CHAPTER 1

INTRODUCTION

1.1 AIMS OF THE STUDY

This thesis is a case study of the development of a management plan to solve a problem of competing demands for water.

The competing users are rural properties carrying out crop irrigation and the residents of a small rural village. The resource for which they are competing is water both flowing in and stored in ponds in the Gwydir River in N.S.W. Both river flow and pond storage are inadequate to meet the requirements of both rural and town users, on an unrestricted basis. A clear case of directly competing demands for a limited resource exists.

The aim of the study is to propose a management plan which can be shown to be equitable to the parties concerned, which is economically feasible and economically efficient and which is based on sound analysis of reliable data.

1.2 ASPECTS OF WATER USAGE CONSIDERED IN THE STUDY

The development of the management plan requires consideration of a wide range of aspects affecting water usage.

These aspects include

- the physical nature of the river valley
- the nature of irrigation
- the nature of town water consumption
- river flow characteristics
- the characteristics of the local weather
- expected developments in the area
- the value of the water to the users
- the economics of water usage
- the economics of resource allocation
- the political influences
- historical precedents and legal matters

- the views of various government agencies and authorities
- the need to consider a wide range of proposed management plans
- the major influence of weather and seasonal conditions on river flow and water consumption, with a resultant major influence on the nature and extent of the conflict between the users.

Computer simulation techniques are ideally suited to assisting in the solution of this type of problem. A major part of this study has involved the development of a computer programme to simulate the situation of competing demands over a fifty year time period. This programme has provided the results upon which development of the management plan could be based.

The computer simulation results have provided data upon which the techniques of microeconomics could be applied to determine the most efficient allocation of resources.

The results of the economic analysis have provided a sound basis for the proposition of a justifiable management plan.

The complete economic analysis of such a multi-dimensional problem is a complex and difficult subject. A uni-dimensional approach has been used in this study, as a first step in the development of a technique for practical analysis of problems of water allocation. This approach has led to the proposition of a reasonable management plan. Further research is needed into methods of economic analysis which will effectively allow the incorporation of the multi-dimensional nature of the problem.

CHAPTER 2

THE CONFLICT

2.1 THE LOCATION

The conflict studied in this thesis exists at Bundarra, the location of which is indicated in Figure 1.

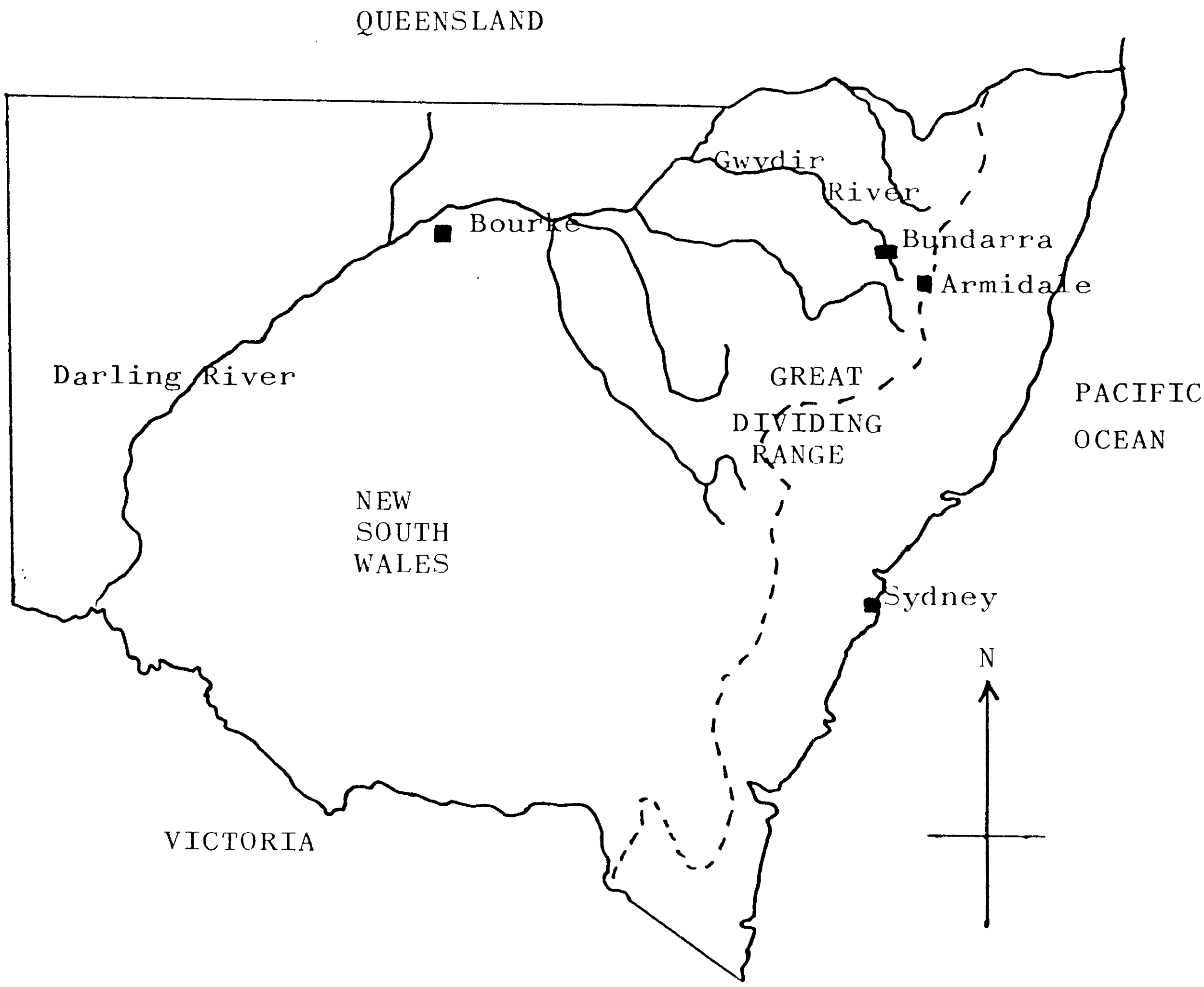


Figure 1 The location of Bundarra on the Gwydir River in N.S.W.

Examination of Figure 1 shows that Bundarra is situated on the Gwydir River, sixty five kilometres north west of Armidale, in the New England Region of the Northern Tablelands of N.S.W. Bundarra is located within the Shire of Uralla.

Bundarra is a service centre for the surrounding rural area, which is comprised mainly of cattle and sheep grazing properties. The services include a central school, which provides classes from Kindergarten to Year 10; a golf course and licensed club; a showground; a small hospital; a small shopping centre; a post office; a police station; a hotel; a public park and churches.

Bundarra has a population of about 400 people. Most workers earn their living from agricultural or associated industries or the service industries in the village. Some work in the asbestos mine at Woods Reef, near Barraba. The population of the town could be described as essentially "working class" people.

The Gwydir River "rises in the elevated plateau which forms the Great Dividing Range west of Armidale and flows in a generally north-westerly direction past Bundarra towards the township of Bingara." (Cameron McNamara Pty. Ltd, 1982). Further examination of Figure 1 shows that the Gwydir Valley is one of the northernmost contributors to the Murray-Darling drainage system.

2.2 THE VILLAGE OF BUNDARRA

In the early 1830's Thomas Mitchell explored and mapped the Gwydir River tributaries in the Moree area. "His explorations lured squatters into the Namoi region and eventually to the upper reaches of the Gwydir Valley around Bundarra and Keera" (Cameron McNamara Pty. Ltd., 1982). The Gwydir Pastoral District was proclaimed in 1846. The growth of urban centres in the valley resulted from activities in the surrounding rural areas. Bundarra grew to service the surrounding grazing industry and that service is still its main function.

The population of the village, based on information provided by The Australian Bureau of Statistics, has fluctuated during this century. The current population of about 400 people has remained relatively constant for the last decade. New cottages are being erected in the town and there is every reason to believe that the population, although not expected to increase significantly, will remain at around 400 people for the remainder of this century.

Figure 2, Population Characteristics of Bundarra during the Twentieth Century, is taken from a report by D.L.Wolfenden in 1977. It is interesting to note that the number of occupied dwellings has remained fairly constant over the last seventy years.

In 1982 there were 140 occupied sites in Bundarra and 193 properties assessed for water rating purposes.

Further information on the nature of the water users in Bundarra is provided in Section 5 of Chapter 8 , which lists the results of a survey used to gain data for economic analysis of the "value of water" to the town users.

Figure 3 is a plan showing the location of the main factors in this study. Examination of Figure 3 shows that the town water supply for Bundarra is pumped directly out of Taylor's Pond, in the Gwydir River, by Uralla Shire Council. The water is pumped to a nearby reservoir from where it is reticulated to the township. Taylor's Pond is a natural pond in the river, and the river bed at its downstream end has been built up using the rocky material of the bed to form a rock weir, which augments the natural capacity of the pond.

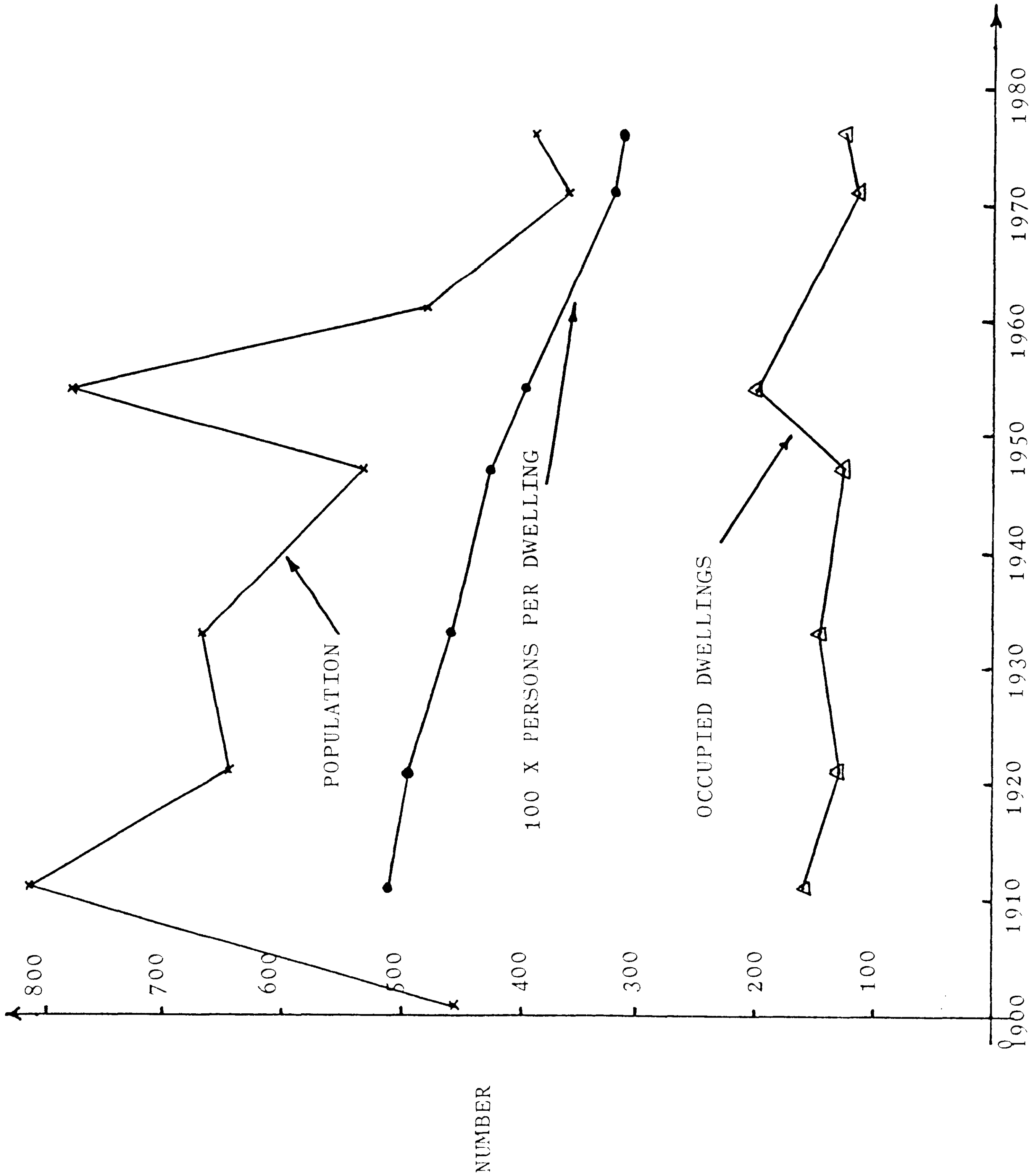
2.3 THE IRRIGATORS

The owners of the properties "Flemington" and "Clerkness" carry out crop irrigation by also pumping directly from Taylor's Pond and the next pond upstream, Worrabinda Pond. The location of these sites can be obtained from Figure 3. The bulk of the irrigation is from Taylor's Pond, the same pond which Uralla Shire Council uses for the town water supply.

Both landowners use spray irrigation techniques and operate under a licence issued by the Water Resources Commission of N.S.W. One property, "Flemington", irrigates lucerne as a summer crop and oats as a winter crop. The other property, "Clerkness", has irrigated sorghum or millet during summer and oats during winter, but has recently decided to grow lucerne in summer.

FIGURE 2: Population Characteristics of Bundarra

During the 20th Century.



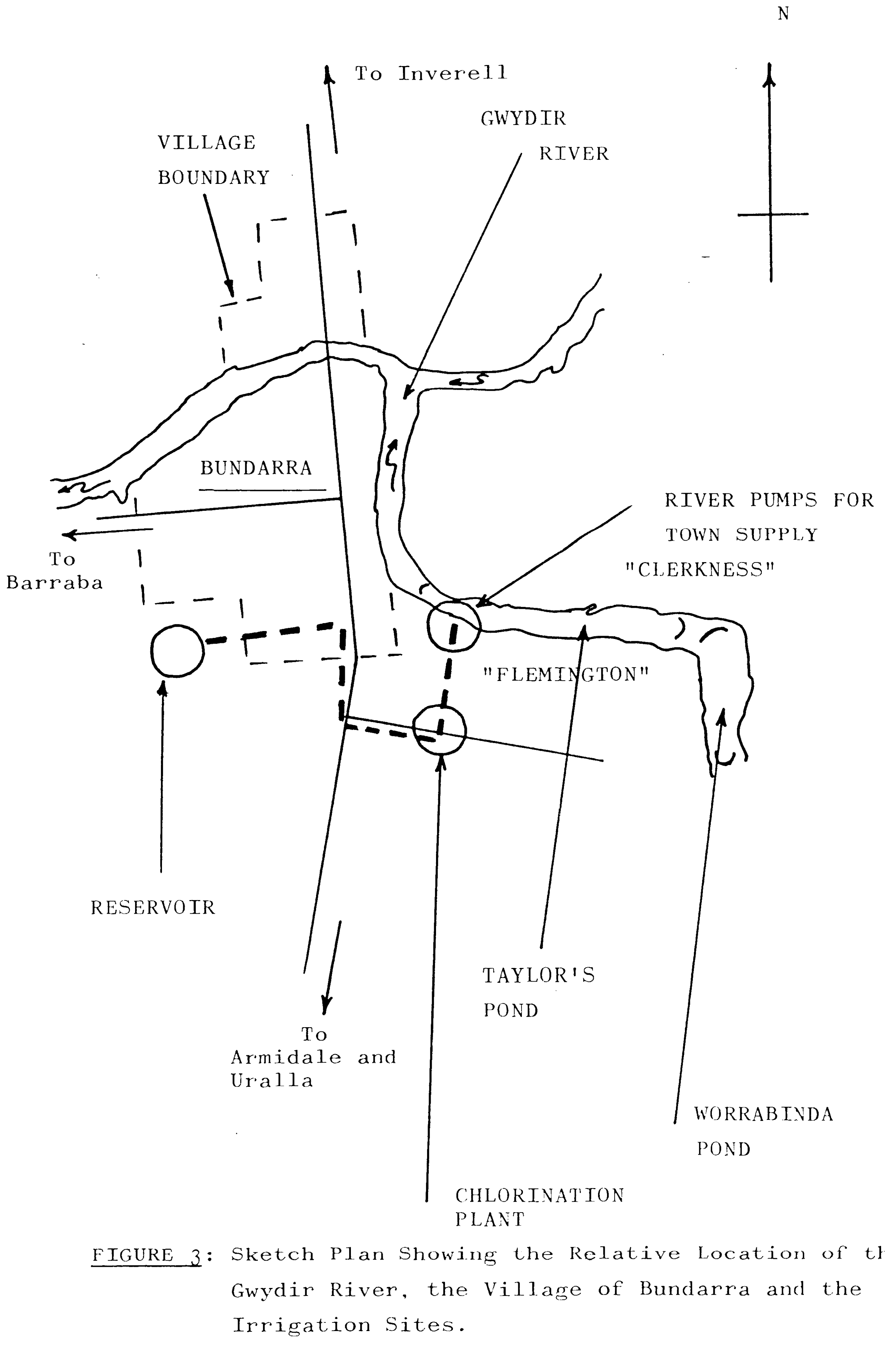


FIGURE 3: Sketch Plan Showing the Relative Location of the Gwydir River, the Village of Bundarra and the Irrigation Sites.

The crops are grown for both on farm stock feeding and as cash crops.

The irrigation works were established in 1973, well after the town supply was installed in 1950.

2.4 URALLA SHIRE COUNCIL

Severe drought conditions in eastern Australia in the early 1980's have highlighted the fact that both flow in the Gwydir River and storage in the ponds at Bundarra are inadequate to meet the total demands of both the town consumption and the irrigation consumption, on an unrestricted basis.

Shortages of water have resulted in a need for restrictions to be placed on both town and irrigation usage. The nature and extent of these restrictions have been based on the judgement of officers of the Water Resources Commission of N.S.W. and Uralla Shire Council. They have not based their decisions on a full analysis of the situation, as the necessary fundamental data for such an analysis have not been available to them.

Consequently, some discontent concerning the restrictions has been expressed by the affected parties. Uralla Shire Council, which is directly responsible for the town water supply and which also needs to consider the welfare of its rural residents involved in the irrigation, is seeking the development of a soundly based management plan to resolve the conflict. The plan needs to solve the problem of sharing a limited natural resource between two directly competing users. The plan needs to be demonstrated as being fair to all parties and to share the resource equitably.

2.5. THE CHOICE

It has been said that "Economics is about scarcity. The word "scarcity" is used here in a special sense: it refers to a state of affairs in which, given the wants of a society at any particular moment, the means available to satisfy them are not sufficient. If all desires cannot be totally satisfied, then choices have to be made as to which of them are going to be satisfied and to what extent. To say that economics is about scarcity then is also to say that it is about choice." (Laidler, 1981).

Such choices need to be made at Bundarra. Those choices can be based on economic analysis to ensure that the result is an equitable sharing of the scarce resource of water. The information for the economic analysis can be provided from the scientific and engineering techniques of analysis of natural resources. A powerful scientific technique for the study of a complex interaction of long term variation in river flow, climatic factors and season and weather dependent demands by town and agricultural water users, is that of computer simulation. All of these techniques have been used to resolve the conflict described in this chapter. They are fully described in following chapters.

The difficulty with this problem is that a single management plan is sought to govern the sharing of a limited volume of water at specific occasions in the future. Both parties have different demands for water which change throughout the year. The value each would place on water could therefore be expected to vary with the season and also with the length of any period of enforced restriction.

For example, town users would not be expected to value highly any water they were required to forego if the period of water restrictions was only for a few days. After a week or two, when lawns, flowers and vegetable gardens started to die, they would be expected to be willing to pay a reasonable price for the benefit of using water to restore those plants. After several months, when valuable trees and shrubs began to die, they would be expected to value highly any water which they could use to restore those trees. This example demonstrates that the value of water in use will vary for individual users, with the seasons and within specific periods of scarcity of water

The sharing of water between users should, ideally, be based on the marginal values they place on the water they may be required to forego as a result of a sharing plan. Such values may vary often for some or all users during water shortage periods. This observation suggests that any water sharing plan should be altered often, depending on the marginal value of water in use at each peak or critical demand period.

However, the water would be of reduced value if users were not confident that their respective shares would not change markedly over short periods. This comment applies particularly to the irrigators who would require a sharing plan which was designed so that they could assess the amount of water available to them for a practical length of time in terms of planning their irrigation schedule. This observation suggests that a management plan should be based on the value of water in use over a whole period of water shortage. That is, the plan would be based on total net benefit over a period of water restrictions.

The choice in this case involves the sharing of a total amount of water during dry periods. Since it is not known, at the start of a dry period when river flow ceases, just how long any specific period will last, a plan is sought which will be reasonable for application during any dry period. It should take account of both the possibilities that it may rain again within a few days of imposition of water restrictions or that any particular period may be the start of the worst drought on record.

At all times the plan should aim to ensure that the town water supply does not fail to meet the basic requirements for health and amenity (i.e. water for drinking, cooking and bathing) even for very short periods.

The choice at Bundarra therefore involves sharing a total but limited amount of water based on the total net-benefits to the competing users over the period of water restrictions, subject to the restriction that the town water supply must not fail.

The concept of reliability of supply must also be considered by the users. A reliable supply is defined here as one which is predictable or dependable. As such both users need to know, on average, how often their supply will be subject to restrictions of various durations. If they know that interruptions or restrictions will be very frequent they may decide that the supply is too unreliable to meet their needs, that they cannot depend on adequate supplies often enough and that their enterprise should be abandoned because of lack of water.

An entirely reliable supply for the irrigators is one which would always meet their water requirements to ensure maximum yield from the irrigated crop. It would allow them to invest in irrigation plant, seeds and fertilisers with confidence

An entirely reliable supply for the town is one in which all the town demand would be met at all times, without the need for water restrictions. It would allow, in addition to the basic use to satisfy health and survival needs, the use of water for the establishment of fine gardens and lawns and for recreation and aesthetic purposes.

The rights and expectations of the users are discussed in Section 3.7 of this thesis.

This problem is clearly multi-dimensional. Because of the limitations of time and resources in a thesis of this nature, this problem has been simplified to allow for the development of a technique which will permit practical analysis of the conflict.

2.6 LIAISON WITH THE PARTIES INVOLVED

If a proposed management plan is to be acceptable to the parties involved, they should be consulted in its development. With this aim in mind, and also to ensure that data used in this thesis were sound, the author had long discussions with both of the irrigators, in order to understand their irrigation practices and the effect of water restrictions on their operation.

Uralla Shire Council made all of its relevant records concerning town usage available to the author. The residents of Bundarra were also surveyed to obtain information on their use of water.

The author also held discussions with officers of the Water Resources Commission and the District Agronomist of the Department of Agriculture of N.S.W. concerning the validity of information used in this study.

As a result of these discussions, it can be said that information used in this study, based on a variety of theoretical propositions, has been checked and confirmed or modified to allow for the application of those propositions by experienced practitioners.

CHAPTER 3

WATER USE IN AUSTRALIA

3.1 THE DRIEST CONTINENT

Most Australians live in cities which have been supplied with an abundance of water. The more arid lands support pastoral development but have deterred close settlement. Holmes (1976) has closely studied and reported on the effects of Australia's water resources on limiting both the location and extent of Australia's future development and the population numbers they will support. Australia is often described as the driest continent and this fact must be recognised by all users seeking the supply of increasing quantities of low cost water. The potential for increased volumes of water to be supplied, without huge costs, in Australia, is very limited. This lack of potential insists that requests for increased water usage are closely studied to determine if such requests are justifiable.

Australia's description as the world's driest continent is usually based on its low average rainfall (432mm) compared with the other continents. Such average values, which do not necessarily indicate the variation in rainfall in location, time and effectiveness, can be misleading. However, McMahon (1982) has reported on a statistical analysis of 220 Australian streams and 184 world rivers, and indicates that "Australian rivers show more variability in terms of annual flow volumes and larger extreme flood events than world rivers". He analysed the variability, skewness and persistence of stream flows and reached two significant conclusions of major relevance to this study:-

- "Not only is Australia the driest continent, but also its streams are considerably more variable than world rivers".
- "Australian streams compared with world ones require relatively larger storages for equivalent regulation".

McMahon's conclusions indicate that problems such as these at Bundarra are bound to occur and reinforce the fact that the availability of suitably priced water will limit Australia's development.

The vast inland of Australia receives very low annual rainfall. The wetter areas are all confined to the coastal and mountainous parts of the continent. The bulk of the population is located in cities in the coastal areas, while the bulk of the pastoral land lies within the drier regions, where rainfall is unreliable and river flows are very variable and not persistent. Bundarra is located just to the west of the Great Dividing Range and even though this area is not typical of the interior, where the stream flow is intermittent and rainfall unreliable, it is subjected to occasional droughts and extended periods of no river flow. It is this very fact that creates the problem at Bundarra and which makes the task of seeking a solution, which proposes a"best" use of the water available, so important. Australians can no longer simply demand that their"water needs" be met, as has often been done in our past. Our dry continent insists that all such requests be closely examined and alternatives to increasing water use be explored.

The above comments are reinforced by McMahon (1975) in a report of his investigations of the low flow hydrological characteristics of Australian and world streams. He has estimated that "the reservoir storage requirements per mean annual flow in Australia are eleven and seven times larger than that required in Europe or North America respectively." His research has also shown that the most variable Australian streams have their headwaters located on the slopes of The Great Dividing Range and are located in the medium summer or uniform rainfall climatic zones. He has also shown that these streams require the largest relative storage to meet specified yield conditions.

McMahon (1978a)carried his previously quoted research into Australia's surface water resources a stage further when he produced illuminating results of his analysis of their potential development. A precise definition of the terms he uses and the statistical measures of surface water data he has studied, are given in "Reservoir Capacity and Yield" (McMahon 1978b). He developed an equation relating streamflow regulation or draft to storage capacity and evaporation. The equation relates the constant draft from a reservoir to the coefficient of variation of annual flows in the stream (C), the required reliability of supply (P), the mean annual flow (X), the nett annual evaporation loss per unit area of resevoir (E), a value representing the topographical relief (R), and the estimated required storage (S). The following figure is a plot of storage against draft for assumed values of C,P,R,E, and X, taken from McMahon (1978a).

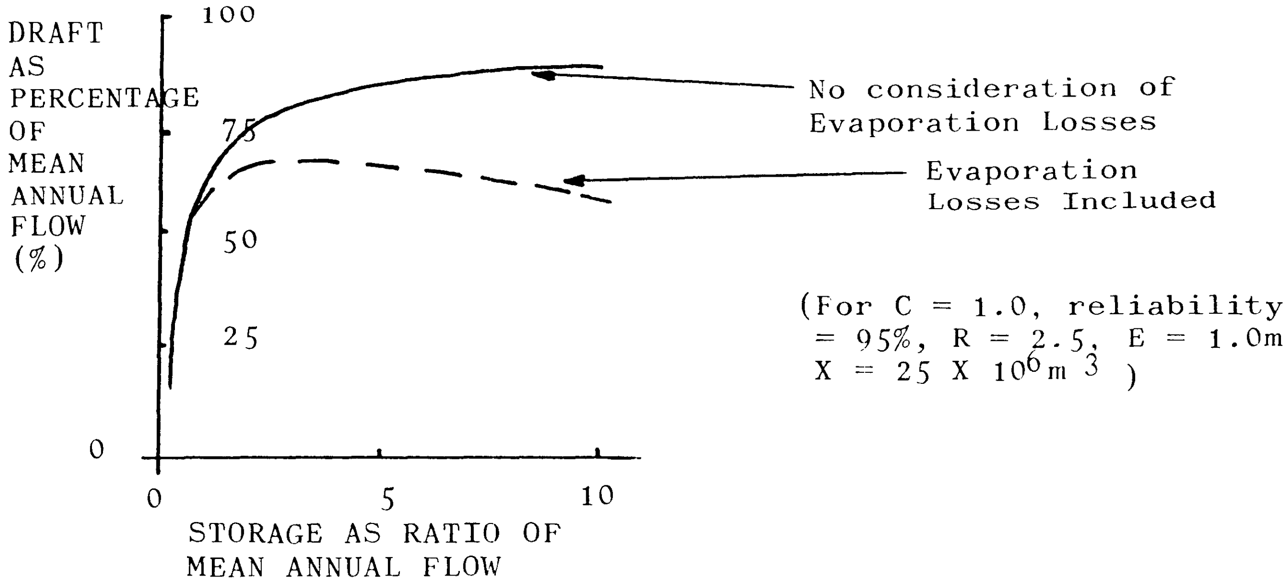


FIGURE 4: Effect of Evaporation on Draft-Storage Capacity Relationships.

Examination of Figure 4 reveals the substantial effect of evaporation on limiting the draft from a typical regulated Australian stream. For comparison purposes, the following values of the relevant variables for the Gwydir River at Bundarra are given:

$$C = 4.9\ M^{-0.33} \quad \ldots\ldots \quad (3.1)$$ (McMahon 1978a)

where M = mean annual runoff (mm) (101.9mm at Bundarra)

$\therefore$ $C = 1.07$

$E = 1.3$ m

$X = 417 \times 10^6\ m^3$

Evaporation losses can be seen to place a clear limit on the draft that can be achieved from Australian streams , no matter what the storage capacity of an impounding structure may be. These results challenge the commonly held view that the dry continent can be mastered, at a cost, by suitable engineering structures. McMahon's results clearly demonstrate that such views cannot be defended, as a general rule.

Generalised analysis leads to the production of the following Figure 5 (from McMahon, 1978a):

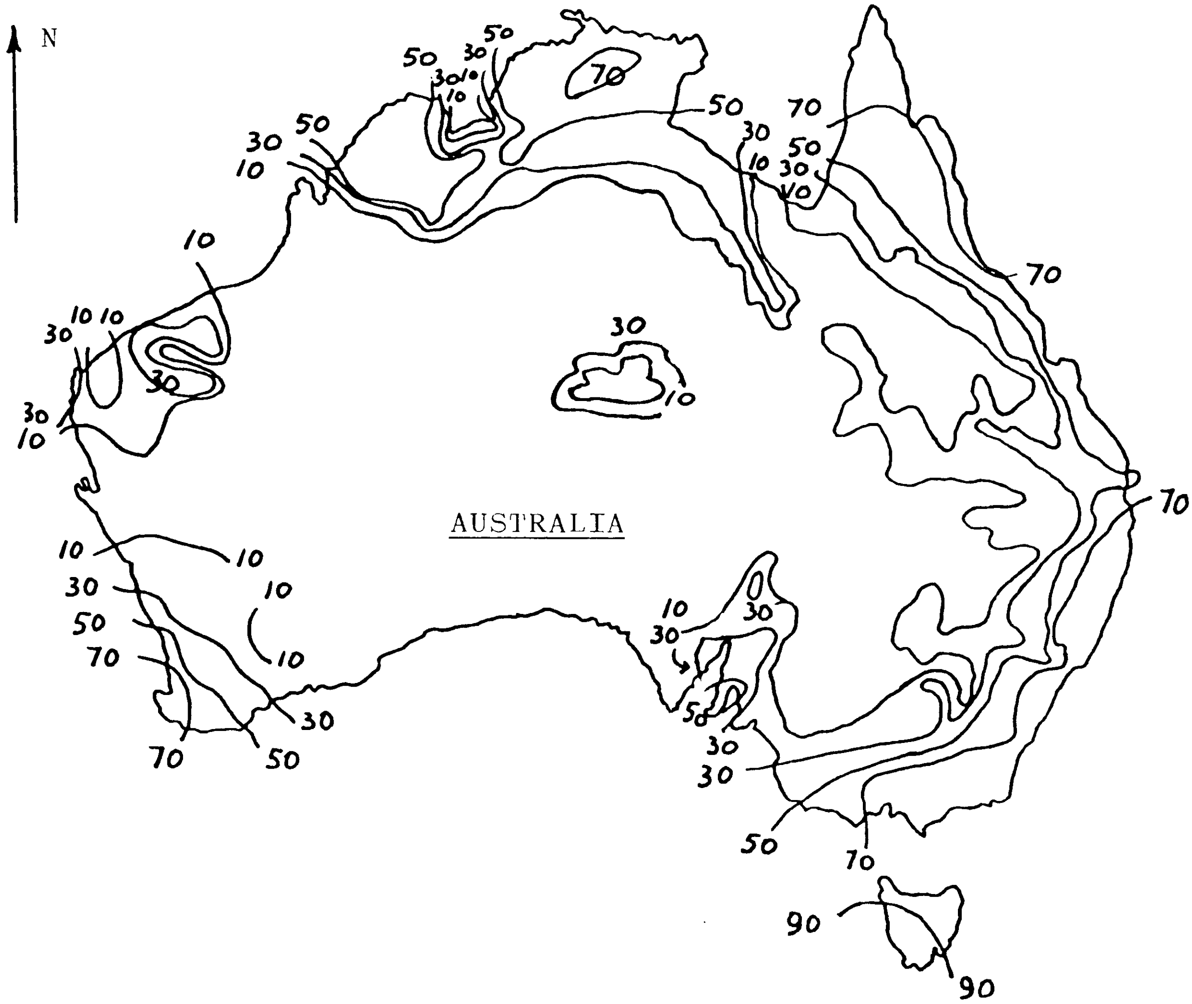


FIGURE 5: Maximum Possible Streamflow Regulations at 95% Reliability (expressed as a percentage of mean annual flow).

Figure 5 shows that maximum potential streamflow regulation varies from above 90% of the mean annual flow in Tasmania to zero in the arid region. McMahon (1978a) has further shown that the maximum draft is often achieved with storage capacities of the order of 2x mean annual flow.

The following Table 1 lists the potential for stream regulation expressed as a percentage of mean annual flow and is also taken from McMahon (1978a).

Table 1 indicates that it is necessary to construct large storages to achieve maximum potential in high rainfall areas (eg. Tasmanian Division), but storages of 1 to $1\frac{1}{2}$ x mean annual flow will achieve maximum potential in drier areas (eg. Darling - Murrumbidgee system). The above results should be used only as a guide but they give a clear indication of the limitation that Australia's water resources place on its future development.

Because of Australia's sparse and intermittent river system and the limiting effect of its surface resources on its development potential, as quantified in the above quoted studies, increased interest is being shown in the use of its underground water resources.

Underground water occurs in three types of rock formation :-

- Unconsolidated sediments (alluvial or windblown sands and gravels)
- Sedimentary rocks (sandstones and limestones)
- Fractured rocks

Underground water usually contains more dissolved salts than surface water. Table 2 , indicates the maximum acceptable concentration of total dissolved solids in water to ensure its suitability for various purposes. (Dunk, et al, 1976).

TABLE 1 - Potential for Stream Regulation Expressed as Percentage of Mean Annual Flow

Drainage Division	Average Max. Potential Draft ± Std. Dev.	Maximum Draft at Various Storage Capacities for 95% reliability		
		1 x mean annual flow	2 x mean annual flow	3 x mean annual flow
1 North-east Coast				
Catchments north of 24°S	39 ± 26	39	33	0
Catchments between 24° and 29°S	57 ± 12	46	55	52
2 South-east Coast				
East Coast	72 ± 9	63	69	71
South Coast	60 ± 25	64	66	51
3 Tasmanian	90 ± 3	91	92	92
4 Murray- Darling				
Darling-Murrumbidgee system	15 ± 18	15	5	0
Murray system	48 ± 26	46	47	28
5 South Australian Gulf	26 ± 17	27	27	0
6 South West Coast	34 ± 20	32	32	0
7 Indian Ocean	11 ± 14	11	0	0
8 Timor Sea	46 ± 24	44	45	23
9 Gulf of Carpentaria	31 ± 25	31	19	0
10 Lake Eyre	5 ± 9	5	0	0
11 Bulloo-Bancanna	4 ± 4	4	0	0

TABLE 2 - Water quality limits

Use	Upper Limits(p.p.m*)
Irrigation	
Very low tolerance crops: Tobacco	50
Low Tolerance crops: Citrus, Legumes	500
Moderate Tolerance crops: Vines Pasture Grass, Cabbages	1,500
High Tolerance crops: Beets, Cotton Asparagus	2,500
Domestic	1,500 (but less than 1,000 desirable)
Stock	
Horses	6,500
Ewes with Lambs, Dairy Cows	7,000
Beef Cattle	10,000
Dry Sheep	13,000
Industry	Varies greatly - less than 500 desirable

* Parts per million of total dissolved salts, assuming most of the salt to be sodium chloride.

Generally, the fractured and sedimentary rocks provide the main source of stock water, while unconsolidated sediments are the most important source of the large volumes of good quality water required for irrigation.

Current concerns over the use of underground water are the effect of large scale bore systems on the underground flows which support surface water systems and the problem of drawing water from underground aquifers at rates in excess of their ability to replenish themselves. Careful definition of both surface and underground water resources is required if safe permanent yields are not to be exceeded and we are to ensure continued productive use of our land. Excessive and wasteful short term use of our water resources can result in arid land being depleted of its limited available water and becoming unproductive wasteland.

3.2 NEW SOUTH WALES - WATER RESOURCES

The Great Dividing Range, running close and parallel to the coastline of New South Wales, as seen in Figure 6, separates the higher rainfall areas to the east from the drier western areas.

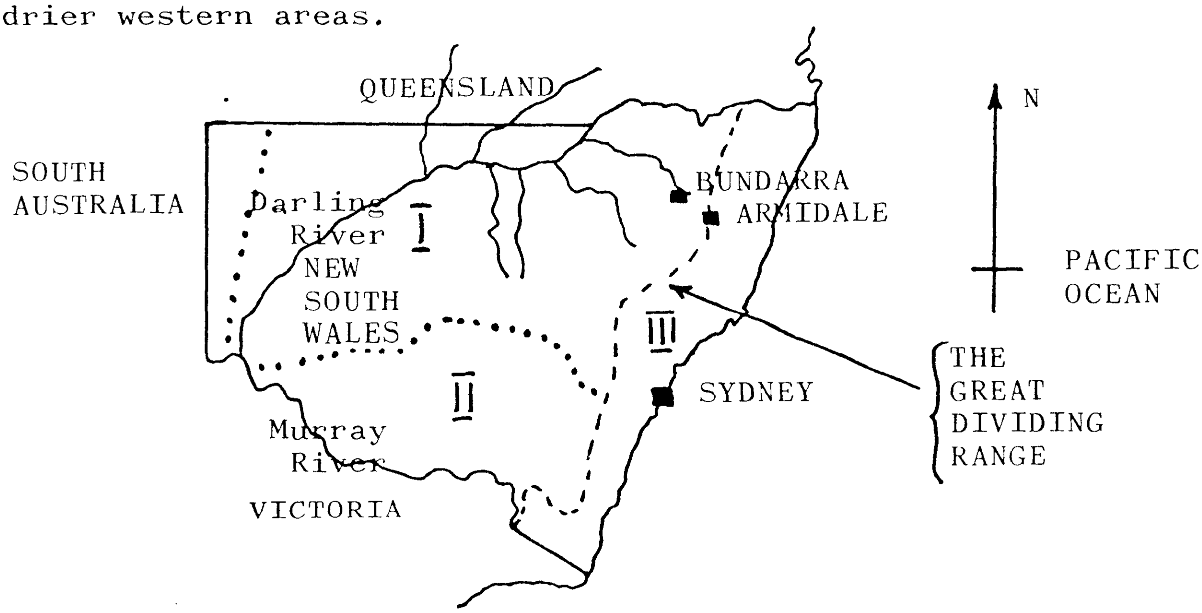


FIGURE 6: The Great Dividing Range In New South Wales.
(Legend: I - Darling River Basin; II - Murray River Basin; III - Coastal Rivers Basin)

Bundarra is located in the New England Tablelands which form part of the Great Dividing Range. The prevailing south-east winds provide the coastal strip with the State's heaviest and most reliable rainfall. Average annual rainfalls vary from less than 150mm in the west to 1600mm on the north coast.

The river systems form three major drainage basins (refer again to Figure 6). These drainage basins are those of the Darling River, the Murray River and the Coastal Rivers. The largest basin is that of the Darling River, whose main rivers are the Macintyre, Namoi, Castlereagh, Macquarie, Darling and Gwydir Rivers.

The water in New South Wales is controlled by many authorities - the Water Resources Commission, the Department of Public Works, the Metropolitan Water Sewerage and Drainage Board, the Hunter District Water Board and local government Councils.

The Water Resources Commission has estimated the data listed in Table 3 for New South Wales (Water Resources Commission of N.S.W., 1976).

Examination of Table 3 reveals the high total annual usage of water for irrigation purposes, of 4781×10^6 m^3, compared to the annual urban water usage of 975×10^6 m^3 and the total usage of 7595×10^6 m^3. This relative proportion of usage is even greater on a national scale, as indicated in a national survey of water use by the Australian Water Resources Council in 1978. That survey indicated that irrigation accounted for 74 per cent of total water use, compared to 18 per cent for urban and industrial water use. (Klaasen, 1980).

Table 3 also indicates that the surface water resources of New South Wales, particularly in the Murray Darling Drainage Division are already heavily exploited. Groundwater resources, however, have not yet been heavily exploited. Certainly the location of these resources and their quality has limited the extent of their usage, but the economics of treatment of groundwaters, to ensure their

SURFACE WATERS						GROUNDWATERS					
Average Annual Discharge	Possible Exploit-able Annual Yield	Current Total Usage	Annual Urban Usage	Annual Irrigation Usage	Other Annual Usage	Volume of water in Storage	Possible Exploit-able Annual Yield	Current Total Usage	Annual Urban Usage	Annual Irrig-ation Usage	Other Annual Usage
A. South East Coast Drainage Division											
28,159	12,746	2,238	731	237	1,270	102,630	1,761	102	24	66	12
B. Murray - Darling Drainage Division											
10,539	7,575	4,855	216	4,339	300	2,587,600	7,637	398	41	139	218
C. Western Drainage Division (Lake Eyre, Bullo Bancannia)											
In view of the low rainfall, high evaporation, low relief and sandy nature of the land, only minimal runoff can be expected from the New South Wales Portion of the basin.						*225,200	696	2	-	-	-

* Almost all with salinity greater than 1000ppm

TABLE 3 Water Resources And Estimated Usage in New South Wales- 1976

All Units are $m^3 \times 10^6$

suitability for required usages will need to be closely studied as the potential for further use of surface waters declines.

3.3 WATER AND THE FUTURE DEVELOPMENT OF AUSTRALIA

"An adult man, in vigorous occupation, needs to take in, as drink and in food, about two litres of water each day. Need for water, beyond this primeval need, has increased enormously with urban settlement. In our cities of modern time, water use averages about 500 litres a day for each inhabitant." (Holmes, 1976). Dunk et al report that, over the last twenty years, there has been a steady rise in the amount of water used; both the total for Australia each year and the amount used per person per year have increased. These increases are the direct result of an expanding population and of improved living conditions.

Large quantities of water are necessary to support our current standard of living. To allow Australia to continue to grow and develop, more dams will need to be built and our underground storages will need to be further exploited. It will also be necessary to ensure that we use our water wisely and without wastage.

Callinan has estimated the following annual water needs per person in a modern industrialised Australia (Callinan, 1970)

Agriculture (Mainly Irrigation)	910kl
General Industry	135kl
Electric Power Generation	70kl
Domestic and Municipal	160kl

Australia's water resources are strictly limited and the availability of water may constrain our ultimate population. Dunk et al (1967) consider that "the optimum population which Australia will be able to support with its improving standard of living will be only 30 million people". They report that others predict a population of 60 million people as more realistic. Holmes (1976) has calculated the "maximum permissible population of Australia, limited only by water potentially available", as 280 million people. He does, however, state that "it would be highly irresponsible to our fellow men if we ever planned to achieve these populations".

It is evident that the extent of our water resources is a limiting factor in Australia's growth. No matter what level of development of storage systems is proposed, we must ensure the best use of the resources by improving the efficiency of the distribution and use of water. Dunk et al (1967) report on research carried out by the Victorian State Rivers and Water Supply Commission, which shows that only 46% of water available in an irrigation district is used to grow plants. The remaining 54% is lost to seepage, leakage, evaporation and overwatering. When the total volume of water used for irrigation is considered, an efficiency level of 46% is a matter for serious concern and further study.

3.4 URBAN WATER USAGE

Domestic water demand in Australia is influenced by a number of factors. These factors have been identified by Pullinger as follows (Pullinger, 1978) :-

1. Climatic Conditions and Physical Factors
2. Family Income
3. Type of housing
4. Size of lots and area of lawn and shrubs
5. Number of persons in residence
6. Number of taps
7. Water pressure
8. Water quality
9. Whether or not the service is metered
10. The price structure for water

The average consumption per person for any town or city also varies with the extent and nature of industry, parks and reserves, population density and the traditional customs of the local community.

Klaasen (1980) has reported that "of the total quantity of urban/industrial water use allocated to the more detailed categories of uses, just over half (54 per cent) is for domestic uses, 14 per cent is for commercial uses, 26 per cent is used for industrial purposes and 6 per cent is for "other" purposes, including distribution losses". Of particular interest are the amounts of water supplied per head in various places in Australia, as listed in the following Table 4, which has been prepared using information given by Holmes (1976), Klaasen (1980), Lindner (1982) and Uralla Shire Council records.

TABLE 4 - Amounts of Water Supplied to Cities and Towns in Australia.

Location	Water Supplied per Person (Ml/yr)		
	1971	1977	1982
Sydney and Wollongong	0.159	0.168	0.190
Melbourne	0.145	0.157	-
Brisbane	-	0.208	-
Adelaide	0.177	0.193	-
Perth	0.239	0.237	-
Hobart	0.243 (unmetered)	-	-
Canberra	0.231	0.241	-
Newcastle	0.209	0.230	-
National Average	0.170	0.259	-
Uralla	0.120	0.169	0.142)*
Bundarra	-	0.199	0.193)*

* Consumption affected by water restrictions in severe drought.

It is interesting to note a general trend of increased water consumption, per capita, for almost all of the locations from 1971 to 1977. Even allowing for inaccuracies resulting from changes in circumstances and methods of recording usage, the trend of increasing consumption is clear. It is also interesting to note that the national average of 0.259 Ml/person/year exceeds the figures for any location listed in Table 4, for 1977. This apparent anomaly probably arises from very high consumption rates for low density, smaller, rural centres in hot, dry climates, which may not have metered supplies. However, such high consumption rates are not evident in either Uralla or Bundarra.

Design of an urban water supply involves the selection of water demands on which to base the capacities of the various elements of the system. Long term (annual) demands influence the size of headworks (eg. storage dams); short term (daily) demands influence the size of service reservoirs and peak instantaneous demand influences the size of water treatment plants, pumps and water mains. Current design practice is to select "design demand" figures for residential usage, based on the number of persons in the town or city or, alternatively, the number of tenements. Allowances are made for holiday populations, camping sites, hotels and motels, industry, stock facilities, hospitals, schools and municipal parks and gardens.

Commonly used design values for domestic use in the coast and tableland areas of N.S.W. are:-

Peak Daily Demand	4,000 l/house
Annual Demand	400 kl/house
Instantaneous	0.15 l/sec/house

Appendix A, is taken from an article by Maysey (1981). It lists the daily water allowances for various types of domestic use, as used by the Department of Public Works of N.S.W. and the consumption data published in the Australian Water Resources Council Technical Paper No. 20.

3.5 IRRIGATION WATER USAGE

"Irrigation may be defined as the application of water to the soil for the purpose of supplying moisture essential for plant growth. There are two main purposes for irrigating:

- to increase the yields and quality of agricultural production.

- to maintain levels of production and yield during periods of insufficient rainfall as a form of crop insurance"
(Clampett, 1976)

Irrigation is of great value when it :

- reduces or eliminates plant moisture stresses which affect crop yield and quality
- increases the period in which certain crops can be grown
- allows the growing of new crops

Clampett(1976) concludes that "where irrigation is used only to maintain general levels of agricultural production and as a form of drought insurance, it is not efficiently practised". He argues that efficient irrigation involves "supplying the plant with irrigation water so as to maintain optimum moisture condition for the plant and thus optimum growth of the plant and the yield of the product".

Detailed discussion of the determination of irrigation need is given later in Chapter 5. Irrigation need depends on many factors including:-

1. type of crop
2. temperature and humidity
3. the season
4. evaporation
5. climate
6. soil type
7. type of irrigation system

Research has been directed towards improving irrigation efficiency. Dudley et al (August,1971) have examined optimal intraseasonal irrigation water allocations and also optimal acreages within a season (Dudley et al, October 1971). This research indicates that an irrigator should maintain available soil moisture in the root zone at a high level, even if it means exhausting the supply early in the season.

As the demand for water in agricultural, industrial, municipal and recreational uses continues to grow, the efficient use of available supplies becomes more imperative. The data given in section 3.3 of this thesis emphasise the clear need to optimise the use of water in the irrigation process. This optimisation requires a thorough knowledge of plant-water-soil relationships. The evaluation of alternative techniques requires sound data on input-output relationships for water, as far as crop yield is concerned. Hexem and Heady (1978) have developed relationships between water input and crop output for a variety of crops in a variety of soils.

There is much scope for further research into determining efficient, practical irrigation practices.

3.6 DROUGHT

Australia suffered a very serious and widespread drought in 1980-82. That drought has highlighted problems similar to those studied in this report.

The Australian Department of Science and Technology, in its Newsletter of October, 1982, has reported that prior to the 1980-82 drought, Australia suffered the following nine major widespread droughts since the keeping of rainfall records began:-

" 1864 - 66	All States except Tasmania.
1880 - 86	Southern and eastern mainland States.
1888	All States except Western Australia.
1895 - 03	One of the worst on record, it halved Australia's sheep population (originally 100 million) and cut cattle numbers (12 million) by 40%.
1911 - 16	Wheat crops affected in most states, sheep numbers declined by 19 million and cattle by 2 million.
1918 - 20	Parts of Western Australia were the only areas completely free from drought.
1939 - 45	Affected crops and pastoral areas in all States. Sheep numbers fell from 125 million in 1942 to 96 million in 1945.
1965 - 67	In Queensland, New South Wales and Victoria it ranked with the 1895 - 03 drought as one of the most severe. It resulted in a 40 per cent drop in the wheat harvest, loss of 20

million sheep, and a decrease in farm income of \$300 - \$500 million. There was a chain reaction to other industries, with heavy losses by manufacturers of farm machinery, and the N.S.W. Railways. Effects of the drought were worsened by water rationing in irrigation areas.

1972 Widespread throughout Australia. "

Research is in progress concerning the causes of drought and drought prediction. Drought conditions require close attention by the nation's farmers and water engineers to suitable methods of water use management. It focuses our attention on the limited nature of our water resources and our often careless use of water during non-drought seasons.

3.7 CONTROL OF WATER USAGE

History records many conflicts which have been created by the imbalance between limited resources and growing requirements for those resources. There is a clear need for a positive legal code to facilitate proper management of our limited water resources, in order to reduce such conflicts in the future.

Bird (1976) describes the history of the development of such a code as the establishment of Customary Law, superseded by Common Law (Customary Law as developed through the judiciary) and then Statutory Law.

Australia "inherited the common law of England with the riparian doctrine as the basis for entitlement to water. Broadly speaking, under the riparian doctrine a riparian owner (i.e. an owner of land directly abutting a stream) had the right to the ordinary use of water flowing past his land" (Bird, 1976). "Ordinary" use is usually considered to be domestic and stock watering use. Irrigation usage would not be covered by riparian rights and it could render him liable to an action in damages by a downstream landowner. (Bird, 1976).

The riparian rights doctrine has largely been superseded by modern Statutory Law, which vests the rights to the control of water in any watercourse to the Crown. Riparian owners usually retain a right to divert water for domestic and stock purposes, but all other diversions are carried out under a licencing system.

Under the prior appropriation system, "as a general case, the person who first made a valid appropriation of water has a superior right to all subsequent appropriations. He has acquired priority of right" (Bird, 1976).

When water becomes scarce, Government assumes a more active role in the disposition of available water and the riparian rights and prior appropriation doctrines become superseded by administrative disposition.

In New South Wales, all but riparian diversions are controlled by licences issued by the Water Resources Commission, under the Water Act. A diversion licence specifies the purpose of the water use, the area of irrigation and perhaps the volume of water to be diverted. A licence is valid for a given time period. In times of actual or threatened water shortage, licences may be suspended or revoked, or licence conditions may restrict usage. Usually there are preferred usages (eg. town water supplies) which may continue while "less beneficial" usages are restricted or prohibited. Bird states that "it is an historical fact that water for domestic purposes has always had priority over other uses." (Bird, 1976).

Cunha et al (1977) describe water "as a public asset" and consider that "water property rights should be so defined and held that the water is used to the maximum benefit of the community". Legal codes controlling the use of water, while having such a goal, need to be framed to allow for flexible and practical implementation by the responsible decision makers.

To attain economic efficiency in the use of water, there is increasing interest by economists in proposals for the marketability of water entitlements. This concept perceives a situation where any user who values water more highly than another user may outbid that other user and purchase his water rights, thereby putting the available water to a higher valued use. Such radical concepts are worthy of further detailed investigation and discussion.

The situation at Bundarra involves the consideration of most of the legal doctrines outlined in this section.

Both of the agricultural properties, "Clerkness" and "Flemington", are riparian owners abutting the Gwydir River. As such they have the right to "ordinary" use of water in the river, but could not claim riparian rights to use water for irrigation.

Statutory Law has led to both of the irrigators and Uralla Shire Council (on behalf of the Bundarra Town Water Supply) being issued with diversion licences. However, the prior appropriation system would appear to give the town supply a priority of right, particularly in times of water shortage, as the town supply was established in 1950 and the first irrigation licences were not issued until 1973.

Administrative control over diversion licences allows for preference to be given to town water supply users, over irrigation users, in times of water shortage. The difficulty in this matter is that an administrative officer needs to be convinced that a water shortage is sufficiently serious, in its threat to an urban water supply, to justify denying irrigators the use of water. Personal experience at Uralla Shire Council has proven the difficulty of achieving such decisions.

The purpose of this study is to provide sound data upon which such decisions can be based and to allow the development of criteria, supported by the affected parties, to make the taking of such decisions easier and less controversial.

3.8 THE VALUE OF WATER AND THE PRICE OF WATER

The cost of water may be defined as the number of dollars per unit volume we need to pay to make it available in the condition required. Similarly the value of water may be defined as the maximum number of dollars per unit volume we would be willing to pay to obtain water in the required condition, or the minimum number of dollars per unit volume we would be willing to accept if someone proposed to take it away from us in that condition. (after Kuiper, 1971)

The value of water is sometimes stated in terms of

(a) the resource value - the cost of providing the water itself

(b) the opportunity cost value - the value of the water in its best alternative use

(c) the social value - where observed costs are corrected to take account of unpriced, intangible, beneficial or adverse social aspects (eg. aesthetics).

In an economically efficient equilibrium state the resource value, the opportunity value and the social value are all equal at the margin and are all equal to the price of water. If the marginal price of water to all users is not equal to the marginal cost of supplying the water, then we are wasting our resources.

Further, in allocating water between users, efficiency rules suggest that "water should be sold to the user who will pay most for it. To achieve allocative efficiency, the price of water should be raised until the amount of water available just equals the amount that the various users will take at that price" (Campbell et al, 1968).

In addition to economic efficiency, society often feels there are equity considerations that justify setting the actual price charged at a value below the market clearing price. If this is the case, it must however first ensure that the allocation between users was based on economic efficiency, or else uses with higher marginal values will be foregone in favour of less highly valued uses.

Further detailed comments on efficiency in water allocations are made later in Chapter 8 . However, it is clear that astute pricing policies offer powerful tools to confront water resource management problems, such as those of this thesis, relating to the adjudication of conflicts between agricultural and urban users.

Charges for water in Australia vary widely. Irrigation users often pay licence fees which cover only operation and maintenance costs incurred by the State in providing the system (Watson and Rose, 1980). Some fees only cover administrative and metering costs (Caldwell 1982). Other licences involve a charge related to the volume of water used. Watson and Rose report that in their analyses of costs and charges in the Bundaberg Irrigation Project, in Queensland, charges for irrigation water equal one-third of the full costs of water supply (Watson and Rose, 1980). This ratio of charge to supply cost is thought by them to be typical for water authorities in Australia.

As of 1977, charges for irrigators ranged from 37c per megalitre on the Darling River tributaries in N.S.W., to $4.50/Ml for the water right in the Murrumbidgee Irrigation Areas, to $14.30/Ml for the basic allotment in South Australian irrigation areas, to $85/Ml for the highest priced block of excess water for South Australian users (see reference 37 for sources).

Blainey (1978) states that charges for irrigation in New South Wales are subsidised as they are "generally throughout the world". He says that "these charges do not recover anywhere near enough to service the capital employed or to meet operation and maintenance costs". Lidner (1982) advises that Copeton Dam, on the Gwydir River, downstream from Bundarra, delivers a mean annual output of 300,000 Ml at an average cost of $21/Ml. This cost and the quoted irrigation charges support the view that irrigation water supply is highly subsidised.

In fairness, it must also be recognised that subsidies are usually available for the capital costs of constructing and augmenting urban water supply systems. In New South Wales, country towns and cities receive a subsidy of up to 50% of the capital costs involved, through the Department of Public Works. Maintenance and operating costs are usually met entirely by water charges on the community. Urban water supply charges in country towns are generally much higher than those for irrigation water (see Table 5) but these charges still involve some element of subsidy from the general revenue of the State Government.

Methods of charging for urban water by the authorities responsible also vary widely. In some localities residential water use is unmetered and revenue is collected by water rates,i.e. a property tax. In others, property taxes cover a substantial basic allocation to each household while excess water is priced volumetrically. This latter method uses price to restrain excessive use of water. The user pays principle, where all water used is priced volumetrically, is gaining favour in some authorities and is expected to gain favour as engineering solutions to provide more water become more expensive.

In Bundarra, in 1983, Uralla Shire Council provides a base allowance of 500kl per tenement for a minimum water rate of $220 per annum (i.e. an average price of $440/Ml). All water used in excess of 500kl is charged for at $600/Ml.

The value of water to the competing users involved in this study is assessed in Chapter 8 of this thesis. However, reported values of water are of general interest. Kuiper (1971) has reported on his studies of the value of domestic water and irrigation water. Wollman (1962) has reported on his studies of the value of water in alternative uses by measuring the contribution of an industry using water to the total product of the national economy. The average value of irrigation water in producing agricultural products in Australia can be determined by dividing the "total on farm value of irrigated production", of $1500 million per year, (Caldwell, 1982) by the total volume of irrigation water use per year, of $13,300 \times 10^6 m^3$ (Klaasen, 1980). These values are listed in Table 5 .

The figures quoted in Table 5 apply to specific locations and uses at a specific time. They do, however, consistently confirm the view that municipal water use is more highly valued, on average values, than is agricultural water use. The values support the administrative doctrine, outlined in

Section 3.7 of this report, which allows for preference to be given to town water supply uses, over irrigation uses, in times of water shortage. The values however are not related to volumes of water usage. The marginal value of the volume of water for which two or more parties are competing is a much more important consideration in such a competitive conflict. This concept is further developed later in Chapter 8 . Nevertheless, the relative average values of the alternative uses are instructive.

TABLE 5 - Reported Values of Water in Alternative Uses $/Ml

Municipal and Industrial Use	Irrigation Agricultural Use	Source
$US 12-33	$US 0-37	Kuiper (1971)
$US 15-25 to $US 40-74	$US 0-17 to $US 0-22	Wollman (1962)
$300 to 600	-	Typical Urban Town Water Supply Charges (1982)
$440	-	Bundarra Water Supply Charges (1982)
-	$112-78	Using Caldwell and (1982) Klaasen (1980)

It is apparent that the Australian water economy has progressed from the expansionary phase, when new water development projects can increase quantity supplied with little increase in real average cost. It has entered a mature phase, characterised by rapidly rising incremental costs of supply and greatly increased interdependencies among water users (Watson and Rose, 1980). The Murray-Darling Basin now exhibits the following problems:

- restricted water supplies for irrigation
- conflict between agricultural, urban and recreational uses of water
- salinity
- ageing reservoirs and delivery systems
- the need for rehabilitation works (Maunsell and Partners, 1979).

The role of price in dampening the demand for water and in ensuring the use of water to the best advantage is coming under close scrutiny in this mature water economy. The concept of "value of water in use" forms an important role in developing a just plan for the sharing of water between the competing users at Bundarra, in Chapter 8 of this study.

Pullinger (1978) claims that demand for water can be managed by economic policy tools. He criticises what he sees as the common management focus on "the production objective" in relation to water supply and and urges greater concentration on an "allocation objective", where pricing is used as the controlling management tool. Pullinger has argued that "the rate at which water is consumed is potentially related to its unit price and this relationship can find expression in a water demand function". He considers that consumption can therefore be managed because the rate at which water is consumed can be controlled by the pricing policies of the water authority. This theory is true while consumption remains sensitive to price but is limited by the range over which consumption is price elastic. (See Chapter 8 , for discussion of this aspect of water demand).

Pullinger's ideas are supported by his research and the results of a survey into water use at Bundarra, outlined in Chapter 8 of this report. However, it is unfair to criticise the "requirements approach", as used by designers, to determine the size of units in a water supply system, when the need to augment that system (or even to build an initial system) has been reached. The "water demand" of any community, as related to the price structure of supplying the water, (which ,in turn, is strongly related to the cost of building and operating the system) needs to be determined, so that the "water requirements" of that community can be designed to be met by the proposed system. The water demand of communities may vary with the unit cost of supplying water to those communities, but once the demand associated with the supply cost involved in any system has been determined, that demand becomes, for the purpose of that design, the "water requirement" for the community. Both the "requirements approach" and the "price-managed consumption approach" are interelated and both are relevant in the development and management of water supply schemes.

3.9 LAND USE AND WATER IN AUSTRALIA

Whenever people exploit the world's natural resources, they make their mark on many aspects of their environment. The hydrological effects of the land use practices in water catchments are being more broadly recognised in recent years and have been the subject of modern research.

Two valuable contributions to the knowledge of the effects of our land use on our water resources have been made by Pereira (1973) and Boughton (1970). These works both give detailed accounts of the effects of a variety of land management practices on water quality and quantity. Some of the effects which are relevant to the situation being studied in this report, in terms of a general understanding of the influences on the performances of the Gwydir River, as taken from these two reports, are summarised as follows:-

(a) Where deep rooted trees are cleared and replaced by shallow rooting grasses, water yield from the catchment increases. This result occurs because trees create a greater soil moisture deficiency in dry times than grass, which must be replenished by the next storm. The lesser deficit under grass results in greater runoff or groundwater recharge from the storm.

(b) Tree clearing affects water quality by increased turbidity.

(c) In areas of tree clearing, torrential rain spates replace infiltration and storage, so that streams dwindle or vanish in the long dry season.

(d) The Gwydir River, downstream from Moree is permanently blocked by a "raft" of river borne dead timber and silt, and is a demonstration of the lasting effects of erosion caused by the clearing of land in New South Wales.

(e) Runoff and erosion both increase when the intensity of grazing is increased. Pasture management techniques need to be aimed at protecting grass cover and maintaining reasonable water yields.

(f) The major sources of pollution of water supplies from rural land use are animal wastes, fertilisers, pesticides, plant residues and saline waste water from irrigated areas. Turbidity results from areas of exposed soil.

(g) Soils formed on granodiorite and volcanics are more prone to release turbid water, either as surface flow or seepage, than soils formed on other rocks. Soils derived from acid igneous rocks are considerably more erodible than soils derived from other parent materials. Chapter 4, which describes the geology of the Upper Gwydir Valley, reveals that this location is, therefore, prone to soil erosion and turbid waters.

(h) Intense bush fires result in increased soil erosion and increased runoff.

(i) In drier areas the reduction of runoff as a result of the increasing number of small farm dams and bores is significant.

(j) Large scale irrigation development substantially alters the hydraulic regime of a river basin, by increasing the evapotranspiration loss and reducing the amount of water available for other purposes. However, the more permanent effect of irrigation development, and the more difficult problem to solve, is that of salinity.

(k) Degradation of the water in river systems with progress downstream is inevitable, if the use of the water resource by man is maximised.

(l) There is some evidence to suggest, at least in alpine areas, that timbered areas collect more rainfall (up to 125mm/year) compared with treeless areas.

(m) Agricultural practices have no significant effect on the normal flow of large and medium rivers, although there may be significant local effects for a short distance downstream from the site of the agricultural property. However, where there are a large number of farm dams, and other storages in a catchment, the total yield of an area can be reduced as a result of the increased evaporation and seepage from the dams, in addition to the use of the impounded storages.

(n) Land use changes have their most significant effect on low flows, rather than on normal or flood flows. The low flows are usually the limiting factor when considering how much development an area can sustain.

(o) Artificial stimulation of rain at present offers no solution to the problems of semi-arid climates or of major droughts.

(p) Improved pasture grasses reduce the total water yield of an area significantly.

(q) The challenge for our water resource managers is in balancing the short-term advantages to standards of living achieved through intensive use of water against the safeguarding of water supplies, soil fertility and countryside amenities for future generations.

All these effects occur to some extent in the study area, indicating the importance of closely monitoring the future performance of the Gwydir River to ensure that land use practices do not result in unacceptable deterioration of the river.

CHAPTER 4

THE UPPER GWYDIR VALLEY

4.1 SOURCE OF INFORMATION

A significant portion of the information contained in this chapter is taken from the publication "Water Resources of the Gwydir Valley" (Water Conservation and Irrigation Commission, 1966). The remainder is based on topographical maps, geological maps and the author's knowledge of the area.

4.2 TOPOGRAPHY AND CLIMATE

This study is concerned with the Gwydir River Valley, upstream of Bundarra. This section of the Valley is referred to as the Upper Gwydir Valley in this report.

The Upper Gwydir Valley is one of the northernmost contributors to the Murray-Darling drainage system. It drains an area of about 3990km^2 extending westward from Guyra and Uralla. The river rises in country with ground elevation of over 1200m above sea level, in the elevated plateau which forms the Great Dividing Range west of Armidale. It flows in a north westerly direction towards Bundarra. Figure 6 shows some details of the Upper Gwydir Valley. A written description of the boundaries of the catchment and the significant streams and creeks in it, which flow into the Gwydir River, is given in Appendix "B".

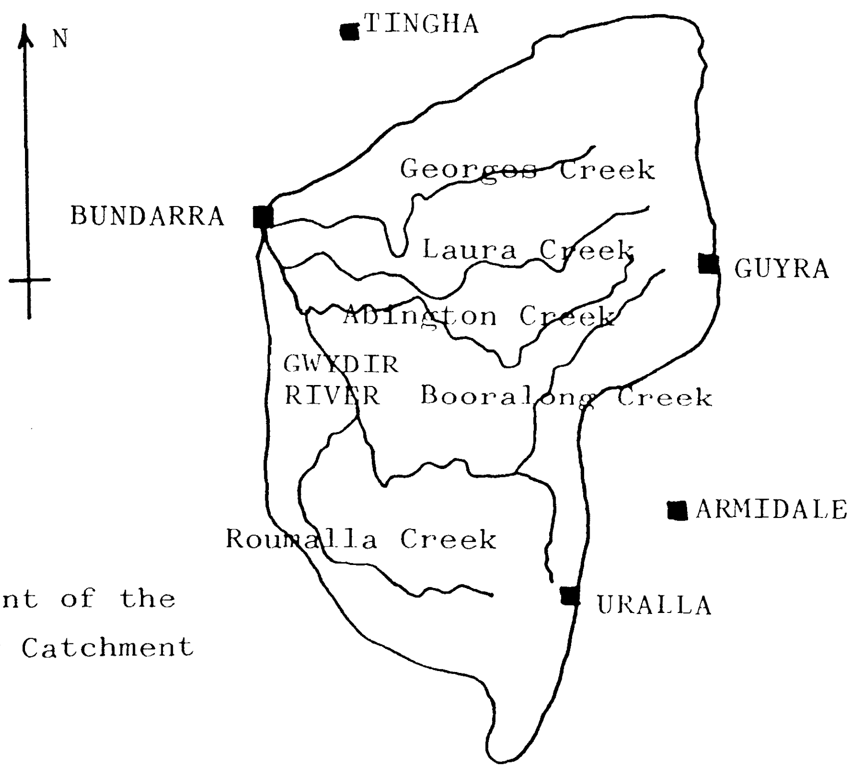


Figure 7 : The Extent of the Upper Gwydir Valley Catchment
Scale - about 1:10^6

The predominant soils in the Upper Valley are the podsolised types which have developed principally from decomposed granite.

Rainfall in the whole of the Gwydir Valley, in general, decreases with decreasing elevation and hence shows a fairly uniform decrease westerly from a maximum along the eastern catchment boundary. Annual median rainfalls of 750-900 millimetres occur over the headwaters above 900 metres elevation.

The catchment receives more than 60 percent of its annual rainfall in the five months from November to March. A short secondary wet spell is generally experienced during June-July when a further 17 percent of the annual rainfall is received. These two wet seasons are separated by two relatively dry periods, April-May and August-September, each of which receives about 12 percent of the annual average. However, rainfall is highly variable. At Bundarra, the lowest recorded annual rainfall is 330mm and the highest recorded annual rainfall is 1215mm, with the average being about 760mm.

Dry spells are not uncommon. For most months of the year, monthly rainfall totals of less than 19mm are experienced on 10% of occasions. Dry spells extending over six months are common. For the six month period from April to September, on an average of one year in ten, totals of less than 216mm are recorded in the Upper Valley, while the median value for this period is 305mm. For the six month period from October to March, which includes the summer maximum, on an average of one year in ten, the area records totals of less than 356mm, while the median value for this period is 483mm.

Table 6 provides temperature information for Uralla, at the headwaters of the catchment and for Bundarra, the site of this study.

The headwaters of the catchment experience an average of 80 frosts per year. Frosts in this area have been recorded as early as 6th January and as late as 29th December.

TABLE 6 Average Maximum and Minimum Temperatures To the Nearest Degree (^{o}C)

URALLA - Elevation 1017m

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Maximum	27	26	24	20	16	13	12	13	17	20	24	26
Average Minimum	12	12	11	6	3	0	-1	0	2	6	9	11

Highest on Record 38 Lowest on Record -9

BUNDARRA - Elevation 610m

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Maximum	31	30	28	23	19	16	15	16	20	23	27	29
Average Minimum	15	14	12	7	3	1	0	1	4	7	11	13

Highest on Record 41 Lowest on Record -10

Table 7 provides average monthly evaporation for the headwaters of the valley.

TABLE 7 - Average Monthly Evaporation (Sunken Pan) for the Headwaters of the Gwydir Valley (mm)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
178	132	127	84	66	41	38	64	79	104	152	173

4.3 GEOLOGY AND GROUNDWATER

The principle geological features of the Upper Valley are shown in Figure 8

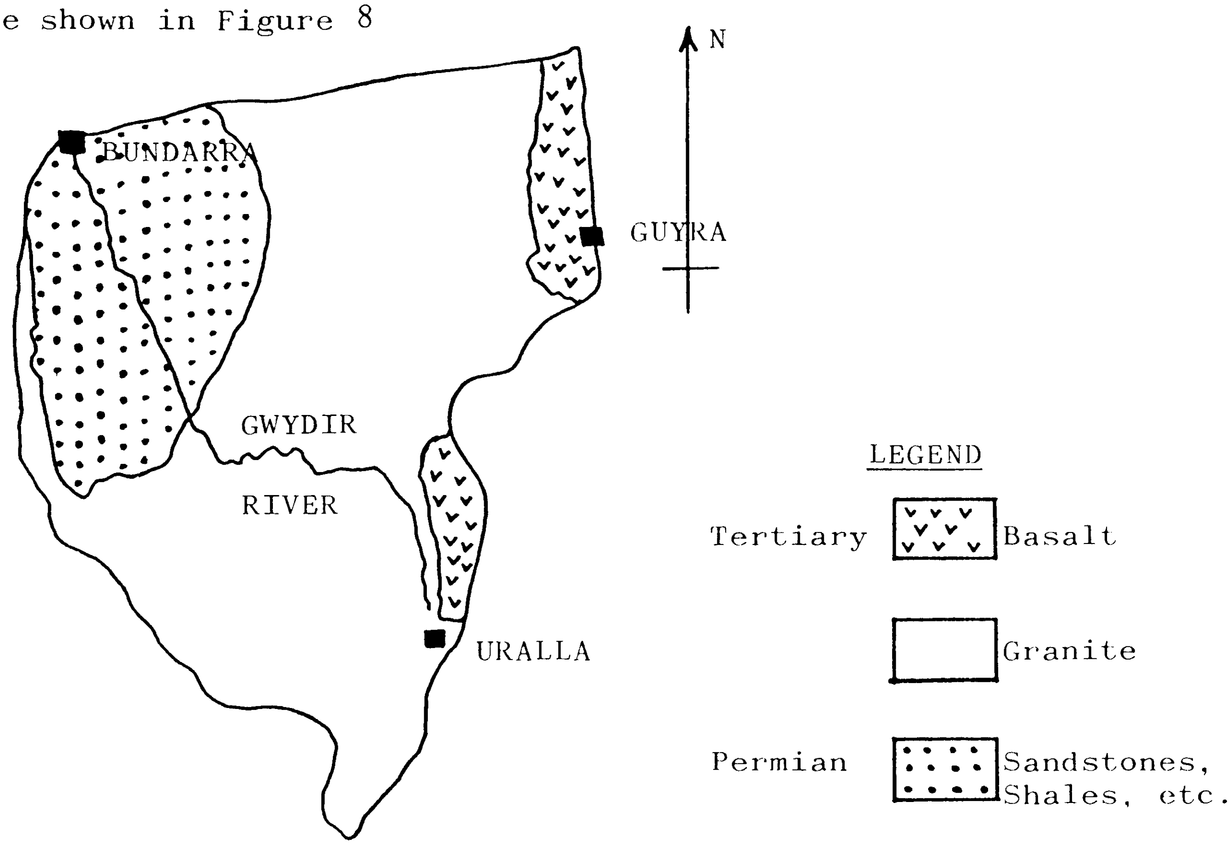


Figure 8: The Principal Geological Formations of the Upper Valley.

The eastern half of the Upper Valley is underlain by relatively hard granites and basalts (biotite leucoadamellite, adamellite, tonalite, granodiorite, tholeiitic and alkaline basalts). The rather rugged country in this area is believed to have been uplifted several million years ago, not long after great outpourings of basalt, remnants of which still cap a good deal of the higher country. Portion of the New England Batholith, a large intrusion of igneous rock of granitic nature, underlies the eastern part of the catchment.

An oval shaped area in the vicinity of Bundarra is comprised of sandstones, shales and conglomerates of Permian age. The granite was intruded after the deposition of these sediments. These sediments comprise part of the geological sequence of strata which make up the Great Artesian Basin, far to the west.

Groundwaters of low salinity and low yield occur in the fractured basalt country on the eastern boundaries of the catchment. However, the Water Resources Commission advises that, elsewhere in the Upper Valley, groundwater is generally either absent or of very small yield and the salinity is always greater than 1000 milligrams per litre (Water Resources Commission, 1976). Groundwater potential for irrigation usage in the Upper Valley is very limited.

4.4 STREAMFLOWS, FLOODS AND DROUGHTS

A streamflow gauging station has been established at or near Bundarra since 1930 and almost uninterrupted daily flow records have been obtained from the Water Resources Commission of N.S.W.

Streamflows in the valley are subject to a high degree of variability. Annual runoff from the valley can range from less than 1% to more than 500% of the long term average annual runoff. On both a monthly and instantaneous basis the variability is even more marked. At Bundarra, the minimum recorded discharge is zero, the mean is $13m^3/sec$ and the maximum is about $4250m^3/sec$.

Streamflows in the Gwydir River do not exhibit a high degree of persistence during dry periods. Appendix "C" shows a flow duration curve for the Gwydir River at Bundarra and Appendix "D" shows a curve analysing the frequency of various durations of periods of no flow. Both of these curves have been prepared by officers of the Council.

Reports to Uralla Shire Council quote the following results of the analysis of the curves given in Appendices "C" and "D" :-

"Council draws the water for the Bundarra town supply directly from Taylor's Pond, in the Gwydir River. No major problems are experienced with the system while the river is flowing. However, when river flow ceases, problems are experienced with water quality (primarily taste and odour) and more seriously, with the quantity of water available in Taylor's Pond.

"Taylor's Pond, in the Gwydir River, is currently used to supply water to three water users. These are the property "Flemington", the property "Clerkness", and the Uralla Shire Council for the Bundarra Water Supply. The irrigation licences issued by the Water Resources Commission contain a condition which specifies a river level below which irrigation is not to be carried out. That irrigation level is 0.88 metres above the inlet pipe for Council's water supply pump. During recent irrigation works, the property "Clerkness" was drawing 1,300 kilolitres per day from the pond, the property "Flemington" was drawing 691 kilolitres per day from the pond, and Council was drawing 650 kilolitres per day for the Bundarra Water Supply, prior to the implementation of water restrictions. Following the implementation of water restrictions, Council's water demand reduced to 300 kilolitres per day.

"No flow occurred in the Gwydir River between 29th September 1980, and 15th December 1980, a period of 77 days. A small flow occurred until 15th January, 1981 when flow ceased again. As at 14th April, 1981 no flow had occurred since 15th January, 1981, a period of 89 days.

"An analysis of the water flow in the river over the last forty years of flow records, indicates that this present experience can be expected to occur, on average, once every twenty years. A period of sixty days of no flow can be expected to occur, on average, once every eight years. A period of 200 days of no flow can be expected to occur, on average, once every 50 years. This analysis shows that, statistically speaking, the recent lack of flow in the Gwydir River cannot be considered to be an extreme event.

"The flow in the river is less than 1,000 kilolitres per day (this is the maximum daily town consumption ever recorded at Bundarra) 11% of the time. The river flow is less than 650 kilolitres per day (the average Bundarra town daily summer consumption) 9%of the time. The river flow is less than 3,000 kilolitres per day (the present total demand by all users on Taylor's Pond) 13% of the time. This analysis indicates that the flow in the river cannot meet the water supply demands placed on it. It is clearly necessary to depend on the water storage to meet the water supply demand.

"Once the level in Taylor's Pond drops to the presently specified level at which irrigation must cease, the storage available would only supply Bundarra town, without water restrictions, for 34 days. If water restrictions were applied in the town, the storage would be able to supply it for seventy days.

"If the level at which irrigation must stop were raised by 600 millilitres the storage available at that time would be sufficient to supply Bundarra town, without water restrictions, for about two and a half months, and with water restrictions for about five months.

"The above figures indicate that Taylor's Pond, in its present state, is not capable of satisfying the water demands placed upon it by the Council and the irrigators in the area.

"The situation may be improved by the inclusion of the storage in the next upstream pond (Worrabinda Pond) in the Council's scheme or by increasing the storage capacity of the Taylor's Pond, by the erection of a low weir at its outlet end. These proposals both require detailed investigation. It may also be improved by amending the current controls over irrigation usage.

"In order to assess the impact of alternative proposals to augment the volume of water stored in either or both ponds, or the impact of alternative criteria to control irrigation and town usage, during periods of water shortage, it is necessary to analyse many years of previous flow records and subject these historical flows to future expected demands.

This complex analysis, which will result in specific, tangible evidence of the effects of irrigation, requires the use of a large and powerful computer. .....(This analysis) will produce sufficient hard evidence to allow a firm case to be argued for proposed amendments to pumping licences aimed at achieving an equitable sharing of the water resource.."

(Uralla Shire Council, 1981).

While this study is primarily concerned with periods of general water shortage and therefore concentrates on drought periods, some comments on flooding in the river are relevant. The Gwydir River Valley is not subject to frequent severe flooding. Gwydir floods have tended to come in groups interspersed with substantial dry periods. In the Upper Valley catchment, tributaries rise and fall quickly and limited overbank flow lasts only a matter of days at most. Flooding is not a severe problem in the Upper Valley where floods are generally confined to narrow flood plains less than one kilometre wide.

4.5 LAND USE IN THE UPPER VALLEY

The bulk of the land in the Upper Valley is used for grazing of sheep and cattle. Some improved pasture is sown and dry land farming of fodder crops is also practised, together with limited areas of irrigation of fodder crops on farms adjacent to the Gwydir River.

Sheep predominate in the headwaters and around Bundarra, while cattle are more common between Torryburn and Bundarra.

Fruit growing takes place in limited areas along the eastern boundary.

The steeper areas retain natural timber cover, but the Valley is essentially used for grazing.

Concern has been expressed at the effect that changing land use, particularly increasing cattle numbers, increasing use of improved pasture and increasing irrigation, is having on both water quality and quantity. Further research into these matters should be encouraged.

Figure 9 indicates the extent of cleared pasture land and natural vegetation in the Upper Valley (taken from Cameron McNamara Pty Ltd, 1982).

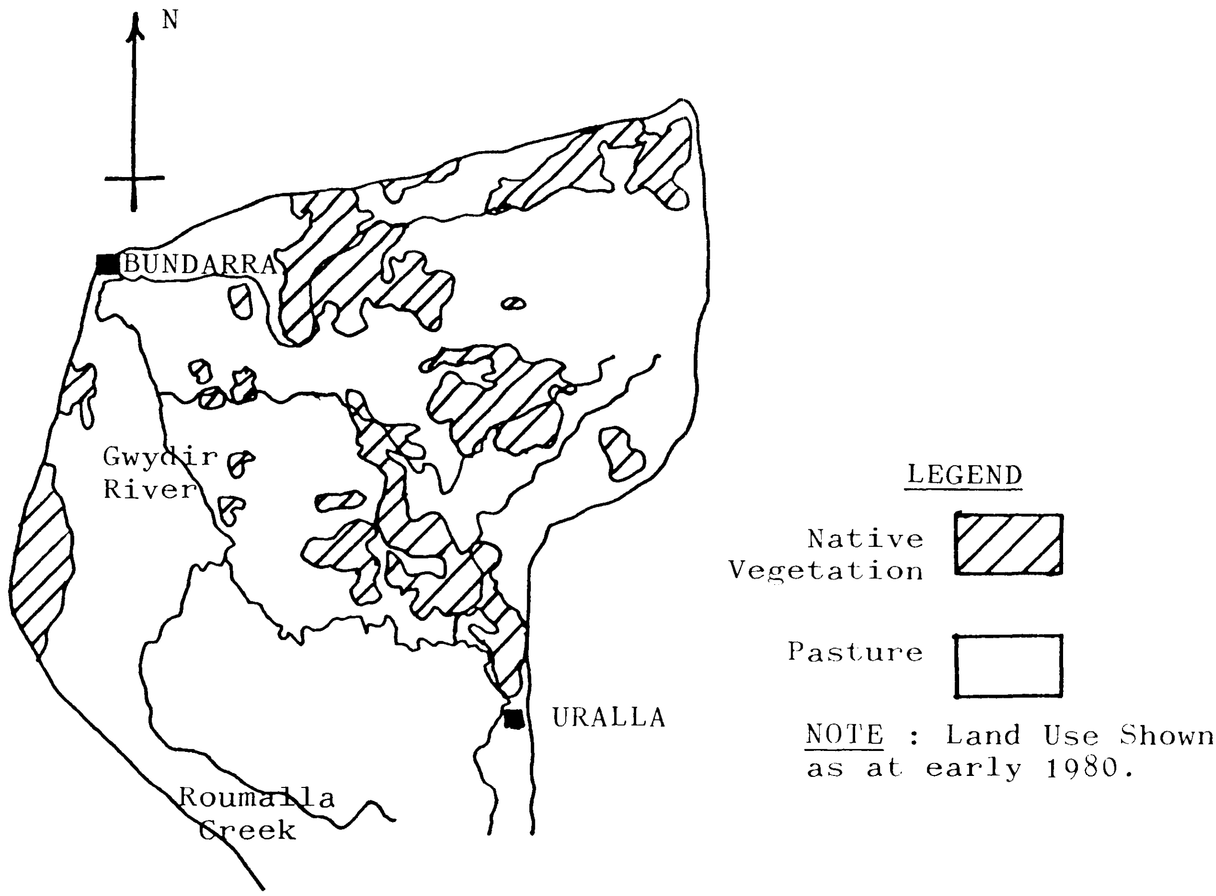


Figure 9 : Land Use in the Upper Gwydir Valley, as at 1980.

In addition to supplying water for the village of Bundarra, the Gwydir River, through its tributary, Kentucky Creek, supplies water to the township of Uralla, in the eastern headwaters. Augmentation of the town's supply weir is planned for 1983.

The potential for major irrigation works in the Upper Valley is limited. Increasing requests for small diversion licences, farm dams and groundwater bores can be expected. The potential for significant industrial growth in Uralla or Bundarra is limited.

Land use in the Upper Valley is expected to change only slowly over the next twenty or thirty years.

CHAPTER 5

THE SIMULATION MODEL

5.1 THE USE OF COMPUTER SIMULATION IN DECISION MAKING

Computer simulation is the art of representing a problem or a real life situation, in mathematical terms, in a computer. It is sometimes referred to as computer modelling. The mathematical model of the real life situation can be manipulated by the computer so that a variety of influences on the situation can be imposed on the model. The effects of the influences are seen by either changes to the model itself or by the results produced by the computer processing.

Simulation is an aid to decision making. If the mathematical model is valid and credible, in that it adequately describes and predicts the behaviour of a given system, under given conditions, it can be a very powerful tool in the decision making process.

The conflict being studied in this report involves a complex system of interaction between competing users, weather influences, river flow and a variety of possible management decisions. Computer simulation allows the effect of changes in all or some of these influences to be analysed over a long period of time. It is a powerful tool used in the development of data upon which decisions may be made about the sharing of the water resource.

5.2 THE STRUCTURE OF THE SIMULATION PROGRAMME

The computer programme developed to simulate the conflict has been written as a conventional programme, written in the computer language "Fortran".

It is composed of a main programme and two subroutine programmes. The main programme is involved in controlling the input and output of data and represents the flow in the Gwydir River. One subroutine represents the water demand in the village of Bundarra. The other subroutine represents the irrigation process and its demand on the water in the river.

Figure 10 shows the physical situation which the programme is required to simulate.

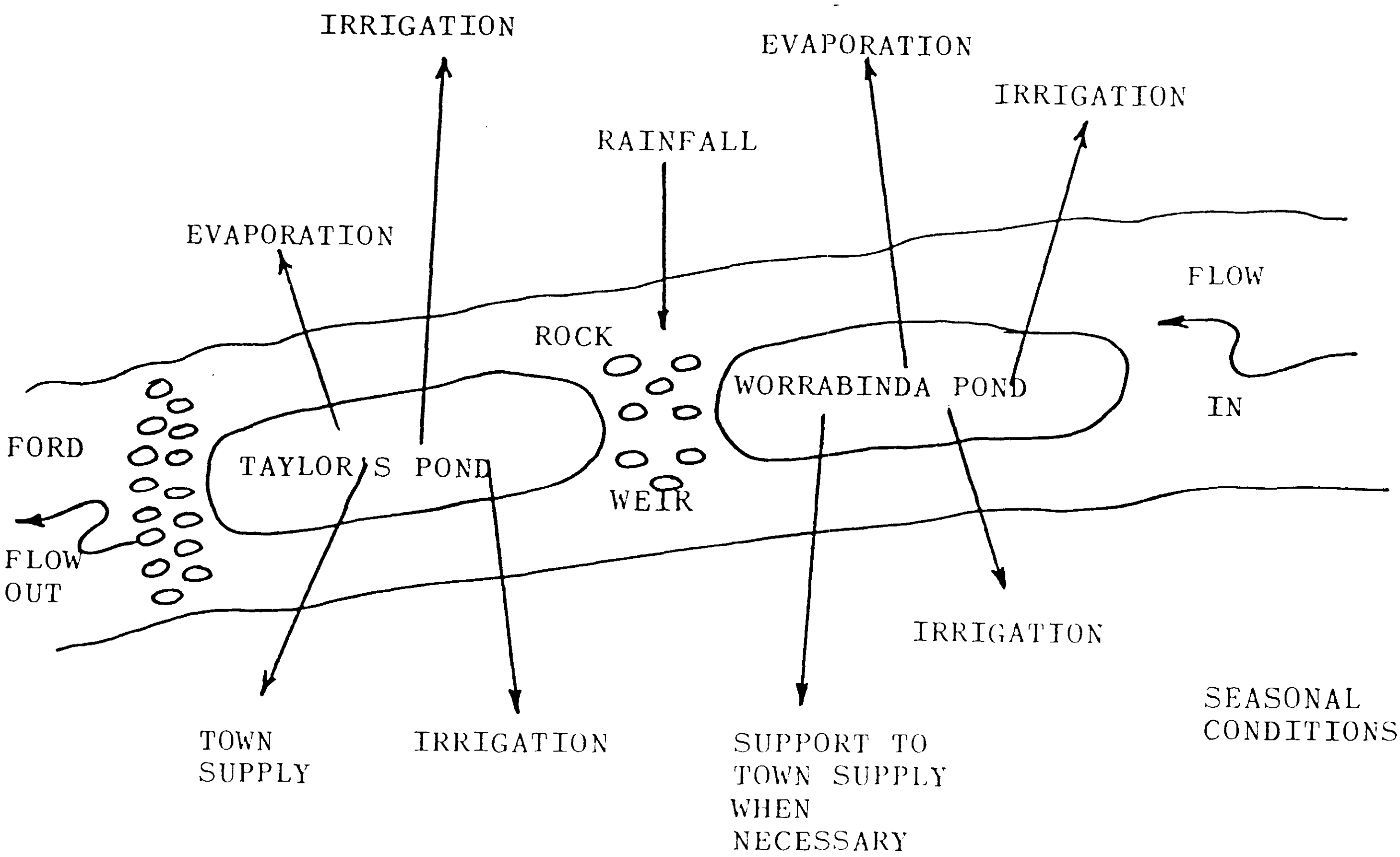


Figure 10 : The Daily Water Supply and Demand Situation in the Gwydir River at Bundarra.

Examination of Figure 10 indicates that the programme must either be provided with data concerning the following features of the situation at Bundarra, or it must simulate those features:

- daily flow into the river
- daily rainfall
- the effect of seasonal conditions on town usage, irrigation usage and evaporation
- the capacity of the two ponds to store water
- the daily irrigation demand, as affected by rainfall and season and any imposed restrictions
- the daily town demand, as affected by season and any imposed conditions

- management plans in force to control usage

The programme simulates the situation represented in Figure 10 by reading in, on a daily basis, data concerning rainfall and river flow. It then simulates the demands made on the water flow, or pond storage, depending on the controls set by the management plan being tested. It determines the water balance situation at the end of each day, when the next day's data can be read in.

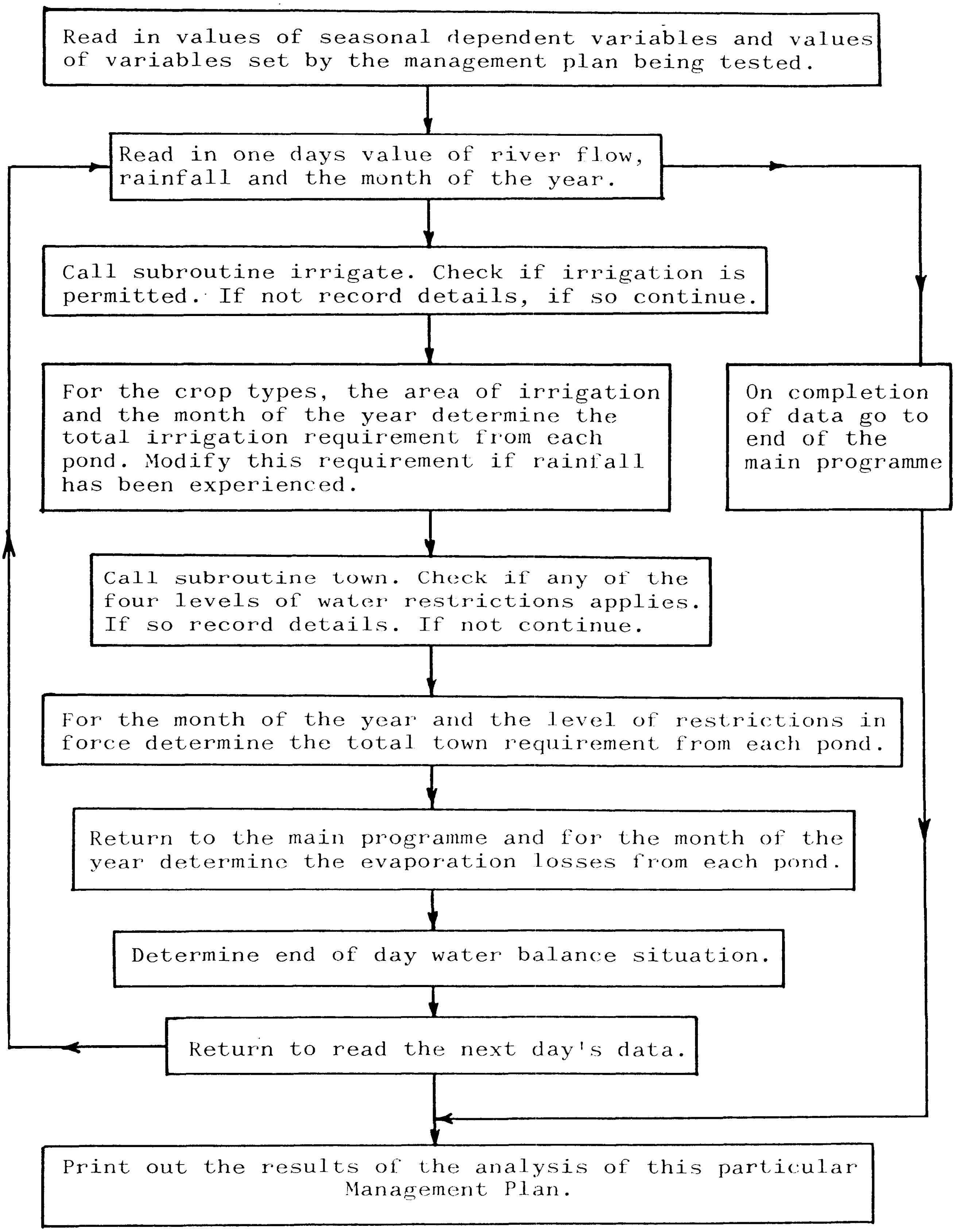
Figure 11 is a simplified flow chart of the programme.

The full text of the Fortran programme is given in Appendix "E". The computer language text is heavily supplemented with comments which allow the programme to be readily followed by those familiar with the language. A detailed flow chart showing all of the logical operations involved in the programme, together with numerous comments and descriptions is given in Appendix "F". Appendix "F" includes an alphabetical listing of each of the ninety five significant variables used in the programme, together with a detailed description of each variable.

Many of the people involved in this particular problem are of the opinion that the present conditions of control over water usage are unsatisfactory and need either amendment or justification. They also are aware that the river is unable to meet all the demands made on it, on an unrestricted basis, and are seeking a set of restrictions and controls on all users that can be shown to be fair to all users.

The programme allows analysis of a whole series of controls and restrictions on the users. Each series would probably result in a change in the way the present consumers can use the water. Each of the consumers would want to know how they would be affected by any proposed management plan, and how other users would be affected. Those responsible for adopting any new plan would need to be convinced that it was fair. The results of the programme, which analyses over 50 years of daily data, have been designed to provide answers to suit these questions and needs.

Figure 11 - Simplified Flow Chart of the Programme



It provides the following types of results:

- a summary of the management plan being analysed
- the number of days

(a) of the whole period of analysis

(b) in which irrigation is not permitted from each pond

(c) in the longest period in which irrigation is not permitted from each pond

(d) in which the stored volume in each pond was in each quartile of capacity, from full to empty

(e) in which each level of a series of increasingly harsh town water restrictions applied

(f) in the longest period in which each level of town water restrictions applied

(g) in which the town supply failed

(h) in which there was no flow out of Taylor's Pond

- the number of separate occasions

(a) in which irrigation is not permitted from each pond

(b) in which irrigation is not permitted from each pond for periods in excess of 5, 10 and 20 days

(c) in which each level of town water restrictions applied

(d) in which each level of town water restrictions applied for periods in excess of 5, 10 and 20 days

- the volume of "required" water foregone as a result of the imposition of water restrictions
- a history of occasions of significant forced interruptions to irrigation.

Acopy of the results of the analysis of one particular management plan is given in Appendix "G".

A full understanding of the methods used in the simulation can be obtained by supplementing the text of this chapter with the information provided in Appendices "E", "F" and "G". Appendix "F" is of particular value in this regard.

5.3 SIMULATION OF THE IRRIGATION DEMAND - THE SUBROUTINE IRRIGATE

Much of the information in this section is based on procedures outlined by Burton in "Water Storage on the Farm, Volume 1 " (Burton, 1964).

The aim of this subroutine is to represent the method of irrigation practised in the area as closely as possible. The validity of results of theoretical analysis of suitable procedures was checked by interviewing the irrigators and determining the practical procedures they use. In this way, the soundness or otherwise of the irrigation practices was checked and the irrigator had the opportunity to assure himself that the simulated irrigation procedures are realistic.

The factors which determine the water requirements for irrigation are the area of the crop, the type of crop, the amount of solar radiation received, the temperature and humidity, the season, the number of hours of daylight, other weather factors related to latitude, the soil type, the method of irrigation and recent rainfall experiences.

The Water Need of a crop (Nw) is defined as the total amount of water required by the crop for its growth over a specified period (eg. mm/month). Water need includes evapotranspiration, evaporation from soil and plant surfaces and percolation losses.

The Irrigation Need of a crop (Ni) is defined as the total amount of irrigation water which must be supplied to it to make up deficiencies in water need not met by rainfall (P), over a given time period.

$$Ni = Nw - P \quad \ldots\ldots\ (5.1)$$

The monthly water need for a given crop in a given location is calculated from equation 5.2.

$$Nw = E \times f \times p \quad \ldots\ldots\ (5.2)$$

where $\bar{E}$ = the mean monthly evaporation (eg. in mm)

f = a crop factor (non-dimensional)

p = a climatic factor (non-dimensional)

Values of f are available for a large range of crops. The factor p varies monthly and values are available for a variety of latitudes. Values of E are available from the Bureau of Meteorology.

A plant growing in moist soil uses water, more or less continuously, at a rate which can be assumed to be proportional to the local rate of evaporation (see equation 5.2). Irrigation water is applied to replace the water removed from the soil by the plant. The plant has access only to a limited volume of soil, within the reach of its root system and this volume of soil has a more or less fixed capacity to hold water, depending on the soil type. The amount of water to be applied by irrigation depends on the water holding capacity of the soil reservoir.

There are three broad categories of soil water. Gravitational water is that which moves freely through the soil and drains downwards to the water table. Except for a brief period immediately after irrigation, this water is not available to the plant roots. Hygroscopic water is water held tightly to the surface of soil particles by molecular forces and is not readily available to plants. Capillary water is that held by surface tension forces, as continuous films around soil particles and in the capillary spaces between particles. Capillary water is available to plants and provides most of their water supply.

If a soil is saturated and allowed to drain freely, the gravitational water will quickly move downwards and be lost. The moisture content of the soil after all the gravitational water has drained away and the soil is holding its maximum amount of capillary water is called the Field Moisture Capacity (FC). Plants growing in the soil extract capillary water from it and so reduce its moisture content. As the soil becomes drier the plants have more and more difficulty removing water. A moisture content is finally reached at which they can no longer extract water and they wilt and die. The moisture content at which this fate occurs is called the Permanent Wilting Point (PWP).

The volume of water available to the soil (W) is given by

$$W = FC - PWP \qquad \ldots\ldots\ldots (5.3)$$

Values of W (eg. in mm/m depth) are available for a variety of soil types.

The capacity of the soil reservoir (S)is called the root constant and is the volume of available water within range of the root system.

$$S = W \times R \qquad \ldots\ldots\ldots (5.4)$$

where R = the effective root depth of the crop (eg. in metres)

Values of R are available for all common crops.

To ensure that crops do not suffer significant reductions in yield or quality, soil moisture levels are not allowed to drop below 40% - 70% of Available Soil Moisture before the soil is irrigated to return its soil moisture level to Field Capacity. This practice is said to maintain a growth rate of 80% of optimum (Hexem and Heady, 1978).

The allowable soil moisture deficit D is defined as

$$D = S \times Y \qquad \ldots\ldots\ldots (5.5)$$

where Y is the yield factor, which varies from 0.4 to 0.7 depending on the climate, the season and the crop type. The allowable soil moisture deficit equals the net depth of water needed at each irrigation to bring the soil back to field capacity.

The gross depth of irrigation application, Dg is calculated by

$$Dg = \frac{D}{n} \qquad \ldots\ldots\ldots (5.6)$$

where n = the application efficiency of the irrigation system used, expressed as a decimal.

The period between required irrigation applications, T, is calculated by dividing the allowable deficit by the average daily rate of water use.

$$T = \frac{D}{Nw/30} \quad \ldots\ldots\ldots \quad (5.7)$$

The irrigation requirement, IR, for any area A, at intervals of time T

$$IR = Dg \times A \quad \ldots\ldots\ldots \quad (5.8)$$

The term application efficiency refers to the effectiveness of the watering method used. It is a measure of all the losses occurring in the field, including evaporation, wind losses, deep seepage, leaks and surface runoff.

The required depth of irrigation application can be reduced or postponed if the soil moisture levels are increased by rainfall experience.

Figure 12 is a diagrammatic representation of the cycle of irrigation application, plant usage of water, occasional rainfall and further irrigation application. Examination of the figure shows that once the values of D and T have been determined, the soil moisture level can be calculated at any time and hence the irrigation procedure can be accurately simulated. The procedure shown in Figure 12 is used to simulate the irrigation process in this subroutine. The subroutine maintains a daily record of the moisture level in the soil and thereby determines when future irrigation is required.

The subroutine requires the following data to allow it to simulate the irrigation process:-

- the net depth of irrigation application by Clerkness and Flemington, respectively, in mm, as calculated by the procedures described above
- the period between required irrigation applications for crops on the properties "Clerkness" and "Flemington"

respectively (in days)

- the area of the crops irrigated by each of the properties, from each of the ponds (in ha)
- the daily volumes drawn from each pond, by each property, for the particular crops being irrigated (Ml).

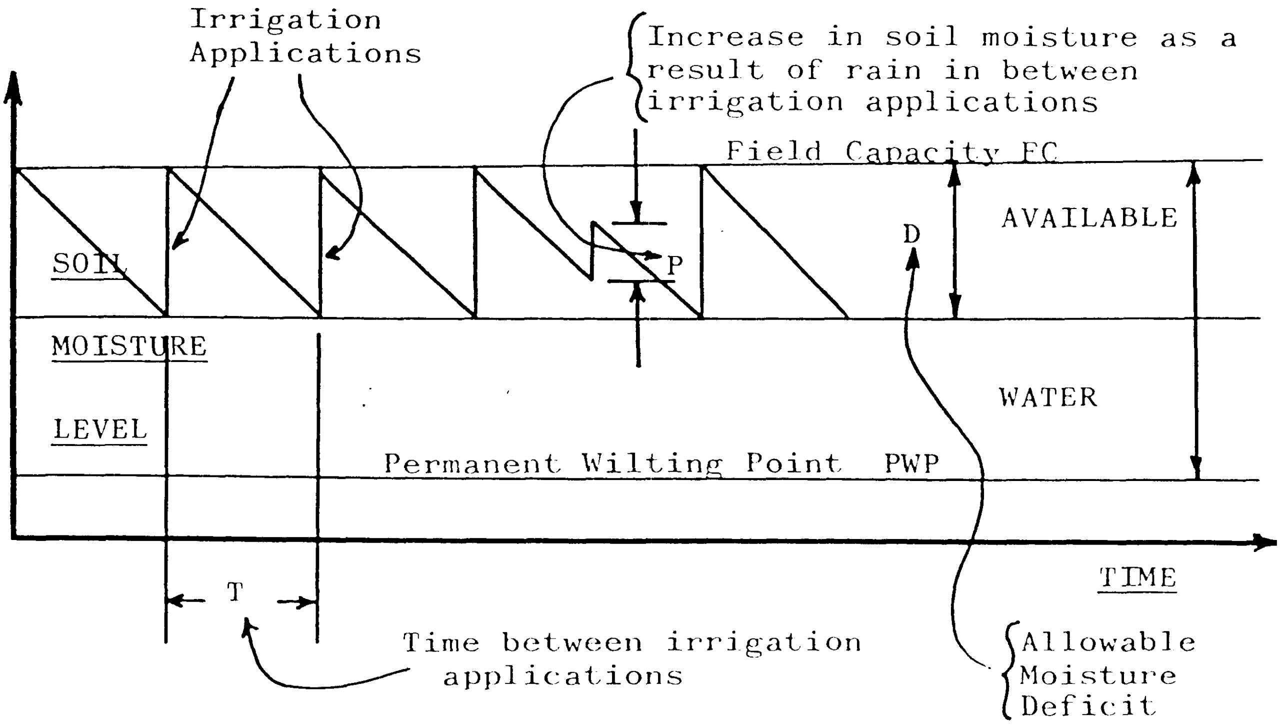


Figure 12 : The Relationship between Soil Moisture level and time during successive irrigation applications, as affected by Rainfall.

The two landowners carry out their irrigation using spray irrigation techniques. Both use a system of watering on a cyclic basis, moving their irrigation pipes across the crop in such a manner that any area is returned to, for another irrigation application, before the allowable soil moisture deficit has been reached in that area. As a result, a regular demand is made on the river during dry periods.

"Flemington" irrigates lucerne as a summer crop and oats as a winter crop. "Clerkness" has irrigated sorghum or millet during summer and oats in winter, but intends to change to growing lucerne in summer.

Values for the above listed data variables, which describe the irrigation practice at Bundarra, have been calculated using the methods outlined in this section of this chapter. The calculated values were discussed with and compared with the practices of the irrigators. The calculated results were supported by the irrigators as representing the practices they aimed to achieve. These values, listed in Appendix H, have been used as data for this simulation programme, to represent current practice. They are provided to the programme in two separate data files. These data files are read by the main programme before it calls this subroutine. The programme is able to simulate different irrigation procedures when it is provided with different values of the variables, through the two data files.

Irrigation may proceed from either or both ponds until the water level in these ponds falls to defined levels. These levels are set as management decision variables and are provided to the programme as data. The purpose of the subroutine is firstly to determine if irrigation is permitted to proceed. If irrigation is permitted, the subroutine calculates the irrigation demand from both ponds, for a particular day and provides those values to the main programme. If irrigation is not permitted, the subroutine calculates information concerning the extent and nature of periods in which irrigation is not permitted. Information concerning the periods in which irrigation is not permitted is progressively written to a further two data files, which are read at the end of the simulation, and reproduced as a printed record of the history of occasions of interruptions to irrigation.

Further necessary data, which is read by the main programme before it calls this subroutine, is a listing, on a consecutive daily basis, of the following variables:-

- the daily volume of flow in the Gwydir River into Worrabinda Pond,
- the daily rainfall experienced on the irrigated areas and
- month in which each day's data falls.

The subroutine uses the value of daily rainfall to modify each day's irrigation demand, to allow for the effect of rainfall experienced on the previous day.

Once the subroutine has completed the above analysis for one day of the simulation period, it provides the simulated irrigation demands to the main programme, which continues its task of determining the daily water balance situation in the river. The subroutine is returned to again when the next day's weather data is read. This procedure is repeated daily for the whole period of the simulation.

5.4 SIMULATION OF THE URBAN WATER DEMAND THE SUBROUTINE - TOWN

The aim of this subroutine is to provide the programme with realistic estimates of daily water demand, depending on the season (month of the year) and the water restrictions which are being applied to town users, depending on the water storage situation in the river.

Town water consumptions vary with time. They increase with improved standards of living and industrial growth and also cyclically with hourly, daily, monthly and annual trends. They also vary with climate, topography, soil type, water quality and pressure, water cost, local practices, lot size and the extent of industrial and public amenities.

Authorities such as the Public Works Department of N.S.W. have adopted design criteria, for various regions of the state, to predict annual, mean day, peak day, peak hourly and instantaneous demands for country town water supplies. Such an analysis requires calculations for domestic use (based on population), commercial use, industrial use, use in public parks and gardens, use in large institutions, schools, hotels and motels, use in street cleaning and stock watering, use in flushing sewers and losses due to leakage.

The Australian Water Resources Council has also published, in its Technical Paper No. 20, various consumption data for a variety of uses.

In the absence of consumption data for particular towns, analyses such as those described above can be carried out to determine expected water demands for use in the simulation programme.

In the case of Bundarra, Uralla Shire Council has comprehensive daily records of town water consumption, which cover both periods of abundant availability of water and periods of serious drought, when stringent water restrictions have been applied. These records have been used to determine average daily town demands, variable on a monthly basis, for both unrestricted use and for use in periods in which various water restrictions apply.

This subroutine allows for the setting of unrestricted usage volumes and volumes for four increasingly stringent levels of water restrictions. Each level of water restriction is applied when the water level in Taylor's Pond falls to predetermined levels which are given to the programme as data. Any of the variables defined in the data files may be altered, to have the programme test the effect of alternative management plans. The data files actually define any management plan being tested.

The values of daily town consumptions are provided to the programme as data and, in this case, cover the following progressively applied water restrictions :-

(1) fixed sprinklers are prohibited. Hand held hoses may be used at any time

(2) hand held hoses may be used only for three hours per day (say 5.00 pm to 8.00 pm)

(3) hand held hoses may be used only for one hour per day (say 5.00 pm to 6.00 pm)

(4) water may be used for domestic purposes only.

Water consumption rates in Bundarra are high on a per capita basis, probably because of the usual abundance of water, the semi-rural nature of the town with corresponding large lot sizes, the extensive vegetable gardens and the keeping of stock (sheep, cattle and horses) in the town. The values of town consumption used in this study are listed in Appendix I. For the purpose of this study, it has been assumed that the town of Bundarra will not alter significantly in size or nature over the next twenty or thirty years.

The purpose of this subroutine is firstly to determine what level of water restrictions (if any) apply for each day. If restrictions do apply, it calculates information concerning the extent and nature of periods of each level of restriction and the volume of water not available to the town because of those restrictions. It also determines the appropriate daily town demand to apply, as a result of the month and the current level of restrictions, and provides it to the main programme.

5.5 THE MAIN PROGRAMME

This section of the programme has four main functions :-

(a) it reads the values of the variables which define the particular situation to be simulated and those which define the management plan to be tested.

(b) on a daily basis, it reads the current weather information of daily river flow and daily rainfall

(c) it provides the required data to the two subroutines and calls on them, for each day of the analysis, to provide it with the daily demands on the water in the river. It analyses the volume loss from the river ponds by evaporation and then calculates the water balance situation at the end of each day. It calculates the current water storage levels in each pond at the end of each day. It records the status of the ponds, for advice to the subroutines, to allow them to determine if restrictions are to be imposed on town users or irrigators. It then reads the next days weather data and repeats the iterative process, on a daily basis, for the period of the simulation

(d) at the end of the simulation it manipulates the files and prints out the results of the analysis of the management plan being tested.

In order to determine the volume lost (Ml) due to evaporation (mm) and also to determine the changes in water level in the pond as a result of volumetric changes, it is necessary to use a mathematical description of the depth-capacity curve for each pond. Each pond was accurately surveyed and a depth-capacity relationship determined by linear regression analysis. In both cases a discontinuous log-log relationship was found to accurately describe the ponds, with a correlation coefficient in excess of 0.98. Depth capacity curves for both ponds may be found in Appendix J.

To check for the effect of siltation in the ponds, the depth-capacity curve developed for Taylor's Pond from survey work in March 1981 was compared with a curve developed from a survey carried out in 1950 by officers of Uralla Shire Council. The comparison showed that 0.7 Ml of capacity has been lost in the lower sections of Taylor's Pond, well below the dead storage level for the town supply. In the vicinity of dead storage level the capacity loss was 1.0Ml in about 29Ml and at present full capacity it was 1.2Ml in about 96Ml. When the accuracy of the depth-capacity curve, which was developed by determining volumes from a series of bed cross-sections, is considered it is clear that there is no evidence that siltation of the ponds is a matter of concern in this case. The depth-capacity curves developed in 1981 have therefore been adopted for use throughout the whole period of the simulation.

5.6 GROUNDWATER FLOW

It should be noted that no attempt has been made to simulate groundwater flow into the ponds in this programme. There are two main reasons for this decision. One concerns the fact that both of the weirs at the downstream end of the ponds are made from earth and rock fill material and therefore allow the seepage of some stored water through them. Measurements of daily water levels during periods of no river flow and associated matching of drop in pond level with known drafts on the ponds, has indicated that any groundwater inflow must closely equal storage losses from the ponds through the weirs. At least, it has been demonstrated by site measurement that groundwater flow into the ponds, during periods of no surface flow, is not significant in this study. This point leads to the second reason for not simulating groundwater flow. That reason is that this study is only closely interested in what happens at the end of prolonged dry periods. At these times pond levels are very low, the ground is very dry and it would not be expected that groundwater flows would be significant for the purposes of analysis.