CHAPTER 6

MODEL DATA AND VALIDATION OF THE PROGRAMME

6.1 MODEL DATA

The data required to permit operation of the simulation programme have been listed in section 5.2, and include:

- river inflow data
- rainfall data
- data concerning the physical situation being simulated
- data concerning the management plan being tested in a particular simulation .

Selection of data needs to be based on principles which ensure that the results produced by the programme are reliable.

6.2 RIVER INFLOW DATA

River inflow data are crucial elements in this study. It is therefore necessary to ensure that the data used are reliable and representative for the purposes required.

The simulation programme is designed to simulate water flow and drafts over a period of time and report on the effects of various management techniques on interruptions to water supply over that time period. It is therefore necessary to use data which represent a range of river flows which could realistically be expected to occur during the period of the study, rather than just extreme conditions. Data could be developed by using historical river flow values (if available) or by using stochastic data generation.

When historical data are used the assuption that those flows will be repeated is implicit. The likelihood of the flows being repeated and the difficulty involved in predicting the reliability of the final design solution, in statistical terms, are two weaknesses involved in using historical data. These weaknesses are reduced when the historical data cover long term periods and include known periods of extreme conditions, such as major floods and droughts. The implicit assumption, in the case of this study, that future flow sequences will not contain a significantly more severe drought than the historical flow sequence, is a recognised weakness in the use of historical flow data. However, the fact that long periods of data do take into account serial correlation and seasonality is an important attribute of the use of historical flow data.

The aim of using stochastically generated data is to "produce "streamflow" sequences with the same statistical properties as the historical record" (McMahon, 1978 b). Fiering and Jackson (1971) are of the opinion that the main advantage of the use of generated data is that it allows designers to place a level of confidence on their adopted design solution. They state that "synthetic flows (or stochastic data) do not improve poor records but merely improve the quality of designs made with whatever records are available". McMahon (1978b) has described the many data generation processes available, together with their suitable application to Australian streams. He concludes that "no model is satisfactory for all purposes. Consequently, if one is using a data generation model in practice, one needs to understand clearly the objectives of the study which should influence model choice".

This study requires the use of daily data to examine the effect of various management plans. It does not need to use very long periods of data, such as the thousands of years of annual data produced by synthetic data models for use in determining required storage in large resevoirs. It is considered that the objectives of this study could be met by the use of a suitable length of historical daily flow records. It is recognised that the use of the historical records to generate synthesised data could create a basis for more confident predictions of the reliability of the results of selected management plans. Further future research could be directed towards the use of such data. However, the use of generated data was not considered to be necessary in a study of this nature, if suitable historical records were available. This decision was influenced by the recognition of the fact that the simulation programme involves a trial and error approach to seeking an equitable solution to an existing problem. It seeks an equitable sharing of an existing water resource, rather than an optimum solution to the design of a new facility.

The Water Resources Commission of N.S.W. has kept daily flow records for the Gwydir River at Bundarra since 1929. Station No. 418045 provides such records from 1929 to 1935 and Station No. 418008 from 1935 to the present. These records are almost entirely continuous, with only occassional periods, of several days, during which data were not recorded. These records were made available by the Commission and were used in the simulation programme to represent future river flows. Some broad statistics concerning the river flow have been given in Section 4.4 of this report.

6.3 RAINFALL DATA

Daily rainfall information is necessary for the simulation of irrigation procedures. Historical data, which can be related to the river flow data, are required for the purpose of this study. The fact that both river flow and rainfall data need to be matched in time is another reason for the use of historical data records, in preference to statistically generated data, in this study.

The Commonwealth Bureau of Meteorology has daily rainfall records for Bundarra, covering the period for which river flow records are available (i.e. at least from 1930 to the present). The Bureau has made its records available for this study (Station No. 56006, Latitude 30° 10'S, Longitude 151° 04' E, Elevation 656m, Bundarra Post Office). Occasional short periods of gaps in the Bureau's records were covered by using information on the hand written records, kept at the Bundarra Post Office, which were kindly made available by the Postmaster.

Some broad statistics concerning rainfall data have been given in Section 4.2 of this report.

6.4 DATA CONCERNING THE PHYSICAL SITUATION BEING SIMULATED

The programme needs to be provided with the following data, to describe the physical situation being simulated:-

- average daily evaporation rates, variable on a monthly basis, for the area (available from the Bureau of Meteorology for Bundarra)

- daily town water consumption rates at Bundarra, variable on a monthly basis, for various levels of water restrictions (available from Uralla Shire Council records)

- parameters to describe the irrigation practice, which vary with crop type, soil type, method of irrigation and weather factors at the site, as described in section 5.3 of this report (available in Burton, 1964 and confirmed during extensive discussions with the irrigators).

The data used to describe the physical situation at Bundarra have been based on official records, discussion with the parties involved and the techniques described in Chapter 5 of this report. They are therefore soundly based and supported by the evidence of the parties involved in the conflict.

6.5 DATA CONCERNING THE MANAGEMENT PLANS TO BE TESTED

The programme needs to be provided with data which describe the various management plans to be tested in the simulation programme. Thirteen management decision variables are used. These are described in Appendix "F" (File MGT.DAT). Many combinations of ranges of the different variables are feasible and have been tested.

The programme tests the effect of the following management options in this study:-

(a) Increasing the capacity of one or both of the ponds

(b) Lowering or raising the water level in the ponds at which irrigation is not permitted to proceed

(c) Lowering or raising the water level in the ponds at which "dead storage" occurs and water cannot be drawn for the town supply

(d) Varying the area of irrigation from both ponds, by both the properties

(e) Varying the water levels in Taylors Pond at which the different levels of water restrictions in Bundarra are applied .

The range of practical and feasible values of the above variables has been determined after consultation with the irrigators, Uralla Shire Council and the Water Resources Commission.

6.6 VALIDATION OF THE MODEL

The results from the testing of 129 different management plans are fully discussed in Chapter 7. However, prior to accepting and analysing the results, it is necessary to satisfy users that the results are sound.

The first test of results, in a simulation programme such as this, is that they are reasonable and sensible. All of the simulation runs produced results which could reasonably be expected by those familiar with the situation (e.g. note the highly correlated results shown in Figures 13 to 20 of Chapter 7). All accurately predicted the serious problems which would result if the droughts of 1941 to 1945 (Year numbers 11 to 15) , 1966 (Year number 36) and 1981 to 1982 (Year numbers 51 and 52) occurred.

The situation which actually occurred in the summer of 1980/81 was simulated. This season resulted in restrictions on irrigation usage and severe town water restrictions. The author kept close daily records of the water storage position at Bundarra during this time. The accuracy with which the computer programme would predict known and documented performance was considered to be a significant test of the confidence which could be placed in it .

In the summer of 1980/81, two significant periods occurred during which irrigation was not permitted from Taylor's Pond. The actual period of these occasions and the periods predicted by the programme are compared in Table 8.

TABLE 8

COMPARISON OF ACTUAL PERIODS IN WHICH IRRIGATION WAS NOT PERMITTED FROM TAYLORS POND, DURING THE SUMMER OF 1981/82 AND THOSE PREDICTED BY THE PROGRAMME GRISB. FOR, FOR THE MANAGEMENT PLAN IN OPERATION AT THAT TIME (V=79Ml; W= 90 Ml; SM= 14Ml; SF= 47.5Ml; BH= 27.8Ml; BI= 10Ml; ACW= 0; AFW= 5.67ha; ACT= 20.23ha; AFT= 9.17ha; REST=60Ml; BJ= 50Ml; BK= 40Ml)

ACTUAL PERIOD			PREDICTED PERIOD	
From	Number of days in period	Month in which period ended	Number of days in period	Month in which period ended
3/11/80 to 16/12/80	42	December	39	December
27/1/81 to 30/4/81	99	April	97	April

In that same dry period, the water level in Taylor's Pond fell below 45 Ml storage (50% capacity)for a total period of 55 consecutive days (from March 28th, 1981 to 22nd May 1981). The model predicted that the level would be below 50% capacity for 53 consecutive days. The model accurately predicted that the water would not fall below dead storage level (about 25% of full pond capacity) in that period.

The above results show the good performance of the programme, when it is compared with the only available actual results of this conflict, during a severe drought period. This fact, together with the reasonable nature of predicted results during previous drought periods and the consistent and generally expected nature of the predicted trends in behaviour with various management options, as highlighted in Figures 13 to 20 of Chapter 7, allows confidence to be placed in the ability of the programme to simulate reliably the conflict being studied.

The results of the simulation programme have been shown to be valid for the purpose of the analysis required in this report.

CHAPTER 7

GENERAL DISCUSSION OF THE RESULTS OF THE PROGRAMME

7.1 TRENDS IN THE RESULTS OF VARIOUS MANAGEMENT CONTROL OPTIONS

A total of 129 various management plans have been tested. The response of the system to these plans, for the irrigation areas and crop types used in the 1980/81 summer, is shown in the graphs of Figures 13 to 20. Comments on these trends follow. The graphs show the effect of varying management decision parameters on the extent of restrictions required for town and irrigation usage. The extent of these restrictions is shown either as the number of days or the number of occasions that various restrictions would be necessary, over the whole period of simulation, from 1930 to 1982 (18,541 days of data).

The results shown in Figures 13 to 20 apply for the situation which occurred during the summer of 1980/81, as follows:-

Capacity of Taylor's Pond	- 90Ml
Capacity of Worrabinda Pond	- 79Ml
Area of Irrigation by Clerkness	
(a) From Taylor's Pond	- 20.23 ha
(b) From Worrabinda Pond	- Nil
Area of Irrigation by Flemington	
(a) From Taylor's Pond	- 9.17 ha
(b) From Worrabinda Pond	- 5.67 ha
Town Water Restrictions Commence (unless otherwise stated)	- 90Ml

It would be expected that raising the level at which irrigation must cease would worsen the situation for the irrigator and improve the town water supply situation. The sensitivity of these effects is shown in the following graphs in this chapter.

It would also be expected that increasing restrictions on irrigation usage would have substantial impact on the reliability of supply to town users. The relative effect of such restrictions on the competing users is also shown in the graphs.

Increasing the storage capacity of the ponds would also be expected to improve the reliability of the supply, particularly during the less severe droughts. The influence of this management option, and other options to control the use of water, is shown in the following graphs.

From hereon, reference to the "irrigation control level" in the text of this report, or "SF" on the various result curves, shall mean the volume of water in Taylor's Pond at which irrigation is required to cease. Reference to the "town control level" in the text, or "REST" on the various result curves, shall mean the volume of water in Taylor's Pond at which restrictions on town usage commence.

(a) FIGURE 13

(1) Curve (1)

This curve indicates that raising the irrigation control level has little significant effect on the reliability of town supply, if the current town control levels are not altered. Presently, the irrigation control level is 47.5 Ml and the town control level is 90 Ml. This curve indicates a need to vary the town control level with the irrigation control level, if the reliability of the town supply is to be significantly improved.

(2) Curve (2)

This curve shows that the reliability of irrigation supply is very sensitive to variations in the irrigation control level, particularly when that level is greater than about 50 Ml. Raising the irrigation control level has a severely adverse effect on the irrigators.

(3) Curve (3)

This curve shows that the number of days in which Taylor's Pond is less than 50% full reduces markedly whenthe irrigation control level is increased above 40Ml. When the control level is lower than 40Ml, little increase in the number of days when the pond is less than 50% full occurs. It is apparent that lowering the irrigation control level below 40Ml is not likely to significantly increase the risk of the pond becoming empty and the supply failing.

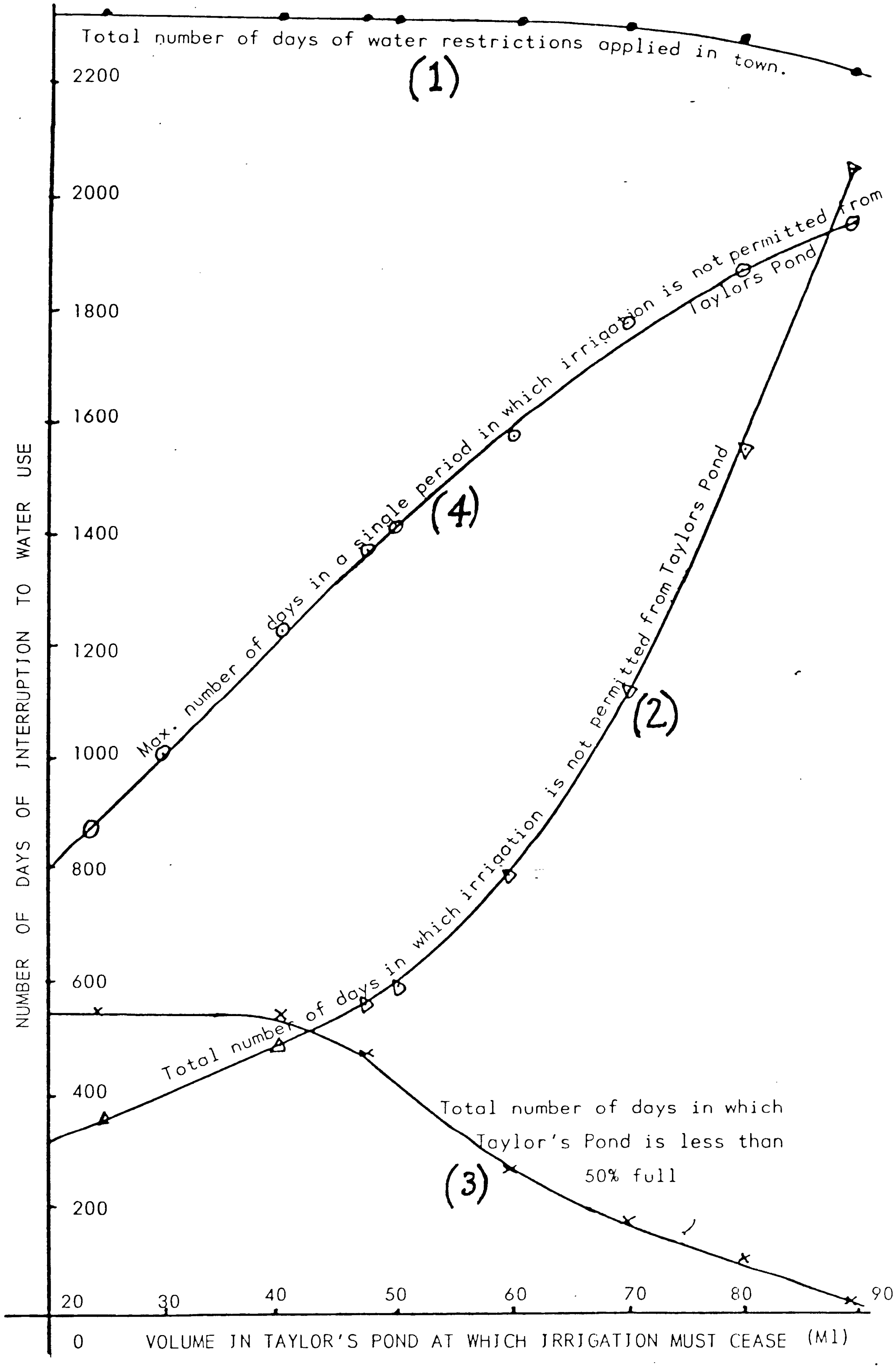


FIGURE 13 The effect of varying the water level at which irrigation is required to cease in Taylors Pond on interruptions to water use

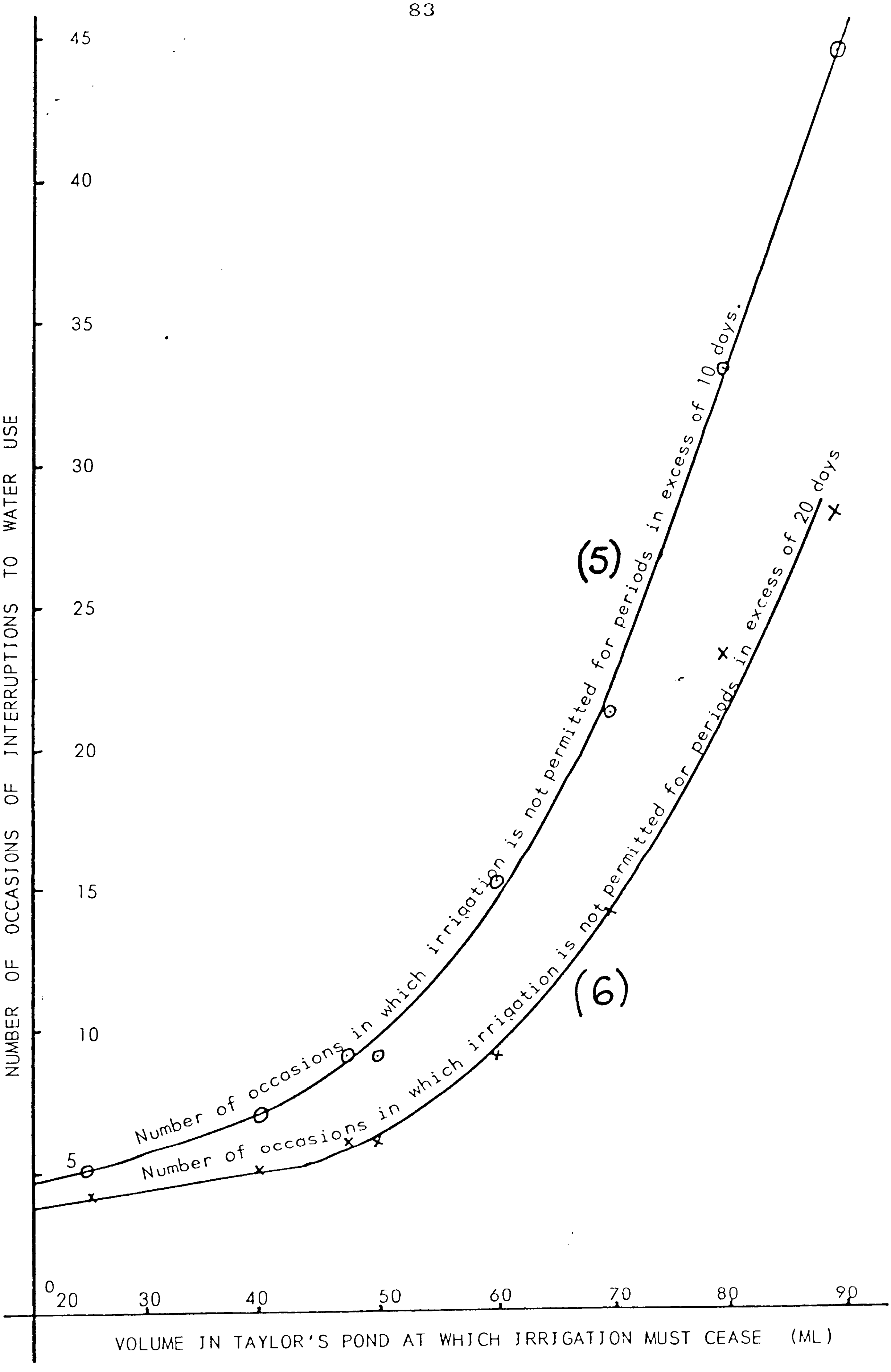


FIGURE 14: The effect of varying the water level at which irrigation is required to cease in Taylors Pond on the occasions of interruptions to irrigation.

(4) Curve 4

Curve 4 confirms the trend of Curve (2), that raising the irrigation control level has a severe impact on the irrigators. That impact occurs consistently over the whole range of feasible irrigation control levels.

(b) FIGURE 14

Interruptions to irrigation are of most concern if they occur for periods in excess of 10 or 20 consecutive days. The frequency of occurrence of such occasions has therefore been examined.

(1) Curves (5) and (6)

Both of these curves indicate that the frequency of occurrence of long periods of interruption to irrigation increases substantially when the irrigation control level is raised. This effect is also seen to be sensitive to values of the irrigation level when that value exceeds 50Ml. It confirms the severe adverse impact on irrigation of raising the irrigation control level above its present value of 47.5 Ml.

(c) FIGURE 15

Curves (1) to (6) have indicated that the town control level needs to be varied along with the irrigation control level, if improvements in the reliability of the town supply are to be achieved. Figure 15 shows the effect of such variation.

(1) Curves (7) , (8) and (9)

These curves show that little adverse effect on the reliability of the irrigation supply results from reduction of the town control level from 90 Ml, to 80 Ml and then to 60 Ml. This trend exists over the whole range of irrigation control levels.

(2) Curves (10), (11) and (12)

These curves demonstrate a marked improvement in the reliability of the town supply when the town control level is reduced from 90Ml to 60Ml. In none of these cases was the town supply found to fail. The curves also indicate

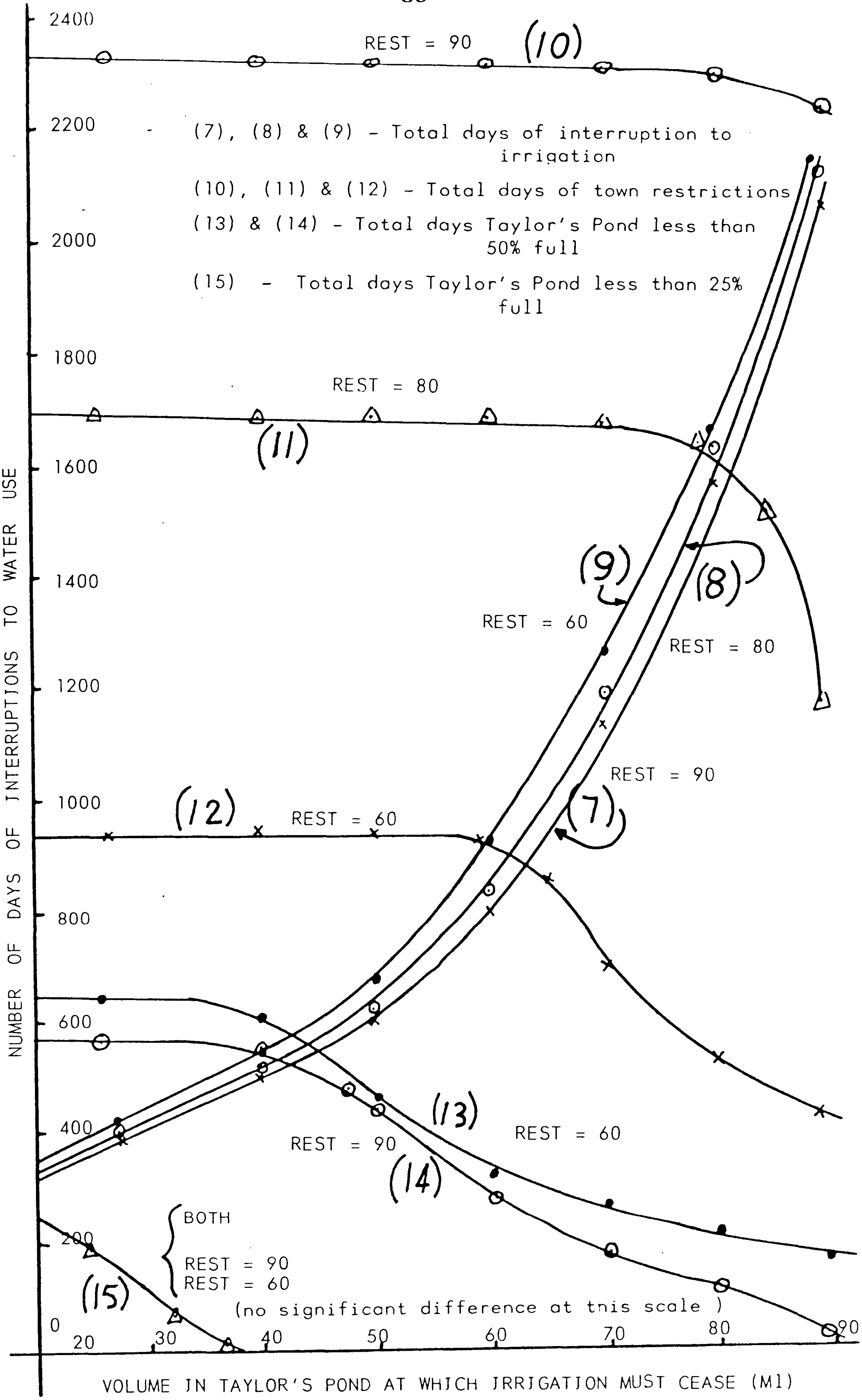


FIGURE 15 - The effect of the level at which restrictions on town supply are imposed (REST), with varying values of the level at which irrigation must cease

that the effect, on the reliability of the town supply, of raising the irrigation control level, only becomes significant when the irrigation control level is raised to the value of the town control level applying at any time. Two guiding trends emerge from these results:-

(a) Council's practice of imposing restrictions on town usage as soon as river flow ceases and the water level in Taylor's Pond falls below the full level of 90 Ml is unnecessarily conservative.

(b) A case appears to be developing for applying restrictions to both town and irrigation users at the same water level.

(3) <u>Curves (13), (14) and (15)</u>

These curves indicate that variation of the level at which town restrictions apply does not significantly alter the periods in which Taylor's Pond is less than either 50% full or 25% full. The indication is that such variation is unlikely to significantly increase the risk of failure of supply. This result probably occurs because the occasional very long dry period will result in low pond levels, no matter what management plan to control town usage is applied. A suitable management plan will minimise the number of short periods in which town restrictions are necessary, but will only have limited value in reducing the impact of extended periods of water restrictions in very dry seasons.

The results plotted so far in Figures 13, 14 and 15 indicate that substantial improvements in the reliability of the town supply are achievable by lowering the town control level. Raising the value of the irrigation control level has a very adverse effect on the irrigators, when the pond capacity is 90Ml. The effect of increasing the storage capacity of the ponds on the reliability of supply is demonstrated in the following Figures 16, 17, 18, 19 and 20.

(d) <u>FIGURE 16</u>

(1) <u>Curves 16, 17 and 18</u>

These curves show that increasing the storage capacity of Taylor's Pond greatly improves the reliability of the

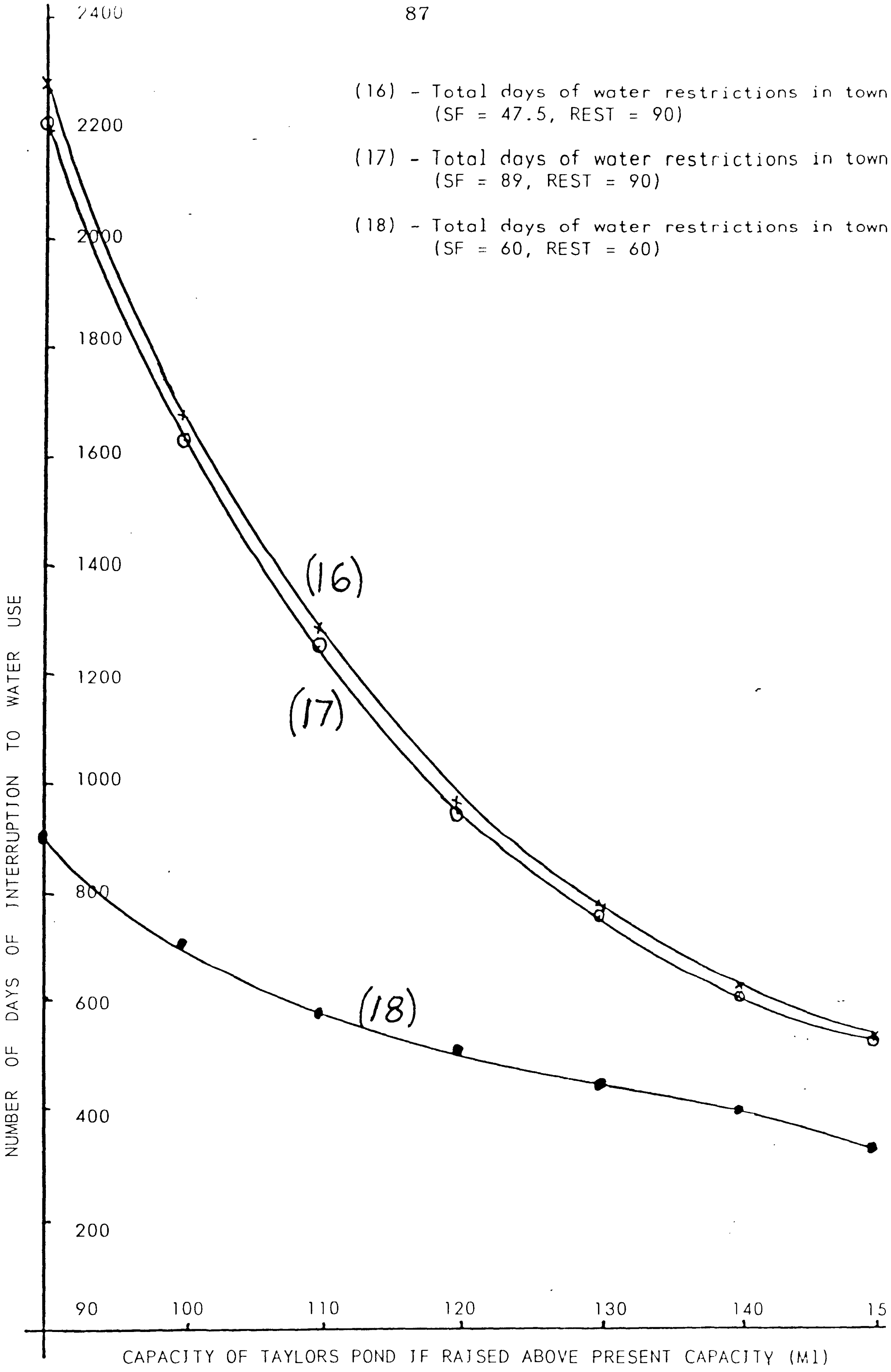


FIGURE 16 - The effect of increasing storage capacity of Taylor's Pond on the reliability of town supply

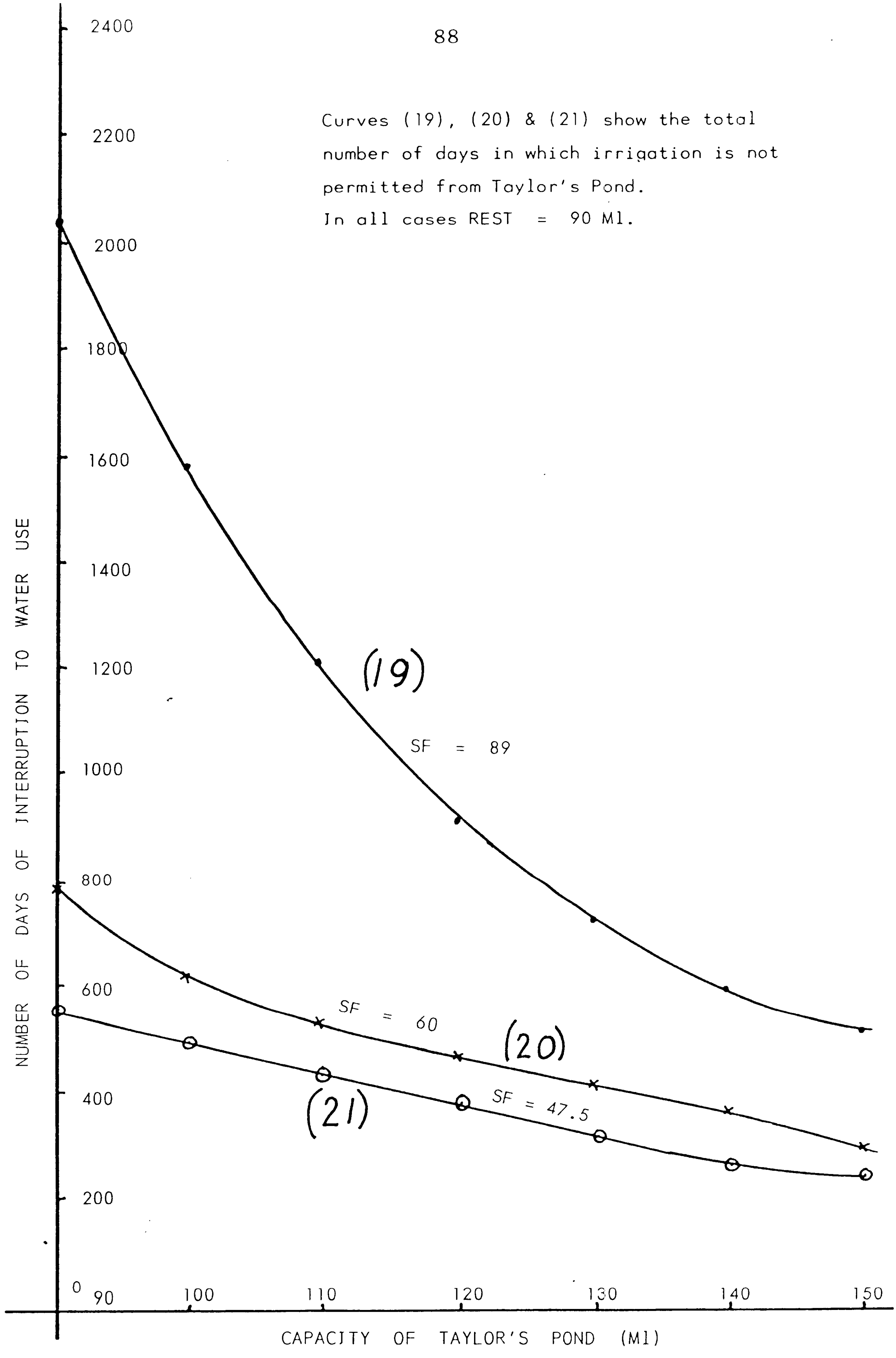


FIGURE 17 - The effect of increasing the Storage Capacity of Taylor's Pond on the reliability of Irrigation Supply

town supply, no matter what irrigation control level is set. Raising the irrigation control level alone has little significant impact on the reliability of town supply. Lowering the town control level greatly improves the reliability of the town supply, but reduces the sensitivity of that reliability to increasing the capacity of Taylor's Pond, particularly when that capacity is greater than about 110Ml.

(e) <u>FIGURE 17</u>

(1) <u>Curves 19,20 and 21</u>

These curves show that the greatest advantage to the reliability of irrigation supply by increasing pond capacity occurs when the irrigation control level is high. When it is at its current level of 47.5Ml, the advantage of increasing pond capacity is only moderate.

A preferred strategy, of lowering the town control level and increasing pond capacity to about 120Ml with a possible increase in the irrigation control level, has emerged.

Graphs 22,23 and 24 of Figure 18, and 25,26 and 27 of Figure 19 show the effect of varying the irrigation control level and the pond capacity, when the town control level is reduced from 90Ml (as in Figure 17) to 60Ml.

(f) <u>FIGURE 18</u>

(1) <u>Curves 22,23 and 24</u>

These curves confirm previous trends that the greatest gains to the reliability of the irrigation supply, by increasing the pond capacity, occur when the irrigation control level is high. That reliability is less sensitive to pond capacity when the irrigation control level is low.

(g) <u>FIGURE 19</u>

(1) <u>Curves 25,26 and 27</u>

These curves show that improvements in the reliability of town supply, as a result of increasing the irrigation control level, are not great unless the control level is raised substantially (up to 89Ml).

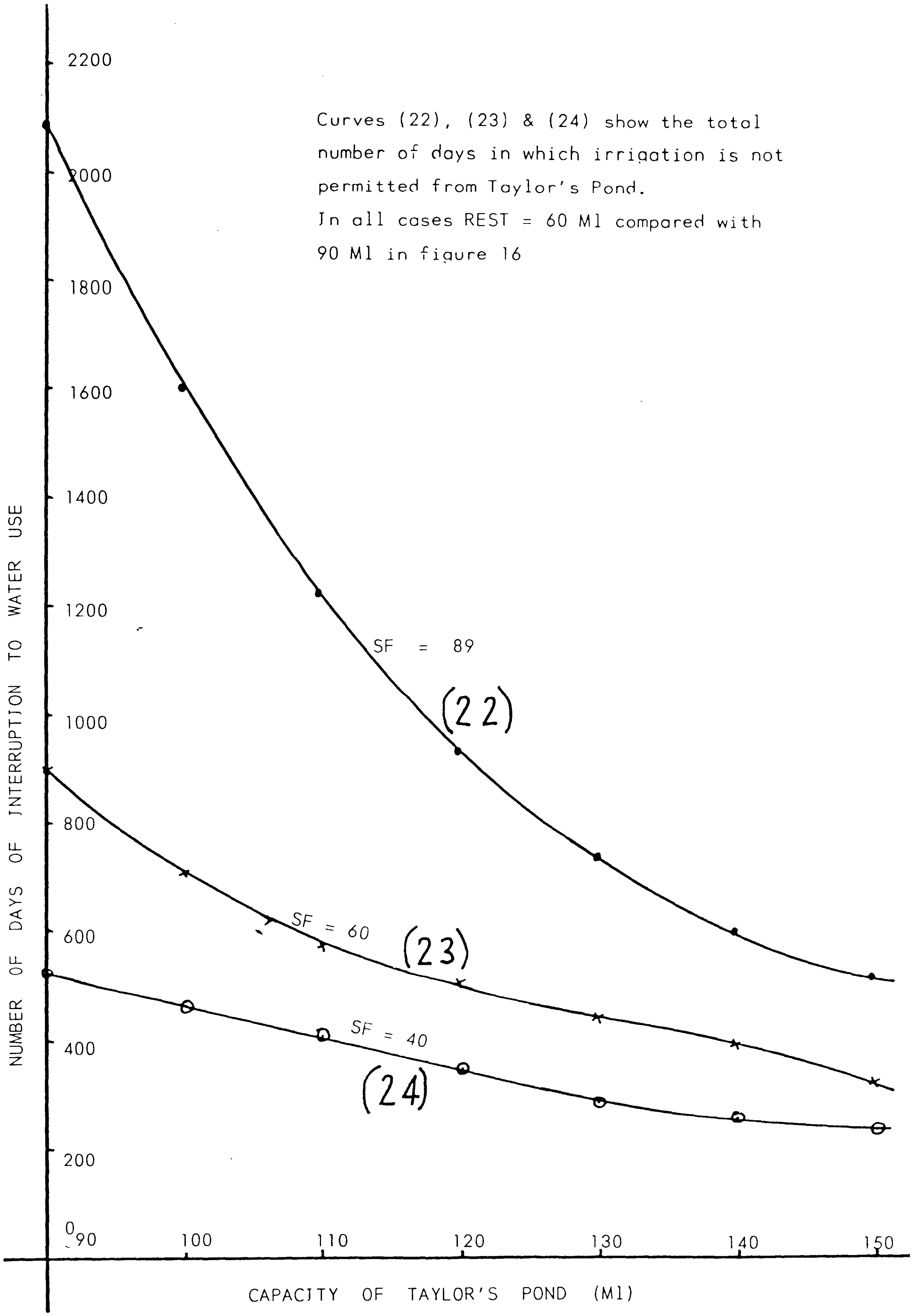


FIGURE 18 - The effect of the level at which water use is restricted on the Value to Irrigation reliability of Increasing the storage capacity of Taylor's Pond.

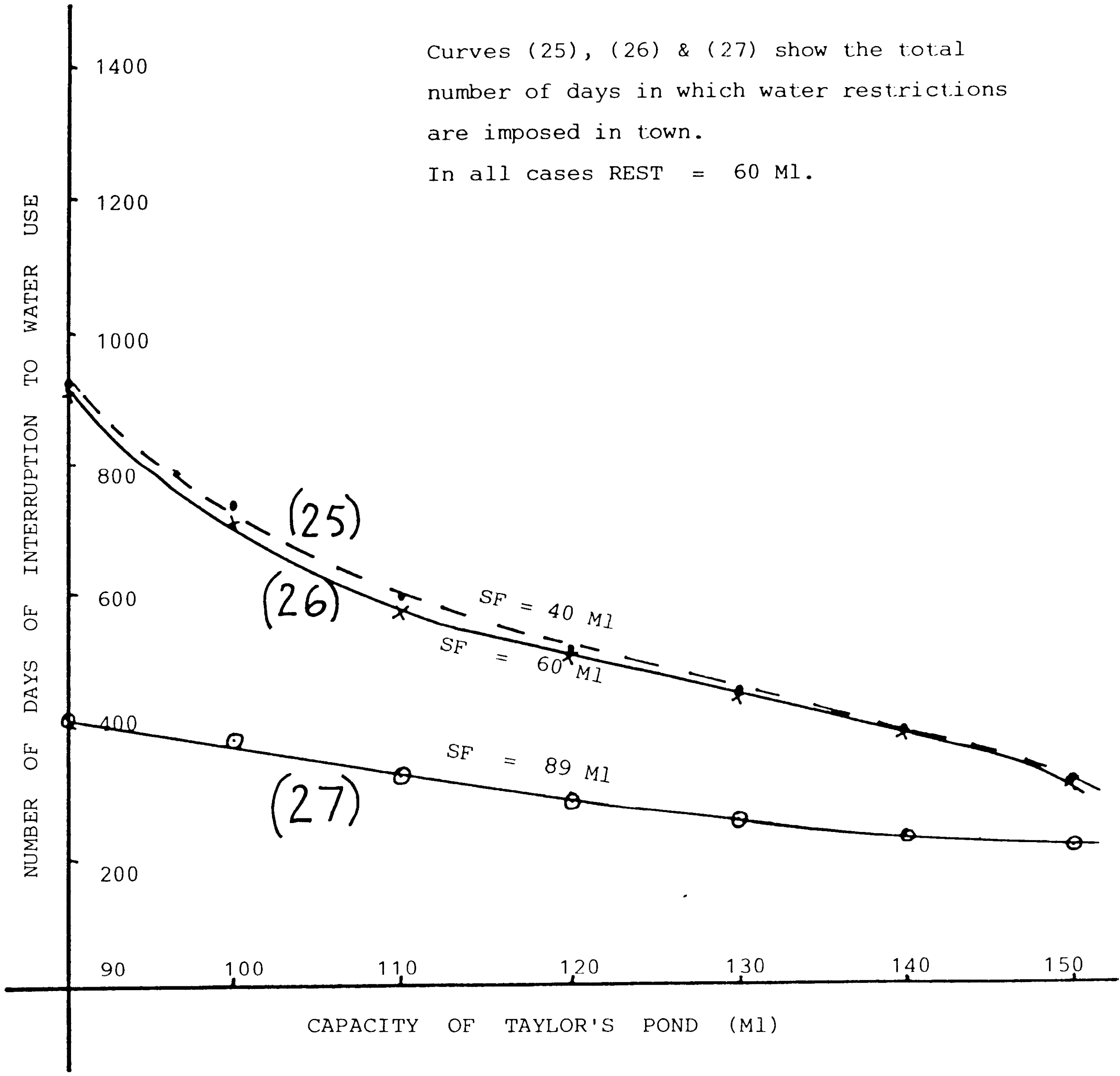


FIGURE 19 - The effect of the level at which irrigation must cease on the value to town users of increasing the storage capacity of Taylor's Pond

They also show that, for irrigation control levels between 40 and 60 Ml, the greatest improvements for the town supply are gained when pond capacity is increased up to about 120Ml. Greater advantage to the reliability of the town supply is gained by raising the irrigation control level to 89Ml than by increasing the storage capacity of the pond, even to 150Ml, and leaving the irrigation control level unchanged at 47.5Ml.

Curves 22 to 27 all indicate that, within the range of feasible management alternatives plotted, no entirely reliable supply is available to either the town or irrigation users. All of the curves approach an asymptote of about 200 days of restrictions. This fact indicates that some long dry periods will inevitably result in the imposition of restrictions, even if favourable management stategies are applied.

The results plotted have indicated that a "fair" plan of imposing restrictions on both users at the same water level can be achieved, with control levels between 40 Ml and 60Ml, without great risk of failure of the supply. They further indicate that increasing pond capacity up to 120 Ml is profitable for both parties. The storage capacity of the pond can be increased from 90Ml to 120Ml by raising the weir by only 0.5m. The demonstrated value of this increase was so evident that, in December 1981, Uralla Shire Council raised the weir by pushing up rock and gravel, from the downstream bed of the Gwydir River, and increased the capacity of Taylor's Pond to 120Ml.

(h) FIGURE 20

(1) Curves 28 and 29

These curves demonstrate the dramatic effect of increasing pond capacity on the extreme periods of interruptions to water usage. Curve 28 again indicates the value of increasing pond capacity to 120 Ml. Curve 29 shows again that extreme dry periods will still cause serious inconvenience to the water users within the range

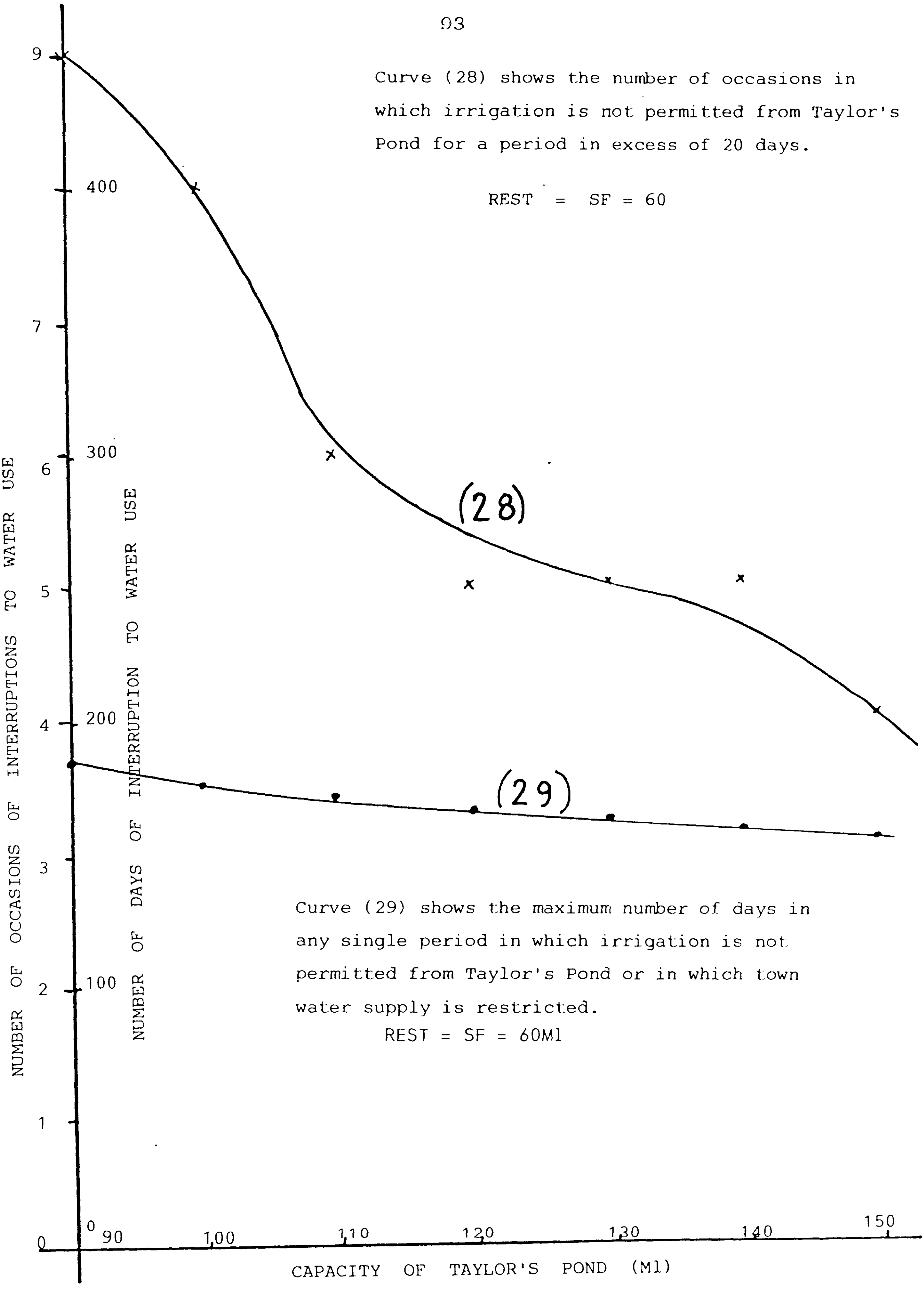


FIGURE 20 The effect of increasing the capacity of Taylor's Pond on extreme periods of interruption to water usage

TABLE 9

THE EFFECT OF RAISING THE LEVEL AT WHICH RESTRICTIONS ON WATER USAGE APPLY FROM 40Ml to 60Ml.

(V=90Ml; W=120Ml; BH=27.8Ml; ACW=5.67ha; ACT=30.35ha; AFT=9.17ha; SF=REST=60 or 47.5Ml)

NUMBER OF DAYS OF DATA = 18545

Irrigation not permitted from Taylor's Pond and Restrictions apply on Town Usage									Level G3 of Town Water Restrictions Apply (Hand Held Hoses allowed for one hour only).									Taylor's Pond 50% Full			Taylor's Pond 25% Full			Level G4 of Town Water Resns. Apply (Dom. Use only)		
No. of Days			No. of Occasions			Max. No. of days in a single period			No. of days			No. of Occasions			Max. No. of days in a single period			No. of days			No. of days			No. of days		
Irrigation Control Lev.									Irrigation Control Lev									Irrigation Control Level								
60	47.5	40	60	47.5	40	60	47.5	40	60	47.5	40	60	47.5	40	60	47.5	40	60	47.5	40	60	47.5	40	60	47.5	40
683	557	494	21	16	13	174	168	164	188	262	208	3	5	5	108	130	89	683	702	703	41	137	208	0	0	0
3.6%	3.0%	2.7%							1.01%	1.41%	1.1%							3.7%	3.8%	1.1%	.2%	.7%	1.1%			

* When REST = 60, BJ = 50; BK = 40

When REST = 47.5, BJ = 40; BK = 35

When REST = 40, BJ = 35; BK = 30

of relatively inexpensive, feasible management plans.

Table 9 shows some results for a procedure in which both "Clerkness" and "Flemington" irrigate lucerne. These results indicate the effect of raising the irrigation control level from 40Ml to 60Ml, in a plan in which irrigation control and town control occur at the same level. They show that, even when the irrigation control level is 47.5Ml, irrigation and town usage will be interrupted on 16 occasions in 50 years, once for a period of 168 days. Further, non tabled results, show that 9 of these occasions will be for periods in excess of 10 days and 5 in excess of 20 days. These results, which don't indicate a very reliable continuity of supply, do not involve the imposition of G4 level of water restrictions (domestic use only) but do involve 137 days (0.7% of the time) when Taylor's Pond is less than 25% full. The results indicate a fair margin of safety in storage, to avoid failure of the town supply, but show that occasions of concern for the supply would occur relatively frequently (level G3 of restrictions being applied 5 times in 50 years). Table 9 also shows that the effect of lowering the irrigation and town control levels to 40 Ml is to markedly increase the period in which the pond is less than 25% full but not substantially improve the reliability of the supply.

7.2 SENSITIVITY OF THE RESULTS TO AREA OF IRRIGATION

The property "Flemington" has little opportunity to substantially increase its area under irrigation. "Clerkness" however, is a large holding and could substantially increase its area under irrigation.

The influence of the area of irrigation (or the volume of irrigation water used)is shown in Table 10. That table is based on management plans indicated by the previous results, where pond capacity is increased to 120 Ml and both irrigation and town control levels are set equal, firstly at 60Ml and then at 47.5 Ml. The area of irrigation

TABLE 10

THE INFLUENCE OF THE AREA OF IRRIGATION ON RELIABILITY OF SUPPLY

Area of Irrigation (ACT) ha	Number of Days Irrigation is not Permitted *	Number of Days in the Longest Period in which Irrigation is not Permitted	Number of Occasions in which Irrigation is not Permitted	Number of Occasions in which Irrigation is not Permitted for a period in excess of 20 days
	A. For SF = 47.5 Ml = REST			
16.19	404	156	7	5
22.26	468	162	12	5
30.35	557	168	16	5
60.70	972	180	31	12
	B. For SF = 60 Ml = REST			
16.19	489	164	12	5
22.26	572	169	16	6
30.35	683	174	21	9
60.70	1147	187	38	16

* Period of Simulation - 50 years - 18545 days

is represented by variations in the value of the area of irrigation by "Clerkness" from Taylor's Pond.

Table 10 clearly demonstrates that the reliability of supply is very sensitive to the area of irrigation. The present area of irrigation, by Clerkness, from Taylor's Pond, as proposed for 1983/84, is 30.35 ha. This area involves, for an irrigation control level of 47.5 Ml, an expectation of 5 occasions, in 50 years, in which irrigation will not be permitted for periods in excess of 20 consecutive days. A closer examination of those occasions shows that they would have occurred in 1941, 1966, 1981, 1981 again and 1982. Each would have affected the lucerne growing season. If this standard of reliability was considered to be acceptable, the reliability when the area of irrigation is increased to 60.70 ha would almost certainly not (12 occasions, in excess of 20 days, when irrigation was not permitted). Since the irrigation and town control levels are equal, even if this reliability was acceptable to the irrigators, it would be unlikely that it would be acceptable to town users.

The indication from this analysis is that the area of irrigation (or the irrigation water consumption permitted) should be limited. The current annual usage (see Appendix "H") would appear to be about the maximum irrigation exploitation that should be permitted. This impression is tested further in Chapter 8.

7.3 SENSITIVITY OF THE RESULTS TO VARIATIONS IN THE VOLUME OF WATER APPLIED TO A SPECIFIC IRRIGATION CROP

The method of determination of the irrigation volume required for a specified area and crop type was outlined in Chapter 5. This calculation is subject to some subjective assessement and judgement and higher volumes could be found to be desirable in practice.

The sensitivity of the reliability of supply to errors in the volume of irrigation required is demonstrated by studies of the following case:-

Volume of Water in Taylor's Pond (W) = 120Ml
Level to Stop Irrigation (SF) = 47.5Ml
Level to Start Town Restrictions (REST) = 47.5Ml
Area of Irrigation from Taylor's Pond
- by Clerkness = 16.19 ha
- by Flemington = 9.17 ha
Crop Type = Lucerne

The daily irrigation demands for this crop were increased by about 24% over those determined by the methods discussed in Chapter 5, i.e. total demand from both ponds, by both properties, for January, was increased from 1.616 Ml to 2.003 Ml per day. In both cases, the number of occasions in which irrigation was interrupted for a period in excess of five consecutive days was seven. A comparison of the extent of these seven occasions is shown in Table 11.

TABLE 11

THE EFFECT OF INCREASED IRRIGATION APPLICATION PER HECTARE ON THE RELIABILITY OF SUPPLY

Occasion Number	Number of Days in Each Occasion	
	Column 1 Irrigation Volume as Calculated per standard techniques	Column 2 Irrigation volume increased by 24% over that as calculated in Column 1
1	7	13
2	66	78
3	9	14
4	156	162
5	61	71
6	26	30
7	79	88
TOTAL	404	456

The results of Table 11 indicate that a large error (of about 24%) in the determination of the irrigation volume required, for a specified area of a particular crop, does not have a very severe effect on the reliability of supply. It does result in minor periods in which irrigation is not permitted becoming more serious (eg. occasions numbers 1 and 2). It does not have a significantly more serious effect on those occasions which were already a very serious problem (eg. occasions 4 and 7).

The indication is that the reasonably small variations in the calculated volume of irrigation required, that would reasonably be expected between the results of various soundly based analyses, will not result in a substantial variation in the predicted reliability of supply. The results are not unduly sensitive to the irrigation volume, over a range of up to 25% in excess of the calculated volume required.

7.4 SUMMARY OF TRENDS IN RESULTS AND DISCUSSION OF MANAGEMENT PLANS INDICATED TO JUSTIFY FURTHER ASSESSMENT

The simulation analysis has indicated the following trends:-

(a) Raising the irrigation control level has little effect on the reliability of the town water supply, unless it is accompanied by a reduction in the town control level.

(b) Raising the irrigation control level above the present level of 47.5 Ml has a very adverse effect on the irrigators.

(c) Raising the irrigation control level results in substantially less time when the ponds are at low levels. This fact affects both the level of protection against failure of the town supply and the quality of the town supply.

(d) Lowering the town control level from the present level of 90Ml to 60Ml and then to 40Ml has little adverse effect on the irrigators.

(e) Lowering the town control level markedly improves the reliability of the town supply, but for values down to 40 Ml, does not involve a failure of the town supply

(f) Benefits to both town users and irrigators occur when the irrigation control level and the town control level are equal.

(g) Lowering the town control level does not significantly affect those occasions when the pond is at very low levels.

(h) The range of feasible management plans (those within the practical resources of the parties involved) can reduce the impact of shorter dry periods on the reliability of supply. However they cannot significantly reduce the impact of the less frequent but extended drought periods.

(i) Increasing the capacity of Taylor's Pond substantially improves the reliability of the town supply. The effect is most significant for capacities up to 120 Ml, especially when the town control level is set at about 50Ml.

(j) Increasing the capacity of Taylor's Pond has no substantial benefit for the irrigators unless the irrigation control level is high (up to 90 Ml)

(k) The single most effective step to improve the reliability of the town supply is to raise the irrigation control level. Raising that level to 90 Ml is more effective for the town supply reliability, than leaving it at its current level of 47.5 Ml and increasing the pond capacity from 90 Ml to 150 Ml.

(l) Increasing pond capacity to 120 Ml results in a marked reduction in the frequency of extended periods of interruptions to water use (periods in excess of 20 days).

(m) Lowering both irrigation and town control levels below 40 Ml does not substantially improve the reliability of supply but markedly increases the risk of failure of the town supply.

(n) Reliability of supply is very sensitive to the area of irrigation. The area of irrigation (or the permitted rates of irrigation consumption) should be limited to present values

(o) The reliability of supply is not particularly sensitive to small changes in the irrigation demand.

(p) Assuming that a limitation on funds will prevent the implementation of substantial capital works to improve the reliability of supply, and presuming that it would be difficult to achieve substantial alterations to irrigation control levels, a strategy for closer examination is evident. That strategy involves a pond capacity of 120 Ml and irrigation and town control levels set equal and within the range of 47.5 Ml to 60 Ml. That strategy is subject to closer economic analysis in the following chapter.

The above summary has identified those features of the situation being studied which are significant, in terms of their effect on the reliability of supply to either or both users. The general trends identified in the results have made it possible to identify potentially feasible management plans which warrant closer examination.

CHAPTER 8

ECONOMIC ANALYSIS

8.1 PROJECT ECONOMICS - THE ROLE OF PRICE

The task of this study is to select a management plan for water sharing. "An important and quantifiable criterion for plan evaluation is the economic benefits and costs a plan would entail were it implemented" (Loucks et al, 1981). A number of management plans have been subject to simulation analysis, to identify the physical results of their implementation. The objective of the economic analysis is to select a management plan which maximises the benefits from the proposed water sharing rules.

The simulation work has identified likely "near optimal solutions". Those identified solutions need to be analysed to determine which most closely meets the objective of sharing the available water between the two users, so that the benefits from the resulting water use are maximised.

Cost-benefit analysis of water resource projects has become a valuable source of research and study. It and other associated project economics techniques are well documented by authors such as Loucks et al (1981), Hall and Dracup (1970), Hirshleifer et al (1960), James and Lee (1971), Hirshleifer (1980), Kuiper (1971) and Randall (1981). Many of the concepts developed by these authors have been used in the following sections of this chapter.

Randall (1981) argues that water is a resource of value and that its value depends both on the condition in which we find it and on its intended use. He states that "resource allocation policy problems are typically highly complex, since they concern complex physical and biological systems and must be solved within a complex social and institutional environment". He claims that price is a useful economic tool to use to assist in solving these problems.

Cunha et al (1977) argue that "the purpose of applying optimisation techniques to man centred systems must be the maximisation of man's welfare". They recognise that "welfare cannot be exclusively quantified on the basis of indices representing the production of consumption utilities, but argue that it must include satisfaction of all those needs which form the concept of quality of life". Such comments are not disputed, but this study involves the allocation of an existing resource, via existing systems, between competing users. The use of simple economic indices, such as the price or value of water to each user, is a very attractive measure to use in sharing the resource. Randall (1981), in arguing that any market has a built-in tendency to reach equilibrium concludes that "price serves to ration goods among consumers". He states that "working on both the demand and the supply sides of the market, price directs the allocation of resources".

Pullinger (1978) has also argued that "it behoves Australian water authorities to accept the principle that water is a resource the demand for which should be planned and managed by economic policies". He defines efficient use of water as occurring "at the level of consumption at which the consumer's marginal expenditure on water equals the value of the benefit he enjoys from this marginal unit of consumption".

Brown (1968), in discussing economic efficiency in allocating resources, states that " 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". If the goal is economic efficiency alone, that price should equal the cost of providing the water. Equity considerations, however, often result in society setting actual prices to some consumers below the market clearing price, to satisfy perceived community views. As a result of this effect on the actual price of water, economic efficiency objectives in the allocation of water between users, need to be met using the "opportunity cost or value of water" as the economic index on which decisions are based.

8.2 THE PRINCIPLE OF EQUI-MARGINAL VALUE IN USE

The discussion contained in this section is based on arguments originally developed by Hirshleifer et al (1960).

One of the facts of life is that there is competition for the use of our natural resources, including water. Generally, the more taken out of existing supplies for one user the less there will remain for others. Even if additional water were made available, as a result, say, of further impoundments, competition for shares of the enlarged supply would continue. This competition results in a fundamental market situation, where a principle of supply is that there is always more water available to any users whose demand is sufficiently highly valued to permit them to bid an existing supply away from current users. This principle indicates that the problem of achieving a "fair sharing" solution is one for rational economic analysis, using market theory from the discipline of microeconomics.

Hirshleifer et al (1960) define " the value in use of any unit of water" as "the maximum amount of dollars which the consumer would be willing to pay for that unit. The marginal value in use is the value in use of the last unit consumed, and for any consumer marginal value in use will ordinarily decline as the quantity of water consumed in any period increases". They define the "principle of equimarginal value in use", to characterise an efficient allocation of resources, as one in which "the resource is so allocated that all consumers or users derive equal value in use from the marginal unit consumed or used". Unless the opportunity cost of water is equal to all users, employments with higher marginal values in use are foregone in favour of employments with lower values and the allocation is inefficient. Whenever marginal values in use are unequal, opportunities exist for exchanges between users until the marginal values are brought into equality.

A schedule of marginal values in use for various quantities consumed, is essentially the demand curve of economic theory, which relates quantities demanded to price.

Resource allocation, therefore, should be guided by the system of market values.

For this study, it remains to determine marginal values in use of the water used by the irrigators and the town users, under various management plans and seek a solution which produces equal marginal values.

8.3 PRICE THEORY AND RESOURCE ALLOCATION

A review of the concepts of price theory involved in this study is necessary to define the terms to be used and clarify the principles to be applied. The following is a review of current literature on this subject and is heavily based on information contained in Hirshleifer (1980), James and Lee (1971) and Laidler (1981).

The demand curve shows, for each price, P, the quantity, Q, that purchasers choose to take from the market. A typical curve is shown in Figure 21.

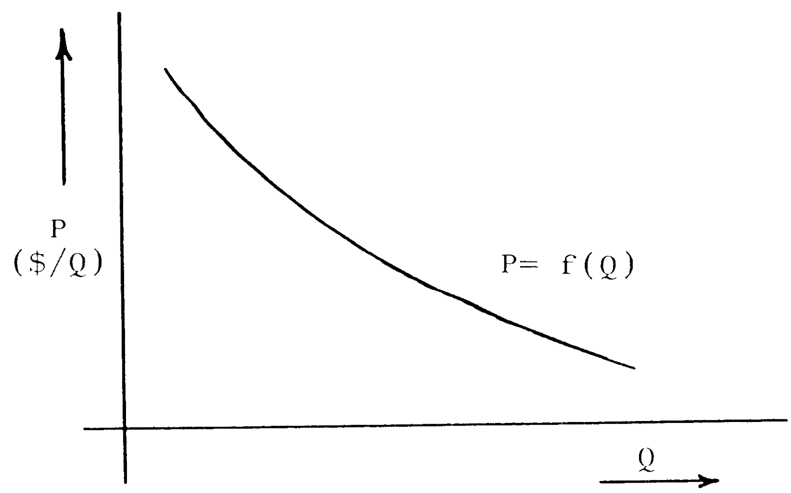


FIGURE 21 : A typical demand curve

The demand curve applies to a particular good under particular circumstances, eg. water for irrigation of lucerne from Taylor's Pond, during a drought period in 1981. It may shift as a result of consumer preferences, the number of consumers, consumer incomes, the price of related goods and the range of goods.

The price elasticity of demand, E, for a particular demand curve, indicates the effect on sales resulting from a change in price. It is defined as

$$E = -\frac{P}{Q} \cdot \frac{dQ}{dP} \quad \text{...........(Eqn.8.1)}$$

A value of infinity for E indicates a perfectly elastic good which no one at all will buy if the price is raised. Goods become perfectly elastic at the price at which they are priced out of the market. As price is reduced, elasticity drops. When E equals unity, the good is no longer said to be elastic and, at this point, the supplier achieves the greatest revenue (the product P.Q is at a maximum). When E is less than unity, the good is said to be inelastic. Sales no longer increase quickly enough to offset the lowering price and revenue declines. A value of zero for E indicates a perfectly inelastic good, or one for which price has no effect on demand.

Values of E for water have been reported as follows:-

Residential water (all users)	- 0.35	James and Lee (1971)
Domestic water	- 0.23	James and Lee (1971)
Sprinkling water	- 0.7	James and Lee (1971)
Sprinkling water (humid areas)	- 1.6	James and Lee (1971)
Residential water (winter)	- 0.06	Howe (1982)
Residential water (summer)	- 0.568 to - 0.427	Howe (1982)
Residential water	- 0.39	(Bain et al (1966))
	- 0.35	(Conley (1967))
	- 0.3	(Turnovsky (1969))

Value adopted for Australian Study at Geelong

- 0.4 (Pullinger (1978))

The demand curve can also be regarded as an Average Revenue Curve, since

$P = \frac{R}{Q}$ = Average Revenue (an average magnitude) and
R (Revenue) = P.Q (a total magnitude)

Figure 22 is used for further interpretation of the demand curve.

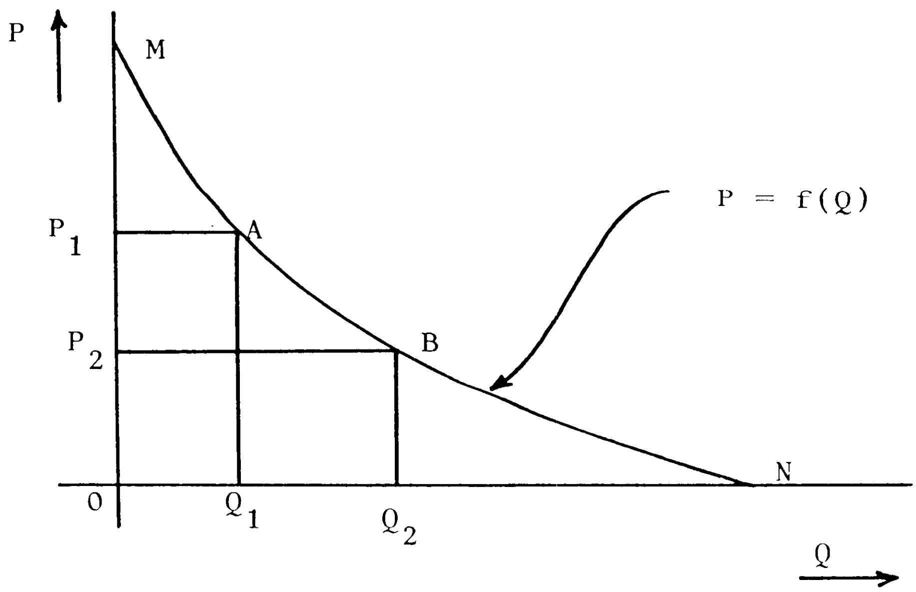


FIGURE 22 The Demand Curve - The concept of utility.

At a quantity of Q_1 units purchased, a user pays a price P_1 (dollars per unit). The total cost is $P_1 A\ Q_1 0$ dollars.

At Q_2 , the price is P_2 and the total cost is $P_2 B Q_2 0$. This cost is a measure of total revenue.

However, the total utility, or satisfaction, the user gains from purchasing Q_1 units is $M\ A\ Q_1 0$. The total utility gained from Q_2 units is $M\ B\ Q_2 0$.

The total utility lost in having consumption reduced from Q_2 to Q_1 units is $A\ B\ Q_2 Q_1$. To regain that lost utility, the user would be prepared to pay $A\ B\ Q_2 Q_1$ dollars to obtain the use of $(Q_2 - Q_1)$ more units. A measure of the marginal value in use of the further $(Q_2 - Q_1)$ units he wishes to consume (MV) is

$$M\ V = \frac{ABQ_2Q_1}{Q_2 - Q_1} \quad \text{dollars/unit}$$

$$\underline{ie}.\ MV = \frac{\int_{Q_1}^{Q_2} f(Q)\,.\,dQ}{Q_2 - Q_1} \qquad \text{............(Eqn.8.2)}$$

If the user bought Q_2 units, at a price P_2 on average for all those units, he would have a surplus of satisfaction over cost of MBP_2. The average price he would pay for Q_1 units (P_1) overstates the price he would pay to have his consumption increased to Q_2 units. Similarly, the average price he would pay for Q_2 units (P_2) understates the price he would be prepared to pay to increase consumption from Q_1 to Q_2 units. The marginal value in use (MV), as defined by equation 8.2, is a measure of the maximum price he would be prepared to pay to increase consumption from Q_1 to Q_2 units.

8.4 THE VALUE OF IRRIGATION WATER

The marginal value in use of irrigation water will vary with conditions existing at the time the irrigator requires further water. The season, the growth stage of the crop, plant water-soil relationships and similar factors affect the result, on crop production, of being denied a volume of irrigation water.

Some information is available on the effect of water on agricultural production. Hexem and Heady (1978) have produced water production functions for irrigated agriculture. These functions could be used to predict the yield of crops from applied volumes of water. Further research into such functions is clearly necessary, to allow proper economic analysis of irrigation programmes. The water production functions presently available apply for specific crops in specific sites. They provide general information on the effect of total water application on crop yield. However, they are too general in nature to be used to determine the value of water foregone by irrigators, in Bundarra, as a result of various water restrictions at various times in the growing seasons there. The functions have provided some general guidance in this study, but they have not been used specifically because of their deficiencies, as outlined above.

Salter and Goode (1967) have identified stages of growth, for a variety of crops, which are the most sensitive to drought conditions, in terms of reduction in yield. Their results are not generally applicable to the situation at Bundarra, but have been a guide to the substantial reductions in yield that drought conditions can cause.

The procedure used in this study to determine the marginal value of irrigation water foregone was as follows:-

(a) the periods in which irrigation would be prohibited, as a result of various management plans, as predicted by the simulation programme, were examined.

(b) for each period, depending on its length of time and its season, the effect on production, in terms of the number of bales of lucerne lost, as a result of no irrigation being permitted, was estimated by the irrigators. This estimate represented the irrigators' assessement of their likely farming decisions, when faced with the predicted situations.

(c) The market cost of a bale of lucerne, in 1982 prices, was estimated by the irrigators, for each period of water restriction, after consideration of the prevailing drought conditions for the period, as demonstrated in the simulation programme data.

(d) The resulting calculated value of the opportunity loss of the crop production and the volume of water foregone, as a result of irrigation restrictions, were used to produce a marginal value for the water foregone. This marginal value, for each period of restrictions, for a number of management plans, was determined as the value of the crop loss divided by the volume of water foregone in that period.

(e) The irrigators' estimates were discussed with the District Agronomist of the New South Wales Department of Agriculture, at Armidale, to confirm their estimates were reasonable.

Table 12 shows the procedure used for the determination of the marginal value in use of irrigation water for periods of water restrictions, resulting from a particular management plan. Results such as those determined in Table 12 require judgements to be made by people experienced in irrigation practices in the particular area. Each period of water restrictions requires separate consideration and assessement. The following general principles of farming practice in the area were used to guide the assessement:-

(a) Lucerne plants last 5 to 7 years

(b) First cuts can be made in October

(c) Cuts can be made every four weeks and produce about 1.9t/ha/cut, with about 30 bales /tonne.

(d) The cost of bales would vary from $2 to $6 / bale, depending on the season

(e) Shorter periods of restrictions on winter irrigation would not significantly reduce oats production.

(f) lucerne production could continue in summer once irrigation recommenced, with, generally, no loss of seed.

The establishment of marginal values in use for a large number of occasions of interruptions to irrigation, (189), using the procedures indicated in Table 12, has involved extensive discussions with the irrigators and a large number of judgements and assessments. Some of these are subjective judgements, but they have been based on the advice of experienced agricultural practitioners and have been consistently applied.

The marginal value of irrigation water so calculated represents the best opportunity cost of the water to the irrigator. That value could be expected to vary substantially in each period in which irrigation is not permitted. Each period resulting from any one management plan, or similar periods resulting from various management plans, is unique. It would not be expected, therefore, that the

TABLE 12 - CALCULATION OF THE MARGINAL VALUE IN USE OF IRRIGATION WATER

PROPERTY - "CLERKNESS" - AREA OF IRRIGATION - 30.35 ha from Taylor's Pond - PROGRAMME AS PER APPENDIX "H"
Volume of Taylor's Pond when full = 120 Ml - Volume in Taylor's Pond when irrigation is required to cease = 47.5 Ml - Town water restrictions commence at 47.5 Ml level in Taylor's Pond
Number of occasions of interruptions to irrigation in excess of 5 days = 12 .

(1) Occasion Number	(2) No. of days in Occasion	(3) No. of Cuts of Lucerne Lost (N)	(4) No. of Bales of Lucerne Lost = Nxarea x$\frac{3}{4}$ton/acre x30 bales/ton =Nx1687.5	(5) Expected Value of Bale ($)	(6) Value of Crop Not Produced ($)	(7) Volume of Water Foregone (Ml)	(8) Marginal Value of Water In Use {[(6)÷(7)] -$20/Ml Pumping Costs}
1	18	1	1687	3	5061	25.146	181
2	9	$\frac{1}{2}$	800	3	2400	17.415	118
3	86	3	5062	4.50	22779	143.312	139
4	8	Negligible					-
5	18	1	1687	3	5061	26.640	170
6	11	1	1687	3	5061	25.157	181
7	168	2	3375	6	20250	69.360	272
8	7	$\frac{1}{2}$	800	3	2400	10.360	212
9	18	Negligible				-	-
10	78	1	1687	5	8435	27.450	287
11	34	1	1687	6	10122	67.388	130
12	92	3	5062	6	25310	117.630	195

results of the marginal value of water would form a definite relationship with the volume of water foregone, to allow the construction of a generalised demand curve. Different circumstances would have resulted in a shift in the demand curve for each result. Because of this aspect of the results, a generalised demand curve for the water covering a wide range of management plans cannot be produced. This study involves a situation of strictly limited resources. The irrigator does not have a choice of volumes of purchases over a continuous range, but either has access to his water needs or has no water at all. Instead of involving the analysis of a classic demand curve, this part of the study involves analysis of the range of marginal values determined for a range of situations, each applying to a unique volume of water foregone.

Marginal values were determined for 189 significant occasions of interruptions to irrigation, resulting from eight separate management plans which represent a wide range of feasible solutions to this problem. The values ranged from \$80/Ml to \$470/Ml. The average value was \$209/Ml with a standard deviation of \$72/Ml. These results indicate that the marginal value in use of water to the irrigator is not often greater that 28c/Kl and in the worst case is not greater than 47c/Kl. Marginal values in the case of an indicated preferred solution (that shown in Table 12 when both irrigation and town water restrictions commence when pond capacity falls to 47.5 Ml) range from 12c/Kl to 29c/Kl.

To allow general conclusions to be drawn, a trend of results of marginal values corresponding with feasible management plans is necessary. For management plans involving the present irrigation areas and crop types, in which the only variable is the level of water in Taylor's Pond at which both irrigation is required to cease and town water restrictions begin, a "demand curve" has been created. This curve relates the marginal value of the water foregone by the irrigator to the control volume of water in the pond. Each level at which irrigation is required to cease results in a number of occasions of interruptions to irrigation, each of which involves a unique marginal value of the water foregone in that occasion. The set of marginal values for all the occasions associated with an irrigation control level can be analysed to determine:

$\overline{MV}$ = the average marginal value of the water foregone in each occasion

σ = the standard deviation of the set of marginal values

MV max = the maximum marginal value for any occasion

MV min = the minimum marginal value for any occasion

Regression analysis of the results of marginal value calculations, for a range of irrigation control levels, yielded the following relationship:

$$\ln \overline{MV} = a \ln SF + b \qquad \text{(Eqn. 8.3)}$$

where a = 0.1887
b = 2.1769
r = 0.9378

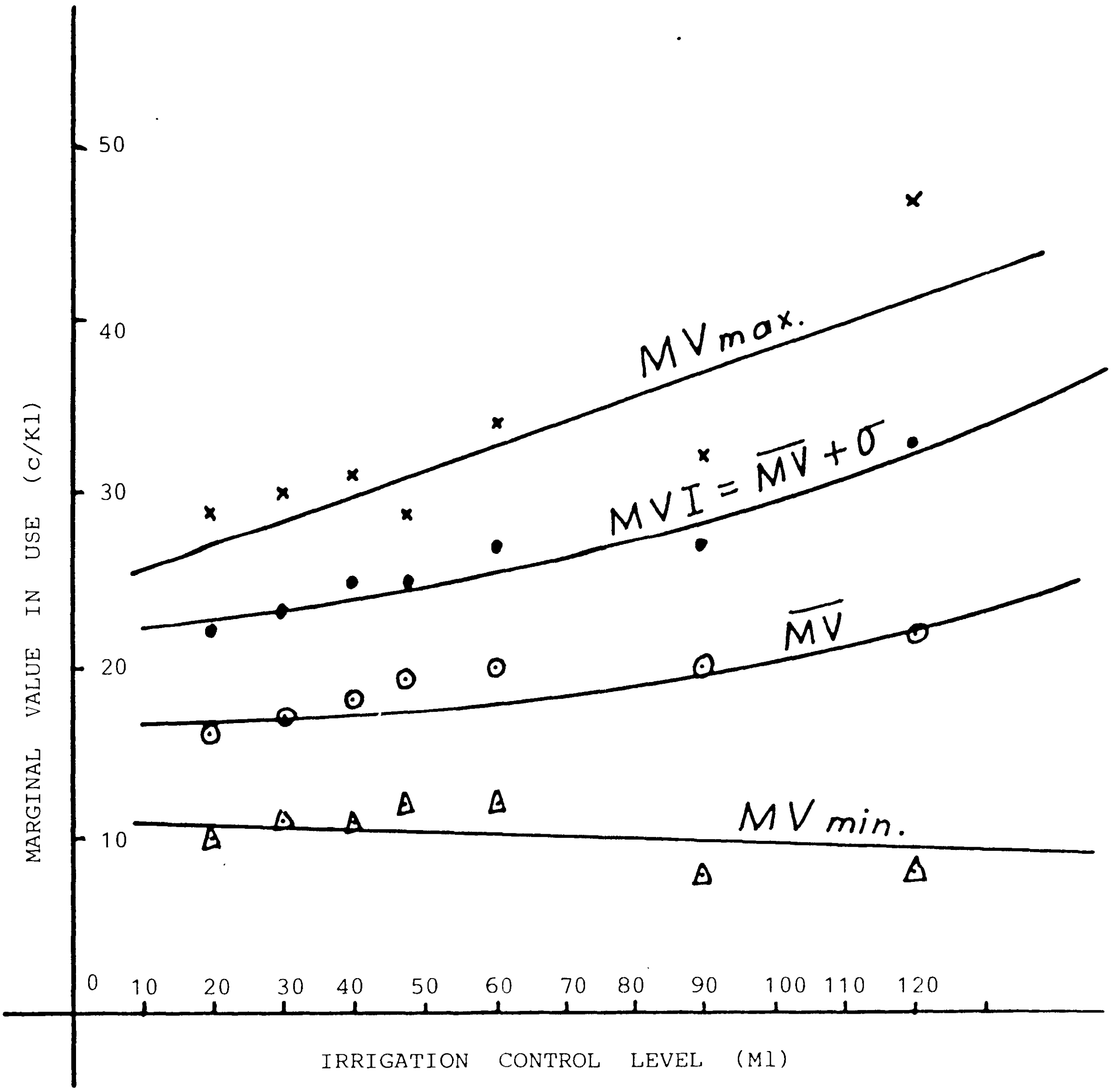
Figure 23 shows a plot of Equation 8.3 and also the range of MVmax and MVmin for various values of the irrigation control level (SF). It indicates that, even though a general exponential trend exists between $\overline{MV}$ and the irrigation control level, the unique effect of each occasion of interruption to irrigation is to produce generally uncorrelated results for the extreme marginal values of water. Figure 23 is an envelope of the expected range of marginal values of water for a range of feasible management plans. It indicates that the distribution of these marginal values has a significant skew to the high side of the average value. To account for the variations likely to occur in marginal values, a fair curve to adopt to define the marginal value of irrigation water in use, as compared with the marginal value in use of town water would be that showing $\overline{MV} + \sigma$. If MVI is defined as

$$MVI = \overline{MV} + \sigma \qquad \text{(Eqn. 8.4)}$$

(marginal value in use of irrigation water.)

FIGURE 23: Marginal Value in Use of Irrigation Water Foregone with Varying Irrigation Control Levels in Taylor's Pond.

POND CAPACITY - 120 Ml



then regression analysis gives

$$\ln MVI = a \ln SF + b \quad \text{......... (Eqn.8.5)}$$

where $a = 0.1782$
$b = 2.5468$
$r = 0.9190$

It is interesting to note that Equation 8.5 indicates that the marginal value in use of irrigation water at Bundarra ranges from about 22c/Kl to about 34c/Kl.

8.5 THE VALUE OF TOWN WATER

In order to determine the marginal value of water in use to the water users in the village of Bundarra, all occupiers of premises which were serviced by the Council's water supply system were surveyed. The survey was by means of a written questionnaire, which the occupiers were asked to complete and return to the Council. Appendix "K" contains a copy of the covering letter sent with the questionnaire, background information to assist in the completion of the questionnaire (Form A) and the questionnaire itself (Form B). The survey was carried out in October 1982.

A total of 138 questionnaires were issued. A total of 65 (49%) were properly completed and returned. The return rate was good. A summary of the results of Parts A and B of the questionnaire are given in Table 13. Those results indicate that the population is made up of a majority of people who do not own expensive appliances and who do not have a keen gardening interest. Many are not employed. The water supply is seen to fall short of commonly accepted standards of quality. However, few residents find the necessary water restrictions represent a severe burden. Most residents never use the town supply for cooking or drinking. The results of Parts A and B of the questionnaire establish the opinion of the residents that the water supply at Bundarra is deficient in quality and quantity. Part C of the questionnaire was designed to indicate how they valued their supply and if they could justify its improvement, in economic terms.

TABLE 13

RESULTS OF BUNDARRA WATER USE SURVEY.

(Results given are percentages of total sample)

1. Number of people normally living permanently in the house

1 to 2	49%
3 to 4	31%
5 to 8	18%
more than 8	2%

2. Ownership of appliances

(a) Automatic dishwasher	7%
(b) Automatic washing machine	28%
(c) Septic toilet system	98%

3. Resident's description of gardening interest

(a) Keen gardener	10%
(b) Average gardener	76%
(c) Not interested in gardens	14%

4. Number of vehicles normally garaged at the house

0	12%
1	52%
2	29%
3	7%
4	Nil
5	Nil
More than 5	Nil

5. Resident's assessement of the problems associated with water restrictions

(a) A severe burden	7%
(b) A nuisance	65%
(c) No problem	28%

6. Number of wages coming into household

0	52%
1	33%
2	13%
3	2%
More than 3	Nil

7. Ownership of premises

Owned	89%
Rented	11%

8. Use of town water for cooking and drinking purposes

Always	2%
Never	90%
Often	Nil
Not often	8%

9. Resident's comment on the frequency of the town water tasting, smelling or looking unpleasant

All the time	26%
Often	26%
Sometimes	39%
Not often	7%
Hardly ever	2%

10. Resident's assessement of the adequacy of water supply pressure

Good	40%
Satisfactory	46%
Too Low	14%
Too high	Nil

11. Number of questionnaires issued = 138

Number returned and satisfactorily completed = 65

Number returned not completed = 4

Number returned with unusable comments or figures = 2

Figure 24 is a plot of the demand curve for town water supply at Bundarra in 1982, based on the results of Part C of the questionnaire.

Demand curves are commonly of two types: the linear curve and the constant elasticity curve. Linear demand curves are of the form

$$P = a.\ Q + b \qquad \text{........(Eqn.8.6)}$$

Constant elasticity curves are of the form

$$\log P = a.\ \log Q + \log b \qquad \text{....(Eqn. 8.7)}$$

or $$P = b.\ Q^a \qquad \text{........ (Eqn. 8.8)}$$

Figure 24 shows that the demand curve for Bundarra has two distinct sections; one applies for a price range from 0 to 30c/Kl and one for a price range of 30 to 80c/Kl.

Regression analysis was carried out to fit a linear demand curve to the results of Part C of the questionnaire. This analysis produced the following relationship :

$$P = a.\ Q+b \qquad \text{.......... (Eqn. 8.6)}$$

where $a = -0.4888$, $b = 269.3322$, correlation coefficient, $r = -0.970$ $\Big\}$ $0 < p < 30c/Kl$

and $a = -0.3255$, $b = 187.2405$, $r = -0.9752$ $\Big\}$ for $30 \leq P < 80c/Kl$

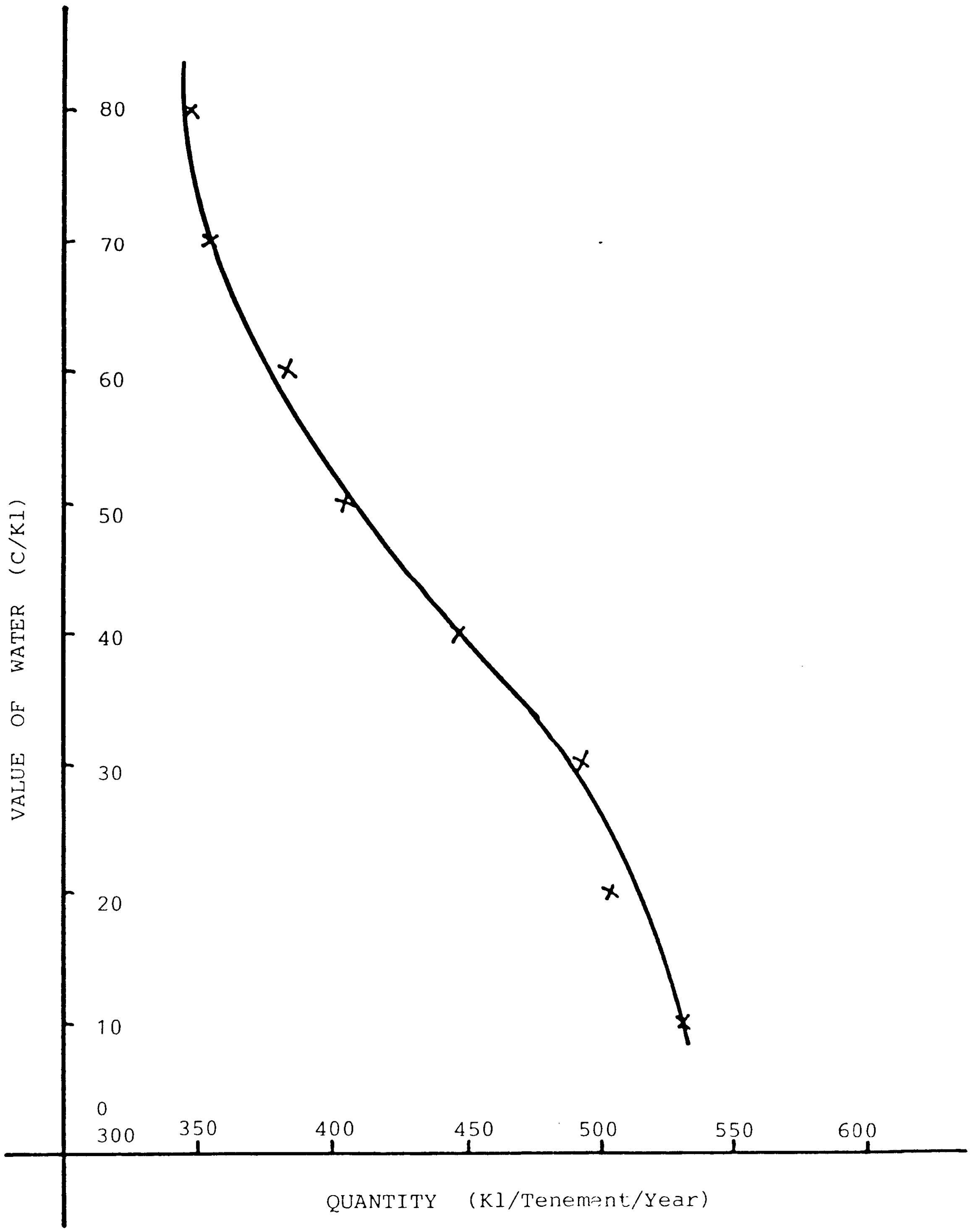
Regression analysis was carried out on a constant elasticity (exponential) demand curve and produced the following results:

$$\ln P = a \ln Q + b \qquad \text{.........(Eqn.8.9)}$$

where $a = -14.3307$, $b = 92.2379$, $r = -0.9963$ $\Big\}$ for $Q \geq 500$ Kl

and $a = -2.6980$, $b = 20.1403$, $r = -0.9965$ for $Q < 500$ Kl

FIGURE 24 - Demand Curve for Water in the Township of Bundarra, Based on the Results of the Bundarra Water Questionnaire.



Equation 8.9 can be re-arranged to

$$Q = e^{\frac{1}{a}(\ln P - b)} \qquad \text{........(Eqn. 8.10)}$$

from Equation 8.1,

$$E = \frac{-d\,Q}{d\,P} \cdot \frac{P}{Q}$$

and from Equation 8.10

$$\frac{d\,Q}{d\,P} = \frac{1}{a\,P} \cdot Q$$

$$\therefore\ E = -\frac{1}{a}\ , \text{ a constant} \qquad \text{.......(Eqn. 8.11)}$$

Equation 8.11 gives a price elasticity of demand for water supply at Bundarra of

$E = -0.07$ for a price between 0 and 30c/Kl

and $E = -0.37$ for a price between 30c and 80c per Kl

These results indicate that water is an inelastic good at Bundarra. At low prices (less than 30c/Kl) price has little effect on demand. At more realistic prices (ie those covering the range of actual prices) the elasticity compares well with the values for residential water given in Section 8.3 of this report, which ranged from -0.06 to -0.568.

From Equation 8.9, the demand function for water at Bundarra may be written

$$P = Q^{(a \ln Q + b)}$$

Equation 8.2 says

$$MV = \frac{\int_{Q_1}^{Q_2} f(Q).dQ}{Q_2 - Q_1}$$

$$= \frac{\int_{Q_1}^{Q_2} e^{(a \ln Q + b)}.dQ}{Q_2 - Q_1}$$

$$\text{ie. Marginal Value In Use of town water at Bundarra, MV} = \frac{1}{(a+1)} \cdot \frac{(Q_2P_2 - Q_1P_1)}{(Q_2 - Q_1)}$$

.... Equation 8.12

At Bundarra, the "standard" water consumption per tenement is 500Kl per year, before excess water rates are charged. Residents would normally expect to be able to consume 500Kl/ tenement / year if no restrictions were imposed. Restrictions would have the effect of reducing consumption below the value of 500Kl.

Equation 8.12 actually represents the marginal value of water which residents may choose to purchase if they were offered the opportunity of increasing their consumption from Q_1 units to Q_2 units. In this study, the measure required is that of the marginal value of water foregone if residents are required to reduce their consumption from Q_2 units (500 Kl) to Q_1 units (less than 500 Kl). Because of the difficulties involved in obtaining a reliable estimate of this value, it has been assumed for the purpose of analysis that the marginal value of water foregone may be reasonably represented by equation 8.12. The nature of those difficulties and the deficiencies of the above assumption are discussed in Section 8.6.

Having assumed that equation 8.12 can be used to represent the marginal value of water foregone, table 14 shows the effect on marginal value per kilolitre of various volumes of water foregone by Bundarra residents, if consumption is reduced below 500 Kl/tenement/year.

When the relationship between MV and Q_1 in Table 14 is examined by regression analysis, the following relationship results:

$$MV = m\,Q_1 + n \qquad \text{..........(Eqn.8.13)}$$

where $m = -0.1570$
$n = 103.8440$
$r = 0.9866$

TABLE 14 TABLE OF ASSUMED MARGINAL VALUES IN USE OF WATER FOREGONE BY RESIDENTS OF BUNDARRA

Unrestricted annual Consumption (Q_2) Kl/tenement	Annual Consumption Reduced by Restrictions (Q_1) Kl/tenement	Annual Volume of Water Foregone Kl/tenement	Marginal Value In Use of Water Foregone (MV) c/Kl
500	475	25	31.3
500	450	50	33.7
500	425	75	36.4
500	400	100	39.6
500	375	125	43.3
500	350	150	47.7
500	325	175	52.9
500	300	200	59.3

Equation 8.13 represents a strongly correlated linear relationship between Marginal Value in use of town water at Bundarra and the annual consumption per tenement, as reduced below the standard unrestricted consumption of 500 Kl/tenement / year.

In Bundarra, the average annual unrestricted water consumption is 70,000 Kl for 140 occupied sites (ie. 500 Kl/ site / year). Using these figures, the value of water foregone in Bundarra, as a result of water restrictions, can be analysed for each occasion of water restrictions corresponding to the town control level at which water restrictions are commenced. For the indicated solutions, where town restrictions commence at the same time as irrigation is required to cease, a curve relating marginal value in use of town water to the control volume of water in the pond was produced, on the same basis as that which produced Equation 8.3, in Section 8.4, for irrigation water. This analysis yielded the following relationship

$$\overline{MV} = a\,SF + b \qquad \text{.......(Eqn.8.14)}$$

where $a = 0.0136$

$b = 35.6280$

$r = 0.9719$

Figure 25 is a plot of Equation 8.14 and also the values MV_{max} and MV_{min}. Figure 25 should be directly compared with Figure 23 of Section 8.4

In a similar manner to Figure 23, Figure 25 shows that the distribution of values of marginal value has a significant skew to the high side of the average value. It should be noted that applying water restrictions at high water levels in the pond results in a larger number of occasions of periods of water restrictions in a given period, than occurs when they are applied at low levels. However, many of these additional occasions are for short periods, in which the inconvenience and the volume of water foregone is low. These short periods produce low marginal values in use of the water foregone. They bring down the average value of the set of marginal values corresponding to a defined value of irrigation control level. Figure 25 shows that the average marginal value in use of town water increases slowly with increasing values of irrigation control level, but that the maximum value of marginal value in use increases at a much faster rate.

If MVT (the marginal value in use of town water) is defined as

$$MVT = \overline{MV} + \sigma \qquad \text{........(Eqn.8.15)}$$

in a similar manner as Equation 8.4, MVT can be taken as a fair curve to compare marginal value in use of town water with that of irrigation water.

For practical purposes, over the range of feasible management plans ($30 < SF < 120$), MVT = 49c/Kl. Comparison of Figures 23 and 25 shows that MVI is less than 49c/Kl for all values of irrigation control level up to 120 Ml. The envelope of maximum values of marginal values in use of irrigation water is below 49c/Kl for all values of irrigation control level less than 120Ml.

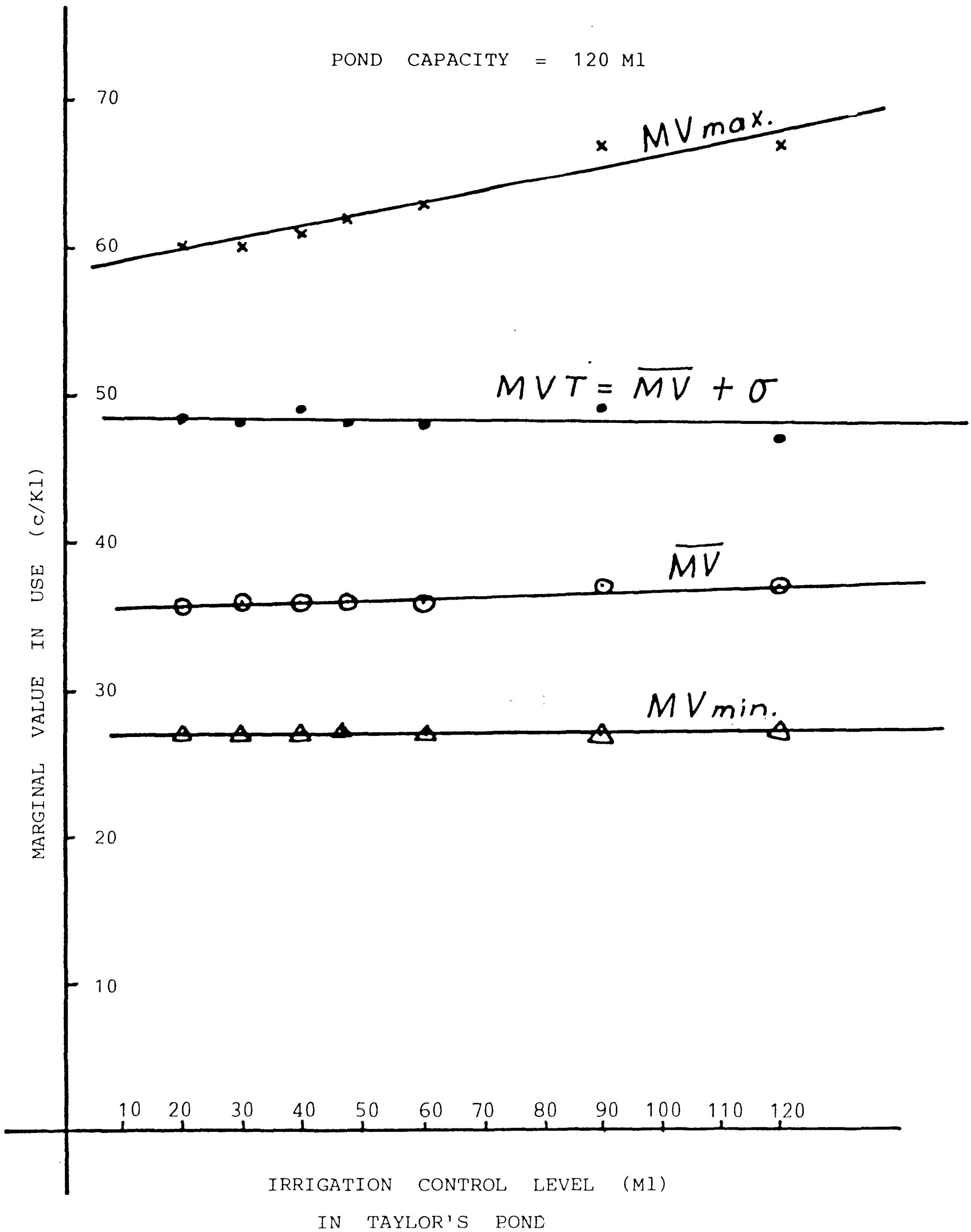


FIGURE 25: Marginal Value in Use of Town Water Foregone with Varying Irrigation Control Levels in Taylor's Pond.

8.6 DEFICIENCIES IN THE ECONOMIC ANALYSIS

The aim of the economic analysis has been to determine marginal values in use of water foregone by the irrigators and by the town users as a result of restrictions imposed on those users. These values have been shown to vary with the conditions applying at any particular time, as well as the volume of water foregone.

In the case of the irrigators it was possible to measure the economic disbenefit of water restrictions by assessing the value of lost crop production caused by the volume of water foregone. These measurements were made for each occasion of interruption to irrigation. As a result, a direct measure of the marginal value in use of irrigation water foregone has been presented in equation 8.5 and in figure 23.

In the case of the town users it is much more difficult to directly measure the value of water foregone.

There is a subtle difference between the value users would put on water if they were offered the chance to increase their usage, from a volume of say 400 Kl per annum to a more desirable level of 500 Kl per annum and that which they would put on water if they were required to reduce their usage, from a customary level of 500 Kl per annum to a restricted level of 400 Kl per annum. The former value measures a willingness to pay for more water, whilst the latter measures compensation demanded for water taken from them. The latter value would normally be expected to be higher than the former. Although the survey of town users measured their willingness to pay for more water, this study has used that measure as one representing the compensation that town users would demand for water allocated to others. The two measures were equated because of the difficulties involved in having relatively unsophisticated people appreciating the subtle differences in the two types of value and accurately expressing those values in a written questionnaire.

The survey was taken at the end of a very severe drought period. Residents were well aware of the issues involved and had had a recent, first-hand experience of the value of water to them. The conflict between urban and agricultural water users was an emotive issue in the town at the time. A number of residents argued strongly that since Council effectively charged users 44¢/Kl for an allowance of 500 Kl per annum (see section 3.8), if consumption is reduced to below that volume because of water restrictions, all users should receive a corresponding reduction in water rates. It could be argued that those residents were expressing their value of compensation for water foregone at an average rate of 44¢/Kl. Whether this value has been derived logically by them or whether it is completely based on the Council's charge is a matter for conjecture.

While these weaknesses in the assumptions made are readily acknowledged, a better estimate of the marginal value in use of town water foregone given the limitations of time and resources was not warranted. Thus equation 8.15 has been adopted as a reasonable measure of this value. If the true marginal value is different from the marginal value used in this study, it is likely to be higher than the adopted value of 49¢/Kl.

One further difficulty with determining the marginal value in use of town water foregone is the multi-dimensional nature of the problem. For example there are 138 separate users, each of whom would value water differently at different seasons and at various times within drought periods. Usually, demand for household and gardening water would be high in summer months when it is also high for irrigation usage. However demand for low volumes of water for "essential" uses such as cooking, drinking and washing is relatively constant in all seasons. Such water would be expected to be highly valued at all times.

It has been possible to account for most of the multi-dimensional characteristics of the irrigation situation, when assessing the marginal value in use of irrigation water. However for the town users the multi-dimensional nature of the problem has been simplified in this study by using average values of all users for average annual consumption volumes. This simplification probably further underestimates the true marginal value in use of town water.

The economic analysis could be improved by refining it to include the multi-dimensional nature of the problem. Further research into methods of accounting more accurately for the difficulties involved in such an analysis would be valuable.

It should be noted here that Parts A and B of the questionnaire involved questions concerning water quality. The quality of water is a measure of the physical, chemical and biological characteristics of the water (such as taste, odour, colour, salinity, hardness and concentration of faecal organisms). The quality of water which users require varies with the purposes for which the water is to be used (for example water for hosing gardens can be of inferior quality to that for drinking). This economic analysis has not attempted to include water quality as a parameter which would affect the value of water. Experience has been that the quality of water for urban usage does deteriorate at Bundarra when the water level in Taylor's Pond is at low levels. As such, its value for residential use would be expected to vary with deteriorating quality. Further research into the effect of water quality on the value of water would be of value.

CHAPTER 9

STRATEGIES PROPOSED FROM THE ECONOMIC ANALYSIS

9.1 CONCLUSIONS FROM THE RESULTS OF THE ECONOMIC ANALYSIS

The economic analysis of Chapter 8 developed a principle on which sharing of the water between competing users can be based. It determined a marginal value of water for both irrigation and urban use. The analysis has led to the following conclusions :-

(a) Price is a valid tool to use to maximise the benefits from proposed water sharing rules.

(b) The principle of equi-marginal value in use should be used to achieve an efficient allocation of the available water between the competing users.

(c) The marginal value of irrigation water at Bundarra, in 1982, varies with the irrigation control level and ranges from 22c/Kl to 34c/Kl.

(d) The price elasticity of demand for residential water at Bundarra was found to be -0.07 for a price range of 0 to 30c/Kl and -0.37 for a price range of 30 to 80c/Kl. These values, which indicate that the water is an inelastic good, correlate well with results reported in other studies.

(e) The residential water demand curve at Bundarra, in 1982, shows that the average price residents are prepared to pay for their "standard allocation" of 500 Kl/ tenement/ year is 30c/Kl. This price is well below the current rate charged by Uralla Shire Council, of 44c/Kl. There is, therefore, no justification for the expenditure of money, to improve the quality or reliability of supply, which will result in a need to increase the actual supply price even further above the valued price.

(f) The marginal value of residential water in Bundarra, in 1982, does not vary significantly with the irrigation control level, and was found to be 49c/Kl over all feasible values of that level

(g) The marginal value of irrigation water was found to always be less than the marginal value of residential water.

(h) The average value of residential water reduces rapidly for supplied volumes in excess of 500Kl/ tenement/ year.

9.2 TECHNICAL CONSIDERATIONS AND PRACTICAL LIMITATIONS

If microeconomic principles are to guide the decision making, then the calculated marginal values of water in use indicate that an adopted management plan should seek to avoid the need for water restrictions in town, which would otherwise occur as a result of the irrigation operation. Raising the irrigation control level will increase the number of occasions in which irrigation is interrupted. However, unless the increase in that level results in the avoidance, or subtantial reduction in the period, of water restrictions in town, then the irrigation operation will be interrupted without significantly improving the reliability of the town supply.

This concept is illustrated in Table 15, which shows the effect of raising the irrigation control level on the reliability of town and irrigation supply. Table 15 applies for a capacity of Taylor's Pond of 120Ml and for the present irrigation practices at Bundarra.

TABLE 15

THE EFFECT OF RAISING THE IRRIGATION CONTROL LEVEL ON THE RELIABILITY OF TOWN AND IRRIGATION SUPPLY (ASSUMING THE TOWN CONTROL LEVEL IS SET AT 47.5 Ml)

Irrigation Control Level	Variation in Irrigation Control Level Above Current Level		Variation In The Number of Occasions In Which Water Restrictions Occur, From That Which Would Occur If Irrigation And Town Control Levels Were Both Set At 47.5Ml (8 Occasions In 50 Years)	
(Ml)	(Ml)	(m)	Reduction For Town	Increase For Irrigator
47.5	Nil	Nil	Nil	Nil
50	2.5	0.06	1	1
55	7.5	0.18	2	3
60	12.5	0.30	2	4
70	22.5	0.52	3	8
80	32.5	0.72	3	12
90	42.5	0.90	3	21

9.3 SELECTION OF A PROPOSED MANAGEMENT PLAN

The results of Chapters 7 and 8 have indicated that reducing the town control level to 47.5 Ml results in improvement in the reliability of the town supply. Raising the irrigation control level above the present value of 47.5 Ml also improves the reliability of the town supply. Both were economically reasonable despite the reduced reliability of supply for the irrigators.

Table 15 demonstrates that the limitations of the capacity of the ponds at Bundarra prevent the achievement of an entirely reliable town supply, no matter what control conditions apply to the irrigator. It also shows that reductions in the reliability of the irrigation supply do not always result in a corresponding improvement in the reliability of the town supply. If the irrigation control level is raised too high, restrictions will be imposed on the irrigator on many occasions. These would include some in which the river flow ceased for short periods, but in which the volume would not have fallen so far as to require town water restrictions. Irrigation restrictions would then have been unnecessarily imposed in these short dry periods.

Increased reliability of the town supply results from fewer occasions when restrictions are applied and shorter periods of restrictions when they are necessary. These improvements reduce the volume of water the town users must forego. The marginal value of that water allocated to town use reflects the tangible benefits of improved gardens and lawns.

Increased reliability of supply to the town users is achieved at the cost of reduction in reliability of irrigation supply. As a result, the irrigators are required to forego more water and the marginal value in use of each unit foregone is increased, reflecting the tangible loss of reduced crop production.

It has been shown that the marginal value of irrigation water foregone was always less than the adopted marginal value of residential water foregone, for residential consumptions of less than 500 Kl per tenement per year. However, if irrigation water is foregone in a particular dry period as a result of restrictions which don't result in avoiding subsequent restrictions on the town supply, then the economic loss to the irrigator is not matched by an economic benefit to the town user. Clearly, the economic objective behind allocating marginal volumes of water to town use in dry periods is not necessarily achieved by raising the irrigation control level to very high values.

A close analysis of the benefits in reliability of supply which are achieved by the town users and the reduction in reliability of supply which results for the irrigators, based on the respective marginal values of water, has been carried out for the range of irrigation control levels shown in Table 15. This analysis leads to the following management plan, to efficiently allocate the water between the competing users :-

Taylor's Pond Capacity	- Increase from 90Ml to 120Ml.
Irrigation Control Level	- Raise from 47.5Ml to 60Ml.
Town Control Level	- Lower from 90Ml to 47.5Ml.
Irrigation Usage	- Restrict "Clerkness" to its present pumping capacity of 1.7 Ml/day from Taylor's Pond only
	- Restrict "Flemington" to its present pumping capacity of 0.7Ml/day from Taylor's Pond and to 0.4Ml/day from Worrabinda Pond.
	- Do not permit further irrigation from the Gwydir River upstream of Bundarra, which would significantly affect river flows at Bundarra.

Town Restrictions - Ban sprinklers when Taylor's Pond capacity falls below 47.5Ml.

- Allow hand held hoses for three hours per day only when pond capacity falls below 40Ml.
- Allow hand held hoses for one hour per day only when pond capacity falls below 35Ml.
- Allow domestic use only when pond capacity falls below 27.5Ml and draw upon water stored in Worrabinda Pond to supplement Taylor's Pond.

This plan does not reduce the area of irrigation (and thereby the volume of irrigation water) that the irrigators may use in periods of good river flow. It does however require them to cease irrigation altogether much earlier than was the case when the irrigation control level was set at 47.5Ml. The extra volume of water remaining in the pond at that time has been effectively allocated to urban use in preference to irrigation use.

9.4 SUMMARY OF CONCLUSIONS OF THE ANALYSIS

The results of the simulation and economic analysis have allowed the selection of a simple management plan to share the water in the Gwydir River at Bundarra between the town and agricultural users.

Substantial improvements in the reliability of the town supply have been shown to be achievable. These improvements have been achieved at some cost to the irrigators, but not a cost which is likely to cause them to abandon their practice. Irrigation will still be valuable in supplementing ground water levels during short dry periods, but will not be available during extended droughts.

It is recognised that having reduced the town control level to 47.5 Ml, only two further occasions of town restrictions in the fifty year period of record would be avoided when the irrigation control level is raised to the recommended value of 60 Ml. It may be that pragmatic political considerations would lead to decision makers choosing to leave the irrigation control level unchanged because of the difficulties involved in implementing changes to achieve relatively minor improvements for a small urban village. The credibility of such decisions would still rest on the results of this study.

Further, the general techniques used in this study could be applied to any similar conflict of competing demand for limited amounts of water.

CHAPTER 10

CONCLUSIONS AND RECOMMENDATIONS

10.1 SUMMARY

A management plan has been developed to solve the problem of sharing water from the Gwydir River between competing users at Bundarra. The plan is based on sound data, is economically feasible and economically efficient and has been demonstrated to be equitable.

Computer simulation techniques have been shown to be of value in dealing with a complex problem in natural resources. They have allowed the effects of a range of natural processes on the availability of water to be ascertained. These natural processes include river flow, rainfall, evaporation, seasonal weather conditions and plant water demand. The simulation techniques have also allowed the effects of man's impact on the natural processes to be ascertained. Man's influence includes town water consumption, proposed management plans and planned future development.

The computer simulation has provided results which have then been subjected to economic analysis to propose an equitable allocation of water between the users.

Engineering and scientific analysis, computer simulation and micro-economic analysis, together with the consideration of practical and legal restrictions governing water use in Australia, have been used to determine an equitable water sharing plan.

The general methodology of this study would be applicable to similar problems, of any scale, at any other site.

10.2 CONCLUSIONS AND RECOMMENDATIONS

For clarity of presentation the findings of this study have been grouped into four categories. Section A covers general findings, Section B covers findings related to the simulation analysis, Section C covers findings related to the economic analysis and Section D lists findings which suggest the need for further research or future action.

A. GENERAL

1. A complex and controversial problem in the sharing of a natural resource has been shown to be able to be solved using rational engineering and economic analysis. Decision makers, as a result, now have sound information on which to base their decisions.

2. The analysis has led to the following management plan, to equitably share the water, being recommended:-

Taylor's Pond Capacity	- Increase from 90Ml to 120Ml.
Irrigation Control Level	- Raise from 47.5Ml to 60Ml.
Town Control Level	- Lower from 90Ml to 47.5Ml.
Irrigation Usage	- Restrict "Clerkness" to its present pumping capacity of 1.7 Ml/day from Taylor's Pond only
	- Restrict "Flemington" to its present pumping capacity of 0.7Ml/day from Taylor's Pond and to 0.4Ml/day from Worrabinda Pond.
	- Do not permit further irrigation from the Gwydir River upstream of Bundarra, which would significantly affect river flows at Bundarra.

Town Restrictions - Ban sprinklers when Taylor's Pond capacity falls below 47.5Ml.

- Allow hand held hoses for three hours per day only when pond capacity falls below 40Ml.
- Allow hand held hoses for one hour per day only when pond capacity falls below 35Ml.
- Allow domestic use only when pond capacity falls below 27.5Ml and draw upon water stored in Worrabinda Pond to supplement Taylor's Pond.

3. A survey of water users at Bundarra allowed the development of a profile of the community. It also clearly indicated their opinions on the quality and quantity of the town supply and the nature of their water use. The results will be of value to Uralla Shire Council in managing the town supply.

4. The parties in the conflict examined in this thesis have all contributed to relevant aspects of the study. The study therefore, can be said to reasonably represent the actual water use practices at Bundarra.

5. Due to the limited nature of Australia's water resources, conflicts of competing demands for that water are bound to continue to occur. All requests for water must therefore be closely analysed to determine their justification.

6. Irrigation accounts for a massive proportion of Australia's water consumption (74%). Since only 46% of that water is used to grow plants (the remainder being lost to seepage, leakage, evaporation and overwatering) it is urgently necessary to improve the efficiency of irrigation practice.

7. Streamflows in the Gwydir River, at Bundarra, are very variable and do not exhibit a high degree of persistence.

8. Groundwater potential for irrigation usage in the Upper Gwydir Valley is very limited.

B. SIMULATION ANALYSIS

9. The simulation programme has produced sound and reliable results, in a form which can be readily understood by the parties involved in this conflict. Practical results from the implementation of various management plans are produced, so the various parties can see the direct effect of each plan on themselves and the other parties. The results also allow further economic analysis of their implications for each party.

10. The results of the simulation model have been shown to be valid, when actual and predicted results were compared for the situation existing in Bundarra during the drought period of the summer of 1980/81.

11. The trends resulting from various management plan options include the following principal observations:-

(a) Raising the level at which irrigation is required to cease, in Taylor's Pond, above its present value of 47.5 Ml has an adverse effect on the irrigators. This measure substantially improves the reliability of the town. supply and results in substantially less time when the ponds are at low storage levels.

(b) Lowering the level at which town supply restrictions are implemented, from its present level of 90Ml, has little adverse effect on the irrigators and markedly improves the reliability of the town supply.

(c) The range of feasible management plans can reduce the impact of shorter dry periods on the reliability of supply. However, such plans cannot significantly reduce the impact of the less frequent, but extended, drought periods.

(d) Increasing the capacity of Taylor's Pond, from 90Ml to 120Ml, substantially improves the reliability of the town supply.

(e) Reliability of supply is very sensitive to the area of irrigation. It is not particularly sensitive to relatively small variations in irrigation demand, for a given area of irrigation.

12. The subroutine used to simulate irrigation demand is based on theoretical analysis of the site conditions. It has been checked with the irrigators, to ensure the procedure simulated closely matches the irrigation practices they aim to implement.

13. The subroutine used to simulate town water demand is based on Uralla Shire Council's records of actual consumption during normal and drought conditions.

14. A period of simulation of fifty years, using historical records for river flow and rainfall at Bundarra, has been used in this study and shown to be adequate for its purposes.

15. The data used in this study requires correlation between rainfall and river flow, making the use of synthetic data very difficult.

16. The water requirements of the village of Bundarra are not expected to alter significantly over the next twenty years.

17. There is no evidence to indicate that siltation of the ponds in the Gwydir River will be a matter of concern, with respect to pond capacity, over the next twenty years.

C. <u>ECONOMIC ANALYSIS</u>

18. For all feasible management plans, the marginal value of urban water was greater than the marginal value of irrigation water. This result is consistent with those of earlier studies.

19. Marginal values of water foregone by the irrigators, as a result of water restrictions, were found to vary between the extremes 8c/Kl to 47c/Kl, depending on the circumstances involved in any particular period of restrictions (length of period of restriction, season, month of year). For the range of likely feasible management plans, the marginal value ranged from 12c/Kl to 35c/Kl.

20. A strongly correlated relationship was developed between the marginal value of water foregone by the irrigators and the level at which irrigation must cease (correlation coefficient 0.919). Over the range of irrigation control levels of 10Ml to 120Ml, and for feasible management plans, the marginal value of irrigation water ranged from 22c/Kl to 34c/Kl.

21. The marginal value of water foregone by Bundarra residents, as a result of water restrictions, was calculated. Over the range of feasible management plans, the marginal value was 49c/Kl.

22. The survey of water users at Bundarra allowed the preparation of a demand curve for their urban water consumption, relating value of water(cents per Kl) to quantity supplied per tenement. This demand curve was accurately described by a discontinuous exponential (constant elasticity) function. The price elasticity of demand calculated for this curve was -0.07, for a price less than 30c/Kl, and -0.37 for a price greater than 30c/Kl. These results compare well with other reported results.

23. Bundarra residents place an average value on their "standard allocation", of 500Kl/tenement/year, of 30c/Kl. This value is less than the current rate charged by Uralla Shire Council, of 44c/Kl. The cost of improvements to the supply, which would inevitably increase the water charge, is therefore not justified.

24. The principle of "equi-marginal value in use" has been shown to be valid to control the allocation of resources between competing users. Resource allocation is thereby guided by the system of market values.

25 . The marginal value in use of irrigation water and urban water have been determined, using the economic principles of market theory and the demand curve.

26. Earlier studies indicate that municipal water use, on average, is more highly valued than agricultural water use.

D. FOR FUTURE ACTION

27. Further research into methods of economic analysis which take account of the multi-dimensional nature of this resource allocation problem is necessary to improve the technique of analysis used in this study.

28. Further research into the effect of water quality on the value of water is necessary to allow refinement of the analysis used in this study.

29. The direct calculation of marginal values of water foregone by urban users is difficult. Further research could usefully be directed into determining more reliable techniques of determining such values.

30. It has been assumed that the proposal to increase the volume of Taylor's Pond be constructing a concrete weir in the Gwydir River is neither economically feasible nor justifiable. Further research should be carried out to test this assumption.

31 . It is recommended that Australian Water Authorities increase programmes to achieve greater efficiency in irrigation practice, so that water is used more effectively in crop production.

32 . The supply of irrigation water is highly subsidised in Australia. Such subsidies should be regularly reviewed to ensure they are justifiable.

33 . The use of price to control water demand should continue to be closely examined by Water Supply Authorities.

34 . Further research into the effect of land use on the quality and quantity of water in the Gwydir River is recommended.

35. Further research is required to develop water production functions for irrigated agriculture, for various crops, in Australian conditions. Such functions should aim to predict the effect on production of applying less than optimum water irrigations, at various stages of growth. Such research would be linked with the earlier recommendation to develop efficient, well-planned irrigation practices.

This study has been an exercise in developing a practical technique to solve a problem of competing demands for water. It is a first step in the development of a suitable technique and further refinement should improve the accuracy of the results.