5 the vegetation of south-west Queensland is composed of a mixture of perennial, annual and ephemeral species whose presence is largely determined by seasonal conditions. Each of these species, contributes differently to the quantity and quality of forage available and exhibits characteristic responses and tolerances to grazing.

The above discussion indicates the need for flexible stocking rates if appropriate levels of pasture utilisation are to be achieved. Otherwise, pastures will be under-utilised in above average years and over-utilised in below average years. In reality, such flexibility in adjusting stocking rate is impractical due to the inability of graziers to readily either dispose of or acquire large numbers of stock in short time periods. Despite this, Scanlan *et al.* (1994) reported a ±50% change in herd size was occurring on cattle properties in the semi-arid woodlands of north-eastern Australia over the three years 1986/87 to 1988/89.

There are several reasons for maintaining relatively "constant" stock numbers. These include: maintaining income stability (as demonstrated in south-west Queensland by Buxton *et al.* 1995), maintenance of the genetic resource for breeding operations, lack of infrastructure for rapid stock adjustment, avoidance of low prices when de-stocking is required and avoidance of high prices when re-stocking is possible. As a result, Wilson and Harrington (1990) and Reid and Thomas (1973) report short-term increases and decreases in livestock numbers lag behind rainfall variation by one to two years in south-west Queensland. Hence, it may be appropriate to calculate an average "safe" grazing capacity for individual properties at which a core flock or herd can be operated and variability in cash flow minimised. Under favourable seasonal conditions livestock numbers may increase above this ‘target’ and reduced in poorer seasons.

In practice, Heady's (1975) approach stipulates stocking rates that result in appropriate utilisation of the average forage yield, or more conservatively that result in appropriate utilisation when "about 70 percent" of the average yield is produced. Methods for estimating average pasture growth will therefore be valuable in establishing appropriate utilisation rates.

The question arises as to what approach (constant stock numbers or constant utilisation) is applicable for south-west Queensland. An examination of the broad pasture types found in rangeland Australia indicates a different approach based on pasture type (Table 2.3) although it is unclear as to exactly what was defined as 'low utilisation'.

Table 2.3 Stocking strategies on three main pasture types found in semi-arid Australian rangelands.

Pasture Type	Longevity (years)	Period when plants most susceptible	Stocking approach most suitable	Reference
Chenopod shrublands	30	Drought and fire	Low utilisation via moderate set stocking rates	Graetz and Wilson (1990)
Grasslands	2.5 - 30	Growing season	Low utilisation over growing season	Orr and Holmes (1990)
Ephemeral	0.3 - 0.6	Establishment and reproduction	Low utilisation year round	Wilson et al. (1990)

As the vegetation of south-west Queensland is predominantly a wooded grassland, a regime of moderate set stocking to achieve ‘low’ levels of forage utilisation during the growing season appears to be the most appropriate for making strategic decisions (20-30 years) on grazing capacity. Due to the variability in seasonal forage production it is unlikely that even low constant livestock numbers will regularly achieve low levels of forage utilisation. However, under such a strategy it is anticipated that both the frequency and duration of periods of over-utilisation is reduced such that plant health is adequate for resource maintenance and production goals. Over several seasons, the average level of forage utilisation could therefore be considered appropriate or “safe”. From ecological viewpoint, “safe” levels of forage utilisation would assist in maintaining plant health (maintenance of photosynthetic tissue, root function and flowering and seeding potential), plant density and diversity and ground cover. From a functional viewpoint the level of forage utilisation deemed “safe” may vary across pasture communities and soil types.

In the United States Holechek (1988) reviewed a range of grazing intensity trials and reported positive relationships between average annual precipitation / pasture type and appropriate levels of pasture utilisation. Generally, as average annual precipitation increases, utilisation can be increased, with some exceptions (Holechek *et al.* 1989). They suggested that 25-35% utilisation is appropriate for desert shrublands in arid regions (under 300 mm mean annual precipitation), 35-45% for the semi-arid shortgrass prairie where shrub encroachment was not a problem, and 45-60% for the humid tallgrass and southern pine regions.

Stated in this way, these findings represent a simplification of potentially complex interactions between precipitation, pasture type and appropriate levels of pasture utilisation. As discussed in Chapter 1 the structure and composition of pastures is determined by a range of factors. A pasture community’s resilience to grazing, expressed above as appropriate levels of utilisation is also influenced by a variety of factors (e.g. soil fertility, soil infiltration rates, soil surface characteristics, soil erodibility, species morphology, phenology, composition and palatability). Conversely, utilisation levels are integral to changes in species composition, plant density, forage yield and soil cover. While appearing simplified, the findings of Holechek *et al.* (1989) provide a useful guide for practitioners making strategic decisions (20-30 years) on grazing capacity in the absence of other information.

An examination of forage growth and “safe” / “low” levels of forage utilisation therefore appears appropriate to objectively estimate strategic grazing capacities of native pastures in south-west Queensland.

Such an approach requires an understanding of plant production in the region, and the effect utilisation has on these plant processes. This is reinforced with the statements of Harrington *et al.* (1990) that “management of rangeland ecosystems is ecological in nature, of a low energy input, and involves actions that seek to modify, rather than control, the natural forces operating on the land” and ”that management is weak in proportion to the dominant climatic forces that control the ecosystem”.

Plant growth in semi-arid areas is directly related to rainfall (Christie 1978, Le Houerou 1984, O'Connor 1985, Sala *et al.* 1988, Robertson 1988 and Scholes 1990), but on a non-linear scale depending on geographical location and pasture species present (Wilson and Harrington 1990). It follows that seasonality and amount of rainfall may be used to estimate pasture productivity and appropriate levels of pasture utilisation (Utilisation as defined earlier, is the proportion of the current year's forage production that is consumed by grazing animals.)

The timing of when to assess pastures and adjust stocking rate deserves attention. Holechek (1988) indicated that most decisions regarding stocking rates for perennial pastures are made at the end of the growing season when the quantity of forage available has peaked. Christie and Hughes (1983) supported this view for south-west Queensland and recommended that annual adjustment of livestock numbers be made at the end of each summer (October to March) growing period. This can lead to over estimates of grazing capacity as the peak standing crop usually does not last due to senescence, detachment and decay of material. However, this reduced forage availability may not reduce grazing capacity during winter, provided plants can tolerate closer utilisation during dormancy and forage intake relative to body weight is reduced as pasture quality deteriorates (Vallentine 1990a).

The important question is the stage at which perennial pastures become susceptible to over-utilisation. Adjustments to stocking rates at the end of summer may lead to over-utilisation at the start of the next growing season resulting in damage to individual plants and the pasture as a whole. Determination of stocking rates to achieve appropriate levels of utilisation at the start of the growing season when individual plants are susceptible to over-use may be a more appropriate goal. An understanding of plant growth responses is necessary to achieve this.

2.3 Plant growth and net primary productivity

The other component influencing grazing capacity is plant production. A multitude of terms in the literature describe plant production. These include:- forage production, pasture production, forage growth, standing crop, pasture yield, dry matter yield, peak yield, browse, and net primary production. In this thesis, plant production is confined to the grass and forb component of the pasture. It is the portion that directly determines grazing capacity. The contribution of browse (most commonly mulga leaf) where it is available is considered additional, and its inclusion as a component of the diet is described in Chapter 5.

The earliest reported measurements of pasture yield in western Queensland were made by Davies *et al.* (1938) and Roe and Allen (1945) on Astrebla spp. grasslands in central and south-western Queensland respectively. Hulett (1970) recorded basal cover, standing crop (green material, standing dead material and litter), root yield and soil moisture in order to examine the net productivity and biomass transfer on a mitchell grass (*Astrebla* spp.) community near Charleville. The first observations of pasture yields in mulga country were reported by Ebersohn (1970). He compared presentation yields from a range of native and sown pastures throughout the mulga zone and showed that greater dry matter yields could be achieved from introduced pastures under favourable conditions.

Numerous authors have since examined many aspects influencing native pasture growth in the mulga zone of Queensland. Brown (1982, 1985 and 1986) reported the effects of defoliation, burning and fertilising on the growth of a number of native grass species. The water use of native and exotic species was examined by Christie (1975a,1978 and 1981) and by Pressland (1982). Growth response to nutrients and temperature was studied by Christie (1975b and 1979) and Silcock *et al.* (1976). The effects of soil loss on pasture production was examined by Pressland and Cowan (1987) and Miles (1993). Beale (1973) described a decrease in pasture yield under increasing densities of mulga trees at two locations, and Carter and Johnston (1986) reported similar relationships for the effects of *Eremophila gilesii* on pasture yield at one location.

In the majority of these studies, presentation yields were recorded and were an adequate measure for the issue in question. However, presentation yields do not indicate the dynamics of pasture production. They reflect what is in a pasture at a given point in time and not what has been produced. Alternatively net primary productivity describes the rates of plant production from a unit area. It integrates the duration of active growth, and rates of litter production and decomposition. Knowledge of net primary production is more meaningful for interpretation of grazed situations than presentation yields taken two or three times a year (Burrows and Beale 1976). Absolute net primary production refers to both the above and below ground pasture components. However, above ground or aerial primary production is the most common measure where large vertebrates are the principal herbivores (Milner and Hughes 1968).

Primary production experiments from around the world are illustrated by Singh *et al.* (1975), Le Houerou and Hoste (1977), Webb *et al.* (1978), O'Connor (1985), Biddiscombe (1987), Redman (1992) and Milchunas *et al.* (1994). In a similar fashion to these authors, Sala *et al.* (1988) summarised data from 9500 sites in the central grassland region of the United States and demonstrated a strong relationship between above ground net primary production, the amount and distribution of annual precipitation and the effect of soil type.

Slatyer (1961) and Christie (1978, 1979) laid the foundations for primary production studies in the mulga zone, the former author working in central Australia, and the latter in south-west Queensland. Christie (1978) related water use, primary production, litter production and decomposition and nutrient dynamics over a twelve month period for a native pasture in the mulga zone near Charleville. In further studies, Christie and Hughes (1983) explored the interrelationships between net primary productivity and the grazing capacity of the mulga lands using systems analysis and computer simulation.

In conclusion, net primary production data from the dominant land systems of south-west Queensland would be crucial to estimating sustainable grazing capacities for individual properties. Using systems analysis and simulation, these data can be extrapolated over time and space to estimate probabilities of plant production and "safe" long-term grazing capacities.

2.4 Role of systems analysis and computer modelling in understanding pasture productivity, grazing theory and decision making processes

The terms "systems analysis", "systems approach" and "computer modelling" can be ambiguous. Weiss and Robb (1986) highlighted this problem and called for consistency in the use and definition of the term "systems". Abel (1977) defined a "system" as a set of interrelated elements which behave interactively and collectively. It enables the synthesis of those attributes of a system which may be useful, and the description of these attributes in a manner which is amenable to manipulation and analysis. This procedure is called model building, and Abel (1977) provided two main reasons for this approach. Firstly, by constructing a model and studying its behaviour we may learn something about the "real-world" system. Secondly, we may be able to use the model to predict the behaviour of the "real-world" system.

The method of describing a system is also important. It must be flexible and capable of being modified to reflect changes and the development of ideas. That is, it must be graphical or numerical in nature (Abel 1977). In order to accommodate the complex interactions and relationships found in biological systems, computers are commonly used for model construction and evaluation. When described mathematically the components of a system are linked within a computer program to form a computer model. Ross (1977a) pointed out that a computer is not essential to modelling, and suggested that many of the benefits of computer modelling projects are dependent on the model building process rather than on the computer.

The field of systems analysis and computer modelling is rapidly growing in all aspects of human endeavour. Originating within the physical sciences, the methods of systems analysis are now widely applied to the biological systems found within agriculture. Van Dyne (1970) described a systems approach to grassland problems which would include (i) compiling, condensing and synthesising much information concerning the system components, (ii) detailed examination of the system structure, (iii) translating knowledge of components, function and structure into models, and (iv) using models to derive new insights about management and utilisation. Two major roles therefore exist for systems analysis and computer modelling in agriculture. The first is describing and understanding how various systems work, and the second is evaluating management decisions made within those systems. The two roles are often linked.

Examples of the first role are models describing beef cattle growth (McCown 1980, Oltjen *et al.* 1986 and McCaskill 1991), lamb and wool production (Pepper and McMeniman (1980)), runoff from catchments (Littleboy *et al.* 1992 and Wilcox *et al.* 1990), cropping systems (DeJong and Zentner 1985, Berndt and White 1976, Hammer *et al.* 1983, Hammer 1984) and grazing and forage systems (Freer and Christian 1980, Caughley 1982, McKeon *et al.* 1982b., Coughenour *et al.* 1984, Smith *et al.* 1985, Clewett 1985, Hanson *et al.* 1988, Stout *et al.* 1990, Hacker *et al.* 1991).

In the role of decision making, McKeon *et al.* (1982a) indicated five main reasons for mathematical modelling:

(i) Modelling allows the decision maker to calculate the outcome of processes operating in opposite directions. For example, increased stocking may increase production per hectare, but decrease individual animal performance and increase the risk of pasture degradation. Similarly, with a management practice such as burning, the likely increased accessibility and diet quality have to be balanced against the increased risk of a forage shortfall.

(ii) Computer modelling allows the decision maker to respond quickly to changing economic situations. Field experiments to explore the best decisions take time and may be out of date before they are completed. Models can be re-run quickly with different inputs.

(iii) Models allow "what if" type questions to be answered without the expense of carrying these out in the real world. If the answers look promising then they can be tested in the field. This allows the decision maker to expand their horizons.

(iv) Modelling allows extrapolation of research results collected over limited time periods (a few years) to a greater range of weather and management possibilities.

(v) Modelling complements experimental work to provide a methodology for investigation of the efficient integration of forage options. Physical models of production systems with native pasture, sown pasture, forage and grain crops require large resources in time and space. Computer modelling is probably the only way the range of possibilities can be tested.

Examples of models used as decision making tools in the field of grazing and forage systems are reported by Swartzmann and Van Dyne (1972), White (1978), McKeon and Scattini (1980), Danckwerts (1982), Maden and Thatcher (1984), Christie and Hughes (1983), Freeman and Benyon (1983), Wight *et al.* (1984), Johnson and Parsons (1985), Tharel *et al.* (1985), Loehle (1985), Walker *et al.* (1989) and Meppem and Johnston (1990). Only two of these models tackle the topic of estimating sustainable grazing capacity. Christie and Hughes (1983) describe the theory within a modeling approach, but only Danckwerts (1982) puts this into practice, and favourably compares model results to actual grazing management.

Examples of the role of modelling in western Queensland are reviewed by Johnston (1992). In this environment, modelling methodology has proved to be a valuable tool in terms of handling year to year climate and production variability.

It is apparent from the above that computer modelling is not an end in itself, but aims to complement experimentation in the solution of management problems (McKeon *et al.* 1982a).

2.5 Modelling pasture productivity using the GRASP model

GRASP (GRASs Production) is a computer model that combines two successful approaches in modelling plant growth, viz., those of McCown *et al.* (1974) and Fitzpatrick and Nix (1970) (McKeon *et al.* 1990). GRASP was chosen for the following reasons:

1. it was available;
2. it was developed for native pastures of northern Australia;
3. it has been well tested on a range of native pasture communities (McKeon *et al.* 1990);
4. it is physiologically sound;
5. it has been peer reviewed in a week long workshop (Littleboy and McKeon 1996); and
6. it is supported by a network of other users.

It uses two basic biological concepts to describe forage growth and is written in the FORTRAN computer language.

The first concept is the soil water balance where changes in soil moisture are calculated as the difference between inputs and outputs of water to the soil profile. Inputs are rainfall, and outputs are soil evaporation, plant transpiration, runoff and drainage. A daily timestep and three soil layers are used, so that the separate processes of soil evaporation and transpiration can be simulated.

The soil water balance component of GRASP was first developed by Rickert (1975) using data from wheat crops in Western Australia. The model was subsequently validated with independent data for native and sown pastures at Gayndah in south-east Queensland (Rickert and McKeon 1982). The methodology of estimating processes in the water balance were reviewed by Rickert (1984) and the different approaches used to link soil water to plant production are described by McKeon (1984) and Clewett (1985).

The second basic concept in the GRASP model is that plant growth is proportional to transpiration (kg/ha/mm of transpired water or transpiration efficiency). This concept has provided a simple yet robust method of estimating forage growth in the Queensland environment. The transpiration efficiency is adjusted to account for forage type and soil fertility (nitrogen). The relationship is modified for temperature as described by Fitzpatrick and Nix (1970). Transpiration is calculated from soil moisture supply, evaporative demand and green cover. When green cover is very low (for example after severe drought or burning), growth is calculated from the potential regrowth rate which is characteristic of the forage. Three forage pools (green, standing dead and litter) are used and modified by growth, death decay and grazing. Details of the forage production model and it's applications are described by McKeon *et al.* (1982b), Carter and Johnston (1986), McKeon *et al.* (1990), Day *et al.* (1993), Scanlan and McKeon (1993), Littleboy and McKeon (1996) and Day *et al.* (1996).

2.6 Conclusions

The above review has described the environmental factors (climate, soils and vegetation) influencing pastoral production in south-west Queensland. The review has aimed to highlight the fact that the rangelands of south-west Queensland are semi-natural ecosystems in which pastoralism seeks to obtain a productive output by simply adding domestic stock to a natural landscape (Harrington *et al.* 1990). Management is dwarfed by the complexity of the landscape and community ecology of the region with manipulation of grazing pressure being the main management tool available to land managers.

Concerns regarding the level of land degradation within this landscape were raised by a number of authors. The processes and extent of land degradation were described by others with excessive grazing pressure regularly identified as a cause of degradation. Yet few authors suggested tangible means of addressing the issue of excessive grazing pressures. However, the Warrego Graziers Association (1988), Mills *et al.* (1989), Miles (1989) and Anon. (1993) suggested a need to review "carrying capacities" / "stocking rates" (grazing capacities) was central to reducing land degradation through a greater appreciation of the capability of the land resource. In addition, Anon. (1993) (Department of Lands publication) recommended these reviews should be done on a property-by-property basis and the revised estimates of grazing capacities should be publicly available.

To examine grazing capacities in the semi-arid rangelands of south-west Queensland an ecologically based approach is therefore warranted. Due to the complexity of ecological systems the potential role of modelling was examined. The end product of these models are decision-support-systems (DSS) which allow research information/knowledge to be used by individual ecosystem managers (McKeon *et al.* 1990). Unlike herd dynamic and economic models (Stafford Smith and Foran (1988), Stafford Smith and Foran 1990 and W.E. Holmes (pers. comm.), many of these grazing system models have not been actively extended and their use in managing native pastures has been limited. This is largely due to (i) the level of generality at which the models have been developed, (ii) the failure of model builders to design models which address the information needs of individual graziers (Cox 1996 and Humphreys 1997) and (iii) apparent failure of modellers to commit to a particular region and application. These issues are addressed in this thesis.

While capable of handling the year to year variability in productivity, current models are incapable of accommodating spatial variability. Such models are unlikely to contribute to the management of native pastures unless they address the variability in soil and vegetation at the individual property scale. The resources of individual properties need to be described within a modelling context so that the calculation of sustainable grazing capacities can be made.

In this thesis the role of modelling at a level useful for managing native pastures is described. An approach based on ecological principles is developed to estimate sustainable "safe" grazing capacities for individual properties in south-west Queensland. This then provided the basis for a quantitative review of grazing capacities on individual properties across the region in a joint Department of Lands and Department of Primary Industries program. The methodology using systems analysis and modelling entails:

1. Collection of net primary production data from the dominant land systems in south-west Queensland (Chapter 3).
2. Calibration of the forage production model GRASP for each of these land systems using these data (Chapter 4).
3. Validation of the forage production model GRASP using independent data from south-west Queensland (Chapter 4).
4. Linking model outputs and resource inventories for individual land systems on "benchmark" properties to estimate average forage growth and "safe" levels of forage utilisation for any location in south-west Queensland (Chapter 5).
5. Examination of real-time forage utilisation on 46 properties over the period 1986 to 1988 (Chapter 5).
6. Development and application of a method for use by land managers and administrators for the estimation of "safe" grazing capacities for individual properties (Chapter 5 and 6).

The hypothesis formulated is that through the measurement of key plant production relationships, and extrapolation of these over time and space, that grazing capacities for individual properties can be estimated, and related to sustainable levels of forage utilisation.