Explaining farmers' monitoring of sustainability indicators: a bore-ing example for salinity in Western Australia

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Dryland salinity is one of the most pressing land management problems in Western Australia. A number of projects are in progress to provide a more comprehensive picture of the location and extent of potentially saline areas in the landscape. Associated with some of these projects, a large number of bores (piezometers) have been installed or are being installed throughout the agricultural area to provide information on depth to groundwater and changes in water levels over time. These bores provide information about whether and when the ground water will reach the surface, causing losses of agricultural production through salinisation of soils. Using data from the Jerramungup Land Conservation District (LCD) we explore factors influencing the behaviour of farmers in monitoring or not monitoring their bores. In 1989, 110 bores were sunk in seven catchments in the Jerramungup LCD. Monitoring responses were initially exceptionally high, with 96 percent of bores observed in 1990, but then fell steadily to 44 percent by 1997. Our statistical analysis indicates that the probability that a bore will be monitored decreases with time but is influenced by physical factors (reflecting economic incentives) such as the depth to groundwater, the salt stored in the soil and the interaction between these variables. As well as these physical factors, we explore some of the sociological and economic factors that influence farmers' bore monitoring behaviour. Farm size, age, education, involvement in land conservation groups and perception of the threat posed by salinity all affect the frequency of monitoring. Monitoring is also more frequent when farmers are using it to assess management strategies they have implemented to attempt to reduce groundwater rise. Overall, the study provides strong empirical support for the view that economic incentives provide the main impetus for monitoring of groundwaters in this region, although the study confirms that social factors also play a role.

Key words: sustainability indicators, environmental indicators, resource monitoring, economics of information, hydrology, dryland salinity, Western Australia

1 Introduction

Dryland salinity is one of the most pressing land management problems in Australia (Anon., 1999) and particularly so in Western Australia (Anon., 1996). Associated with some projects investigating the location and extent of salinity in Western Australia, a large number of bores (piezometers) have been installed and are being installed throughout the agricultural region.

Bores to monitor groundwater levels are also a component of many catchment plans, and many are being installed by farmers. They represent a sizeable investment by both farmers and society (through government funding). Data from the drilling of piezometers provides information to hydrologists, farmers and policy makers on factors such as the salt stored in the soil, groundwater conductivity, depth to water and depth to bedrock. If farmers continue to monitor the depth to water, the bores provide information about whether and when the groundwater will reach the surface, causing losses of agricultural production through salinisation of soils. This information is one of many possible ‘sustainability indicators’; that is, “*environmental attributes that measure or reflect environmental status or condition of change*” (Smyth and Dumanski, 1993).

Sustainability indicators have been widely promoted by some Australian scientists and agencies as a practical means of facilitating improved on-farm management of degradable natural resources (e.g. Standing Committee on Agriculture and Resource Management, 1993; Walker and Reuter, 1996). In general, however, farmers have been relatively unresponsive to calls for increased monitoring of environmental indicators. In the case of salinity, the proportion of farmers who are monitoring their groundwater levels is low (e.g. Kington and Pannell, 2000) even amongst farmers situated in regions of high salinity risk who have borne the expense of installing piezometers. Given the serious and largely irreversible consequences of land salinisation, this observation may be considered surprising, and a cause for further investigation.

Using data from the Jerramungup Land Conservation District (LCD), where 110 bores were drilled in 1989/90, we explore the factors which influence farmers to continue or to cease monitoring groundwater levels. After an initial very high monitoring response, farmers now monitor less than 50 percent of these bores. Disadoption is usually associated with a perception that the practice was not useful, or is no longer relevant (Rogers, 1995). In their review of the application of sustainability indicators in agriculture, Pannell and Glenn (2000) argue that the value of a sustainability indicator is directly related to its potential to improve decision making. In other words, the value of an indicator arises from the usefulness of the information it provides. Additionally, Pannell and Glenn (2000) conclude that many sustainability indicators are strongly technical in focus, with no close link to management. This provides one possible hypothesis that may help to explain the observed high rate of cessation of monitoring. Other explanations, such as social pressures or misinformation, are also possible.

The aim of this research is to identify and quantify the various factors influencing farmers’ decisions to monitor, or not monitor, piezometers that have been installed on their farms. It is also intended that the study provide understanding of broader relevance to farmer monitoring of sustainability indicators in general.

2 Background

The Jerramungup LCD is located on the south coast of Western Australia within the south-west agricultural region. Like many of the “lighter” (sandy soiled) lands in Western Australia, the area is a comparatively new farming district. The great majority of the district has been settled and cleared since the 1950s, firstly under the War Service Land Settlement Scheme in the 1950s and then in the 1960s when 35,000 hectares were allocated to Conditional Purchase blocks (Davis, 1997). Twigg (1987, p. 12) comments that settlement that occurred under the War Service Land Settlement Scheme at Jerramungup/Gairdner River was *“perhaps the largest land clearing venture in Australia at that time”*.

Dry seasons in the early 1980s resulted in the district experiencing severe wind erosion problems and this, together with an awareness of the insidious nature of increasing dryland salinity, provided the impetus for the formation of a Soil Conservation District Advisory Committee in 1983 (Twigg and Lullfitz, 1990). The Jerramungup Land Conservation District

Committee (LCDC) which grew from this beginning was one of the first LCDCs to form in WA. The first catchment group within the LCD, Jacup, formed in 1984, and the second, Corackerup, in 1989. Both these catchment groups had specific objectives which indicated their concern about dryland salinity (Davis, 1997).

In 1989 the LCDC obtained funding from the National Soil Conservation Program (NSCP) for a network of piezometers to monitor groundwater levels. The original impetus to set up the monitoring scheme came from individuals within this functioning LCDC who were anxious to raise awareness. They were concerned that *"some people thought that they didn't have a problem …. they didn't believe that they would have a saline watertable"* (Jerramungup LCDC members, pers. comm., 1999). The project was supported strongly by the state government agency, Agriculture Western Australia (AGWEST), who were responsible for the drilling of the bores and the collection of the initial data. AGWEST was also committed to providing analysis and feedback to farmers on the bore data that farmers had collected.

In 1989/90, 110 bores were installed on 81 farms in 7 catchments in the Jerramungup LCD - Gairdner/Bremer, Carlawillup, Needilup North, Corackerup/Ongerup/ Nawainup, Fitzgerald, Jerramungup North, and Jacup. The LCDC was keen to involve as many farmers as possible so most farms only had one bore drilled. Although the drilling was done by AGWEST and a senior hydrologist was involved in the siting of the first 10-15 bores, farmers were consulted about bore location and required to be present and work as the 'off-sider' when the bore was drilled. *"Involvement was the biggest thing we wanted so bores went where farmers wanted"* (Jerramungup LCDC members, pers. comm., 1999). A consequence of this was that many bores were not ideally sited. For example, some were placed low in the landscape where saline groundwaters were already close to the surface. The bores were drilled to bedrock wherever possible and as each bore was drilled, samples of the cuttings were collected at regular intervals.

Farmers were (and still are) sent quarterly reminders to read their piezometers from the local LCD coordinator, and the information passed on to AGWEST for data interpretation. The project initially had what can only be described as an exceptional response, with close to 100 percent of the bores being monitored.

The first detailed feedback on the bores was given to farmers in 1992. The salt profile associated with each bore was presented in a graphical format. The salt attributed to each profile was calculated and expressed as tonnes per hectare and kilograms per cubic metre, the latter measure taking account of the depth to bedrock and giving a measure for average Total Soluble Salt. For bores not drilled to bedrock, the assumed depth to bedrock was used and the last electrical conductivity reading was extrapolated to the assumed depth. Comment was made on the Total Soluble Salt as compared to other bores in the Jerramungup catchment. Information on groundwater readings was given back to the farmers in a graph format and comments made about the depth of the groundwater and any early trend. For example, comments on a particular bore state:

> *The plot of water level shows seasonal fluctuations superimposed on a rise of around 1 m. Further data is required to confirm that this rise is part of a long-term trend. As the water level is within 2 m of ground level there is imminent danger of land degradation in the vicinity of this bore. … Regular monitoring of water level and water quality is strongly recommended.* (Greenham, 1992).

A plot of bore water level over time has been made available to farmers each year since 1992. By 1993, 82 bores had sufficient data to enable average trends in groundwater levels to be estimated and these were presented at the 1993 Jerramungup Agricultural Science Exposition (JERAC), a community-organised event involving farmers, researchers, advisers and others. The average district trends that were displayed at JERAC were not encouraging, but not surprising to AGWEST hydrologists. For example, analysis of the bore data indicated that:

> *The average rate of rise has been 14 cm/year. This represents a rise of about one metre every seven years, although individual bores were rising by up to one metre every year. Of particular concern, the average depth of the watertable was only 6.5m. … On average, there is over 2,500 tonnes of salt stored under each hectare in the Jerramungup region. Some areas have over 10,000 t/ha. This salt is being dissolved by the rising groundwaters resulting in their average salinity being 2703 mS/m or 14,867 mg/L. This is almost half as saline as sea water (35,500 mg/L).* (McFarlane and Ryder, 1993)

The data were also presented on a catchment basis, and this clearly illustrated that trends in some catchments were worse than in others.

At JERAC in 1994, AGWEST presented data from the bores on a landform rather than catchment basis in the form of salinity hazard maps. The maps illustrated that salinity in some areas would be harder to control, with less options available to instigate salinity management strategies. There was some negative reaction by a few farmers to this public disclosure of what was considered sensitive information. For example, there was concern about the potential effect of such information on land values. Because of these concerns a field trip was organised and issues and management options were discussed.

By 1993 the number of bores being monitored had fallen to 74 percent and by 1995 it was 52 percent. This approximate monitoring level has continued until the present. Although this is considerably less than the initial monitoring rate, it is high by many standards. Since 1989/90 more bores have been installed in better locations in conjunction with new projects (40 in the Upper Gairdner, 20 in the Fitzgerald), but as with the existing piezometer network, not all are regularly monitored (Jerramungup LCD coordinator, pers. comm., 1999). Some farmers have been experimenting with new farming systems incorporating perennial pastures and have become district and state ‘champions’ of these changed systems. The Jerramungup LCDC is still very active.

3 Methodology and analysis of the data

Our analysis focused on investigating the reasons for the drop-off in the level of monitoring whilst explaining the generally high level of initial and on-going monitoring. We conducted Probit analyses to explain the probability that an individual bore would be monitored as a function of

(a) the physical characteristics of the bore (e.g., salt storage, depth to groundwater), and
(b) socio-economic data obtained from a mail survey of farmers monitoring these bores.

Additionally, data from the mail survey and the semi-structured interviews with AGWEST personnel, the Jerramungup LCD coordinator and some Jerramungup LCD farmers which preceded the survey, provided some qualitative data about monitoring behaviour. Some reasons for monitoring behaviour that were suggested to us by these interviews were subsequently tested statistically.

Probit analysis is a form of multivariate regression analysis used when the dependent variable is a dichotomous variable with the value of either 1 or 0. In this case we consider an index variable, Y, which takes a value of 1 if the bore is monitored at a specific time and 0 otherwise. We believe that a set of technical and socioeconomic factors (x), loosely derived from underlying theory, might explain that decision, so that:

$$\mathrm{Prob}(Y=1)=F(\beta x)$$

The function F should be defined such that the probabilities generated are well behaved, and the normal distribution provides that restriction, giving the Probit model:

$$\begin{aligned}\mathrm{Prob}(Y=1) &= \int_{-\infty}^{\beta x}\phi(t)\,dt \\ &= \Phi(\beta x)\end{aligned} \tag{1}$$

where ϕ and Φ are the standard normal density and distribution functions respectively.

Our hypotheses were as follows:

- The probability that a bore would be monitored would increase with increased water level, with increased salt storage and groundwater conductivity readings. (Intuitively, the value of information about a hazard would increase with the magnitude of the hazard.)
- A rising trend in water levels in bores would increase the probability that a bore would be monitored. (Again, the increasing hazard argument applies.)
- Differences in the monitoring rates between catchments would be explained by the physical characteristics of the bore data and/or location of “Focus Catchments”[1].
- Farmers using groundwater readings to assess management strategies designed to reduce groundwater rise would monitor more frequently. (Information is of greater value if it is useful in a management decision.)
- Farmers who perceived that their land was threatened by salinity would monitor more frequently. (Again, the increasing hazard argument applies.)
- Farmers who were more active in landcare activities would monitor more frequently. (This may be because the monitored information is useful for management, or because past landcare activities indicate a particular sensitivity to land conservation issues by the farmers – e.g., a “stewardship ethic”.)

3.1 Description of the physical data from the Jerramungup piezometers

We were provided with both the initial physical data taken when the bores were drilled and quarterly water level readings for individual bores (if taken) from 1989. Additionally, we had

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[1] Some catchments in the Jerramungup LCD have been made Focus Catchments. A Focus Catchment is designated by AGWEST to receive extra inputs of money and personnel over a limited period (usually 3 years) to address land management issues in the catchment.

access to trend analyses conducted by AGWEST in 1993, 1996 and 1999. As previously stated, the data showed that monitoring responses were initially high: 96 percent of the bores were monitored in 1990, but this fell to 74 percent by 1993 and then further to 44 percent by 1997 (see Figure 1). As some farms had more than one bore, we investigated whether the monitoring percentage was different when expressed in terms of percentage of farmers monitoring (rather than percentage of bores monitored), and Figure 1 illustrates that it is essentially similar. The percentage of farmers monitoring bores varies by catchment. In 1998 it ranged from 36 percent in the Gairdner/Bremer/Carlawillup catchment to 70 percent in the Corackerup/Ongerup/Nawainup catchment (see Table 1).

The physical data associated with the bores varied greatly between the catchments (see Table 2). This reflects different land forms, soil types and climate variables (McFarlane and Ryder, 1993). The trend analysis done by AGWEST in 1993 showed that only 16 percent of bores (of those with sufficient water level readings) had falling water levels. On average, water level in the bores was rising at the rate of 14 cm per year, although some were rising at rates of greater than 60 cm per year. Jacup and Needilup North catchments showed the highest rate of rise (see Table 2). The trend analysis done by AGWEST in 1996 showed that 37 percent of bores had falling water levels. However, the 1999 analysis, using a different methodology to estimate groundwater trends (Shao *et.al.,* 1999), estimates that of 68 Jerramungup bores with sufficient readings only 10 percent show an overall falling trend. Another 18 percent of the bores however are measuring shallow watertables with strong seasonal fluctuations where the water is within one metre of the surface, and the remainder display a rising trend of variable type (Crossing, Agriculture Western Australia, pers. comm., 1999). The variation in trends over time primarily reflects fluctuations in annual rainfall.

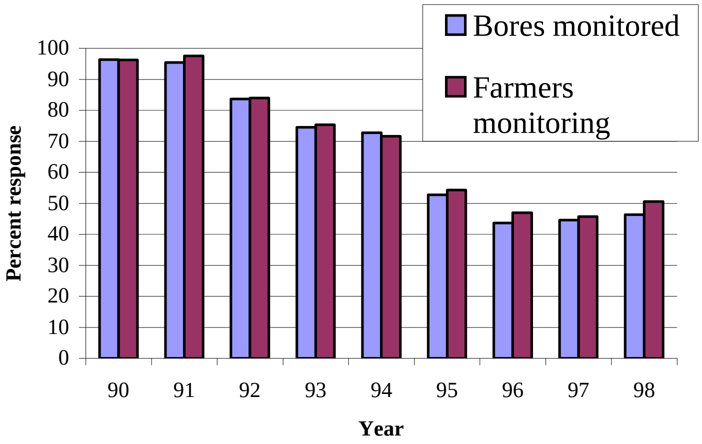

Figure 1. Bore monitoring response in the Jerramungup LCD
(110 bores on 81 farms were installed in 1989/90)

Table 1. Percentage of farmers monitoring bores by catchment and year*

Year	Gairdner/ Bremer/ Carlawillup (n=14)	Needilup North (n=8)	Corackerup/ Ongerup/ Nawainup (n=10)	Fitzgerald (n=7)	Jacup (n=28)	Jerramungup North (n=14)
1990	100%	100%	100%	71%	96%	100%
1991	100%	100%	100%	71%	100%	100%
1992	93%	88%	90%	29%	93%	79%
1993	71%	63%	80%	43%	82%	86%
1994	71%	63%	80%	29%	86%	64%
1995	43%	63%	70%	29%	64%	43%
1996	36%	50%	50%	29%	57%	43%
1997	43%	50%	70%	29%	50%	29%
1998	36%	38%	70%	57%	54%	50%

* To count as monitoring, farmers must monitor at least one bore once in the year

Table 2. District groundwater data in 1993* (Source: McFarlane and Ryder, 1993)

	Gairdner/ Bremer/ Carlawillup (n=26)	Needilup North (n=8)	Corackerup/ Ongerup/ Nawainup (n=17)	Fitzgerald (n=9)	Jacup (n=34)	Jerramungup North (n=16)
Rate of rise in groundwater levels (cm/y)	6	16	13	13	28	24
Depth of the watertable (m)	5.5	6.8	6.1	20.7	6.3	5.5
Salt storage (t/ha)	1614	2925	3473	2565	1972	3937
Salt concentration (kg/m^3)	8.5	12.3	16.7	10.6	10.6	12.9
Groundwater salinity (mg/L)	14119	21654	24090	11638	16643	24481
Depth to bedrock (m)	18.2	18.0	18.9	24.1	16.2	25.0
Average annual rainfall	468	390	413	396	406	395

* The groundwater trends for the Fitzgerald and Needilup North districts may be less accurate than for other catchments as they are based on only six or seven well-monitored bores.

3.2 Description of the survey data

The survey was constructed after initial Probit analyses using only the physical data from the bores, and after conducting semi-structured interviews with AGWEST personnel, the Jerramungup LCD coordinator and some Jerramungup farmers to identify issues and concerns. The survey was piloted with 3 farmers who had not been interviewed, including one who was not monitoring. The survey was distributed by mail in early November by the Jerramungup LCD coordinator along with the quarterly piezometer reading reminder. A follow-up letter was sent two weeks after the survey had been sent. A mis-understanding between the authors and the Jerramungup LCD coordinator resulted in not all farmers who had bores receiving a survey. Unbeknown to us, some farmers had indicated to the LCD coordinator that they did not want to receive quarterly reminders to read their piezometer, and these farmers did not receive a survey.

Thirty two people (from a total mail-out of 46) answered the survey, a response rate of 70 percent. This accounted for 50 of the bores for which we have data, i.e. 45 percent. Eighty four percent of the respondents said they were “regularly” monitoring their bores (i.e. at least once per year), 10 percent were monitoring “infrequently” and 6 percent were not monitoring at all. This high monitoring frequency is not surprising given the bias that had been created by the mail-out. However, checks showed that farmers claiming to monitor “regularly” ranged in actual monitoring frequency from once every quarter to once every 12-18 months. The monitoring was almost without exception done by farmers or members of their family.

Of the respondents monitoring either “regularly” or “infrequently”, 77 percent agreed that “they were interested themselves in the data and trends from the groundwater readings”, 13 percent that they “feel the data is needed for community and regional hydrology purposes”, and a further 10 percent ticked both those options (a choice that might have been attractive for more farmers if the questionnaire had not specifically asked them not to do this).

Forty four percent of respondents had installed additional piezometers on their property since the installation of the initial ones in 1989/90. The number of additional bores ranged from one to 20, with an average of 4.5. All these piezometers, except for those that were dry, were reported as being regularly monitored. Overall, respondents indicated that both initial and continued groundwater monitoring provided useful information. Table 3 shows the distribution of replies about the value of monitoring. No respondents indicated that monitoring was “not at all” useful. Recall, however, that our survey sample consists only of farmers who have not objected to receiving quarterly reminders to monitor.

Table 3. Respondents’ opinions on the value of information from groundwater monitoring (n = 32)

	Percent of respondents		
	Considerably useful	Somewhat useful	Not really useful
Initial reading	39%	48%	13%
Continued monitoring	59%	34%	6%

Opinion as to whether regional data from groundwater monitoring done by farmers should always be made publicly available was slightly in favour of some restriction on the availability of information: 44 percent of respondents said “yes, always”, 53 percent said “only in certain circumstances” and 3 percent said “never”.

The average farm size of the survey respondents was 2563 hectares, with a range from less than 1000 hectares to more than 4500 hectares. The majority of the respondents’ farms were located in focus catchments (72 percent). Thirteen percent of farms were not located in a focus catchment, and 16% of respondents were not sure whether their farm was in a focus catchment. Only nine percent of respondents thought that their property was “considerably” threatened by salinity, but a further 66 percent thought it was “somewhat” threatened. Twenty two percent thought that their property was “not really” threatened by salinity and a further 3 percent thought their property was “not at all” threatened.

Eighty eight percent of respondents said that they had tried strategies on their farm to try to reduce the rise of groundwater levels, including all farmers (except one) who had indicated that salinity threatened their farm either “considerably” or “somewhat”. The majority of respondents had tried either planting of perennials (lucerne or trees) or surface water management by installation of shallow drains, or often a combination of these two strategies. Of those respondents who had tried strategies, 57 percent said they used their piezometers to assess the effect of these strategies on groundwater levels.

Forty three percent of farmers who completed the survey were over 50 years of age, and a further 34 percent were over 40 years of age. This translates into an enormous wealth of farming experience amongst the respondents with 59 percent having worked as a farmer for over 30 years. A further 38 percent had worked as a farmer for between 11 and 30 years. The majority of respondents (50 percent) had completed education to secondary level year 11/12, and a further 15 percent had TAFE or university qualifications. Twenty two percent of respondents indicated that they were “very active” members of a land conservation group and a further 59 percent said that they were “fairly active”. Only 3 percent of respondents indicated that they were “not involved at all” in a Land Conservation group, although 16 percent indicated that they were “not actively” involved.

3.3 Statistical results

A number of variables were defined for the purpose of the Probit analysis[2]. Our dichotomous Yes=1/No=0 dependent variable was defined as whether or not the bore was monitored in each quarter (February, May, August, November) for the years 1989 to 1998. The first reading for each bore was ignored in the analysis as it represents the ‘test’ reading done at installation rather than a decision by the farmer to monitor. We were aware that there could be a number of practical reasons why a bore might not be monitored. For example, the bore might be dry or have been damaged so that water level could not be read, but our data does not allow us to distinguish which, if any, bores are not monitored for such reasons. However, bores indicated as dry or damaged from the survey data (6 bores) were excluded from the analysis. Initially, no socioeconomic data was included in the statistical analysis, only technical data related to the bore readings and the bore location are included. The independent variables investigated are listed in Table 4.

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[2] All analyses were done in STATA 6 (StataCorp., 1999)

Table 4. Independent variables used in the initial Probit analyses (models 1 and 2)

Independent variable	**Description**	**Expected sign**
CATCHMENT#	Dummy variables to specify a particular catchment	?
AVGSALT	The salt concentration in the soil in kg/m3	Positive
SALTSTORE	The salt stored in the soil under each hectare of land in tonnes per hectare. [Ln(SS) is the natural log of this variable]	Positive
GWCOND	The groundwater conductivity measured in mS/m	Positive
DEPTH	The depth to bedrock	?
TIME (*)	The time in quarter-years from the first recorded reading	Negative
DUM93	Dummy variable =1 for dates after and including August 1992, 0 otherwise	Negative
GWLEVEL (*)	The distance to the groundwater (expressed as a positive number i.e the higher the reading the deeper the groundwater) at the last reading	Negative
GWCHANGE (*)	The change in groundwater level between the last two readings	Positive
SEASON# (*)	Dummy variables to allow for the quarter in which the reading occurred	?
MULTI	Total number of bores potentially monitored by farmer monitoring this bore	Positive
RAINFALL (*)	The rainfall for the quarter recorded at the Jerramungup Post Office	Positive

(*) Only these variables vary across time for each bore: SALTSTORE etc. relate to measurements made at the initial reading of the bore.

From casual inspection of the data, it is clear that the probability of reading a bore declines over time. This may be due, for example, to failure of the bore, a loss of interest in the project, or a perception that there is no further information of value to be gained from monitoring. Given the different dates at which bores were drilled, the measure of time elapsed is conditioned on the date of the first reading, which occurred when the bore was installed. However, we anticipated that increased severity of the problem (i.e. higher water tables and increased salt) would increase monitoring. The appropriate measurement of these variables was something explored within the analysis, by including levels and changes in distance to groundwater, and alternative definitions of salt load. One problem faced in the analysis was that once a bore is not monitored there is no information generated on water levels. We therefore define the measure of groundwater level as that at the most recent reading, and the change in water level as the most recent recorded change in water level, prior to the current quarter. We also explored the possible interaction between salt load and depth to water, on the expectation that high or rising water tables may not have so great an impact on monitoring response, if they have a low salt load.

Two results are statistically very robust across all specifications. Changes in water level are not associated with monitoring behaviour, while water levels are, and it is the total measure of salt storage which is the most significant variable, and not ground water conductivity or average salt concentrations. All of these variables were available to farmers at the start of the monitoring process. In theory, total salt storage will not be a good estimate of the potential salt problem, as it is partly a function of the distance to bedrock. Nevertheless, despite the three measures having correlation coefficients ranging from 0.5 to 0.8, it is salt storage which appears to be the variable which influences monitoring behaviour.

As a general modelling strategy, quadratic terms were included to allow for flexibility in the response function. Furthermore, the coefficients for GWLEVEL and $(\text{GWLEVEL})^2$ were allowed to vary as a function of (logged) salt storage. Both TIME and $(\text{TIME})^2$ are used, and a dummy variable (DUM93) was also included to identify if there was any change in monitoring after farmers received the first detailed information on their bores in 1992. Other significant variables were catchment and season dummies. Bores are less likely to be monitored in May and November, times which coincide with peak workloads on farms for sowing and harvesting.

The results from the final specification (model 1) are reported in Table 5. As noted, dF/dx reports the change in probability of monitoring following a unit change in the exogenous variable, or, in the case of dummy variables, a switch from 0-1. In each case, all other variables are at mean levels. This gives some indication of the relative importance of each variable. These measures are not reported for variables that have quadratic or interaction terms, as the individual marginal impact has no sensible interpretation in those cases.

As a result of the analysis we have to reject our second and third hypotheses, that changes in the water levels in bores would increase the probability that a bore would be monitored and that differences in the monitoring rates between catchments would be explained by the physical characteristics of the bore data. Change in water level was not significant in any specification used and there are still significant catchment effects, even allowing for the physical data available to us. Bores located in the Corackerup/Ongerup/Nawainup, Jacup and Carlawillup catchments are significantly more likely to be monitored than those in the baseline catchment, Gairdner/Bremer, even after allowing for measured physical differences.

Interpretation of the impacts of time, water level and salt storage is complicated by the non-linear and interaction terms included in the model. The effects are shown in Figures 2 and 3 for representative bores. To derive these figures, other variables have been held constant at values of TIME = first quarter (Figure 3), GWLEVEL = 6 metres (Figure 2), default SEASON 1 (Jan-Mar) and default CATCHMENT Gairdner/Bremer. Figure 2 gives the evolution of the probability of monitoring as time elapses, assuming the bore was first monitored in quarter 1 1989. This figure shows a relatively constant rate at the start (with the quadratic function giving a slight rise) but with the onset of a decline at around 9 quarters. The step in the function is the large negative impact of the 1993 dummy, representing the approximate time when detailed information on the bores and average district trends had been given to farmers, which is strongly significant. The probabilities then decline further with time.

Table 5 Results of the Probit analysis: full data set (model 1)

Number of observations = 3446
Wald $\chi^2(17) = 360.70$
Pseudo $R^2 = 0.1916$

Variable	Coeff	Std Err	z	P>│z│	dF/dx
CATCHMENT-NN	2.67E-01	3.19E-01	0.836	0.403	0.10
CATCHMENT-CON	7.44E-01	2.48E-01	2.997	0.003	0.27
CATCHMENT-FITZ	-3.01E-01	4.35E-01	-0.693	0.488	-0.12
CATCHMENT-JACUP	6.34E-01	1.87E-01	3.386	0.001	0.24
CATCHMENT-CW	4.79E-01	1.71E-01	2.809	0.005	0.18
CATCHMENT-JN	1.05E-01	2.31E-01	0.453	0.65	0.04
SEASON-Apr-June	-1.61E-01	5.19E-02	-3.099	0.002	-0.06
SEASON-July-Sept	-6.32E-03	5.51E-02	-0.115	0.909	-0.00
SEASON-Oct-Dec	-1.76E-01	5.04E-02	-3.498	0.000	-0.07
TIME	6.22E-02	1.82E-02	3.417	0.001	
$(\text{TIME})^2$	-2.64E-03	4.08E-04	-6.485	0.000	
DUM93	-7.59E-01	1.23E-01	-6.148	0.000	-0.28
GWLEVEL	-6.48E-01	2.34E-01	-2.773	0.006	
$(\text{GWLEVEL})^2$	3.44E-02	1.31E-02	2.618	0.009	
Ln(SS)*GWLEVEL	9.24E-02	3.11E-02	2.969	0.003	
$\text{Ln(SS)*(GWLEVEL)}^2$	-4.94E-03	1.70E-03	-2.9	0.004	
Ln(SALTSTORE)	-1.42E-01	1.10E-01	-1.291	0.197	
Constant	1.50E+00	8.02E-01	1.866	0.062	

Z is the ratio of coefficient to standard error, P the significance level. Standard errors corrected for clustering by bore. dF/dx is the change in probability of monitoring, for a discrete change of dummy variable from 0 to 1, or for a unit change in other variables, all other variables measured at their mean. Baseline CATCHMENT is Gairdner/Bremer, baseline SEASON is Jan-March.

Figure 3 gives the impact of water depth on monitoring, for 3 different levels of salt storage. Here the interaction between salt storage and the quadratic leads to distinct changes in behaviour. At higher levels of salt storage there is a confirmation of the hypothesis that if the water table is deep, the incentive to monitor is low. It also indicates a possible effect of very high water tables leading to reduced monitoring, as the problem becomes self-evident, or overwhelming. For a wide range of depths, higher salt load is associated with higher rates of monitoring. At lower salt loads the shape of the curve is inverted, but there is a tendency for low salt loads to be associated with lower probabilities of monitoring. At the tail of the distribution this is reversed, but it should be noted that there are relatively few bores that have actual observations in this range (e.g. there are no observations with salt levels less than 300 and depths to water exceeding 17m). The nature of the quadratic generates the result that all curves pass through the two fixed points, irrespective of load, and this may also be biasing the estimate of the response function. There may well be benefit in exploring more flexible specifications for the interaction.

Figure 2: Relationship between probability of monitoring and time, by salt storage (model 1)

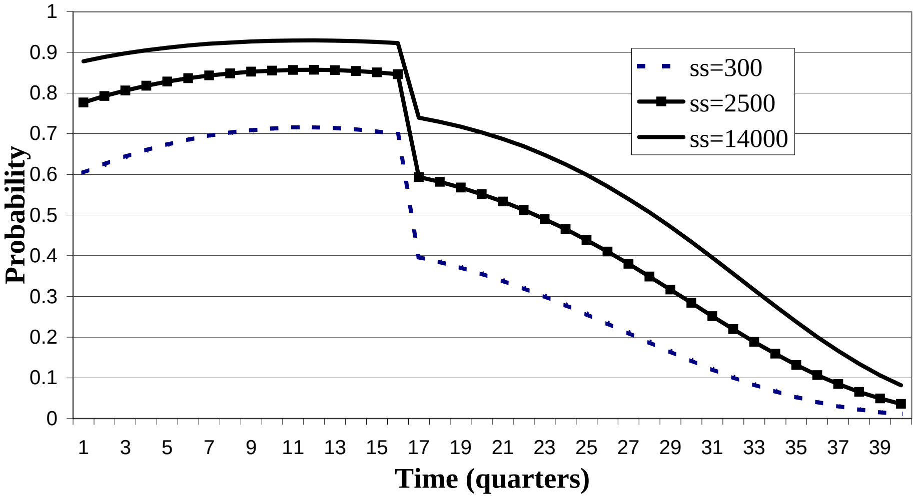
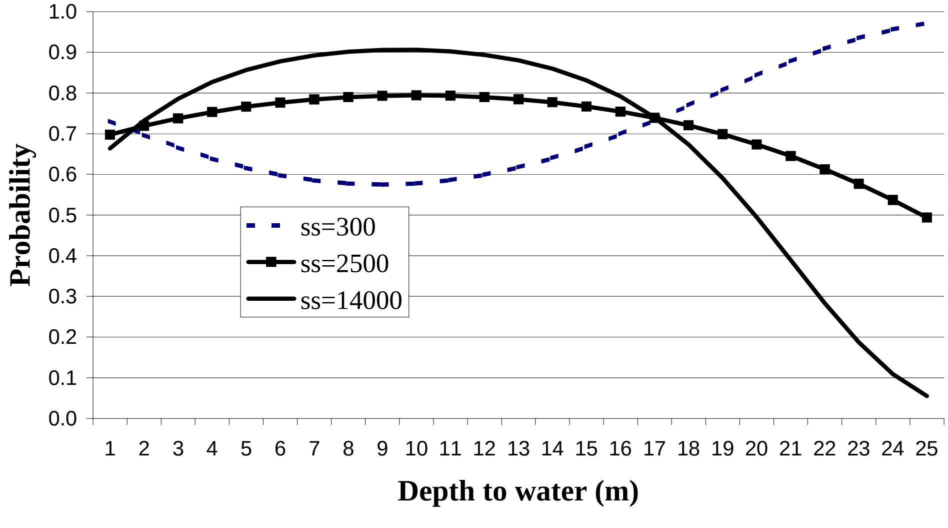


Figure 3: Relationship between probablity of monitoring and depth to water, by salt storage (model 1)



There are a number of additional limitations to the statistical approach employed here. Firstly, the standard probit model is based on an assumption that the error terms are independent, but in this case we have repeated observations on the same bores, so the assumption is questionable. We have allowed for that to some extent by estimating robust standard errors, which assumes that there may be some correlation between the residuals associated with observations on the same bore, but that there is independence of the residuals across bores (StataCorp., 1999). However, the overall results have been remarkably robust to other statistical specifications (such as a Random Effects Probit model, or explicitly modelling the structure of within-bore correlation of errors). An alternative approach that may also be fruitfully explored is to treat each year as an observation, and apply a count model to the number of times the bore is monitored in each year. This may overcome a problem of farmers selectively deciding to monitor at a low frequency each year, but continuing to monitor.

Overall, the physical data relating to the bore is an incomplete predictor of whether or not a bore will be monitored; the explanatory power is only approximately 19 percent using a pseudo R^2, defined as $1-L_1/L_0$, where L_1 and L_0 are the log likelihood values for the full and constant only models. The distribution of actual versus predicted monitoring of bores generated by the model (assuming a 50 percent cut point) is reported in Table 6.

Table 6. Predicted v. actual monitoring, full data set (model 1).

	Actual values	
	0	1
Predicted Values		
0	**1050**	438
1	523	**1435**

Although illustrative of how the model works, such a table, or estimates of the proportion of correct predictions, should not be used as a measure of the goodness of fit of the model (Veall and Zimmermann, 1996). Instead we report one of the "R^2" type measures, given by

$$\sigma_n = \frac{p_{11} + p_{22} - p_{\sim 1}^2 - p_{\sim 2}^2}{1 - p_{\sim 1}^2 - p_{\sim 2}^2} \tag{2}$$

where p_{ij} is the fraction of times the realisation was outcome i when the model predicted outcome j, and $p_{\sim j}$ is the fraction of times alternative j is predicted. σ_n is positive for a model with any predictive power, and bounded at the upper limit by unity. A value of 0.432 is calculated for the model presented in Table 5, which indicates a relatively high level of fit.

Our analysis has to some extent mechanistically modelled the process of the fall-off in bore monitoring, but it does not explain why people drop out or keep going. The TIME and '93 dummy variables do not give us any idea why the monitoring has stopped; they just describe how it does. The following analysis explores this issue further by incorporating the survey data with the physical data. One issue here is that we have only 32 responses from the original 81 farmers (accounting for 45 percent of the bores). As noted earlier, this is in part due to non-response to the second survey, but also because only a sub-set of farmers were contacted. In the circumstances it may seem to be appropriate to employ a selection model, to adjust for any selection bias. However, the resulting model is non-standard: there would be multiple observations for each individual 'selected' (although note that what is unobserved is a sub-set of the explanatory variables, rather than the independent variable as in the more conventional framework). Secondly, it was not possible to generate an adequate model for the selection decision.

However, what can be done is compare the estimated equation reported above for the two sub-sets of data. This analysis reveals that they are significantly different sub-populations (a Wald test value of 137.15, compared to a $\chi^2_{(18)}$ value of 28.87). Table 8 below reports the results for the sub-population who responded to the survey (model 2), using the same specification as before.

Table 7. Results of the Probit analysis: restricted data set (model 2)

Number of observations = 1508
Wald $\chi^2(17)$ =274.69
Pseudo R^2 = 0.1881

Variable	Coeff	Std Err	z	P>│z│	dF/dx
CATCHMENT-NN	7.19E-01	4.46E-01	1.613	0.107	0.22
CATCHMENT-CON	4.88E-01	4.44E-01	1.1	0.271	0.17
CATCHMENT-FITZ	6.61E-01	3.69E-01	1.795	0.073	0.20
CATCHMENT-JACUP	3.78E-01	3.96E-01	0.953	0.34	0.13
CATCHMENT-CW	5.96E-01	5.25E-01	1.136	0.256	0.16
CATCHMENT-JN	1.75E-01	4.09E-01	0.428	0.669	0.06
SEASON-Apr-June	-4.15E-02	9.00E-02	-0.461	0.645	-0.02
SEASON-July-Sept	-6.09E-02	8.97E-02	-0.679	0.497	-0.02
SEASON-Oct-Dec	-2.44E-01	8.60E-02	-2.831	0.005	-0.04
TIME	8.28E-02	3.03E-02	2.731	0.006	
$(\text{TIME})^2$	-3.02E-03	6.58E-04	-4.586	0.000	
DUM93	-8.70E-01	2.21E-01	-3.939	0.000	-0.28
GWLEVEL	-1.36E+00	4.40E-01	-3.094	0.002	
$(\text{GWLEVEL})^2$	6.38E-02	2.21E-02	2.892	0.004	
Ln(SS)*GWLEVEL	1.86E-01	5.72E-02	3.256	0.001	
Ln(SS)*$(\text{GWLEVEL})^2$	-8.78E-03	2.85E-03	-3.082	0.002	
Ln(SALTSTORE)	-4.08E-01	1.65E-01	-2.478	0.013	
constant	3.64E+00	1.26E+00	2.904	0.004	

Z is the ratio of coefficient to standard error, P the significance level. Standard errors corrected for clustering by bore. dF/dx is the change in probability of monitoring, for a discrete change of dummy variable from 0 to 1, or for a unit change in other variables, all other variables measured at their mean. Baseline CATCHMENT is Gairdner/Bremer, baseline SEASON is Jan-March.

Some of the parameter estimates for catchment and season variables have changed, while the time variables are quite robust. The greatest change appears to be among the water level and salt storage variables, with the parameters in Table 7 being approximately double those in Table 5. However, interpreting the impact on the probability of monitoring is difficult, given the interactions involved. Figures 4 and 5 are the equivalents to 2 and 3, and these reveal that the effects of these variables are similar across the two equations, and gives us some confidence that the basic structure of the model holds for the sub-population. Table 8 reports the actual and predicted values, with a value of $\sigma_n = 0.376$.

Figure 4: Relationship between probability of monitoring and time, by salt storage (model 2)

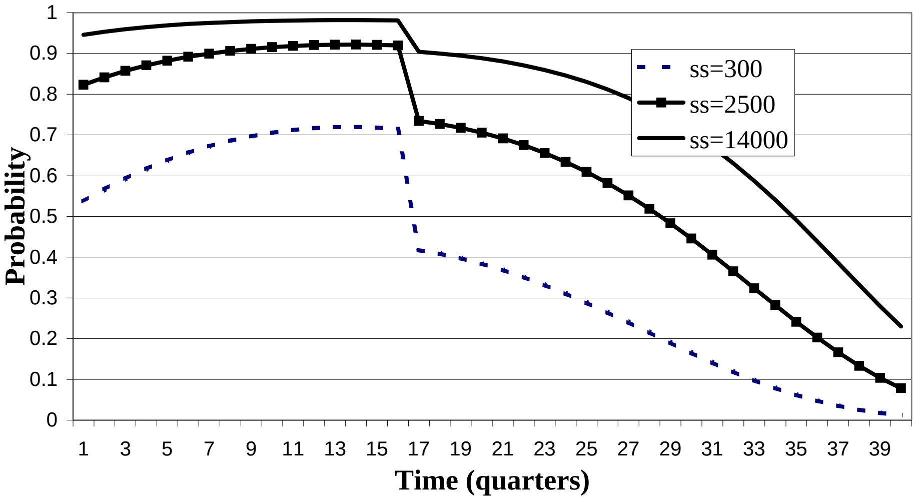


Figure 5: Relationship between probablity of monitoring and depth to water, by salt storage (model 2)

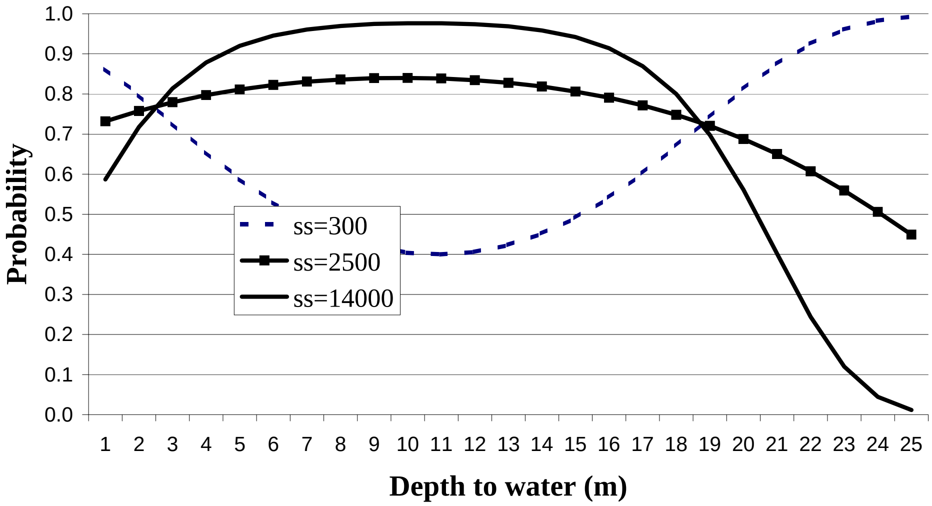


Table 8. Predicted v. actual monitoring, restricted data set (model 2)

	Actual values	
	0	1
Predicted values		
0	**302**	129
1	255	**822**

A further Probit analysis was conducted for the sub-sample who replied to the postal survey, using the additional explanatory variables generated from the survey. The additional variables are defined in Table 9. Results from the analysis (model 3) are given in Table 10. The results indicate that farmers with higher levels of education, older farmers, and farmers with smaller farms are less likely to monitor. Farmers who are more actively involved with a land conservation group, those who perceive that their properties are more at risk from salinity, and those who use groundwater monitoring to assess on-farm strategies to reduce groundwater rise are more likely to monitor. The total number of bores on the property, and whether or not the property was in a focus catchment, did not significantly affect the level of monitoring. These results confirm the rejection of our third hypothesis (that physical characteristics or whether the catchment was a designated focus catchment explain monitoring differences between catchments), and suggest that the hypotheses concerning the effect of perceived threat of salinity, involvement in landcare activities and the use of monitoring to assess management strategies can be accepted.

Table 9 Additional independent variables used in the restricted data-set Probit analysis

Independent variable	**Description**	**Expected sign**
FARM SIZE	The size of the farm in hectares	Positive
TOTAL BORES	The total number of piezometers on the property	Positive
ASSESS#	Dummy variable to specify whether bores were being used to assess management strategies	Positive
FOCUS#	Dummy variable to specify if farm is located in a focus catchment	Positive
AGE#	Dummy variable to specify the age group of the farmer	?
EDUCATION#	Dummy variable to specify the education level of the farmer	Positive
THREAT#	Dummy variable to specify the perceived threat posed to the property by salinity	Positive
L/CARE#	Dummy variable to specify the level of involvement by the farmer in a land conservation group	Positive

Table 10 Results of the Probit analysis: restricted data set (model 3)

Number of observations = 1508
Wald $\chi^2(17)$ =4398.19
Pseudo R^2 = 0.3127

Variable	**Coeff**	**Std Err**	**z**	**P>│z│**	**dF/dx**
CATCHMENT-NN	-4.81E-01	4.97E-01	-0.968	0.333	-0.18
CATCHMENT-CON	-6.39E-01	2.30E-01	-2.783	0.005	-0.24
CATCHMENT-FITZ	-1.01E+00	4.27E-01	-2.37	0.018	-0.39
CATCHMENT-JACUP	7.21E-01	2.40E-01	3.005	0.003	0.24
CATCHMENT-CW	2.04E+00	6.86E-01	2.975	0.003	0.34
CATCHMENT-JN	5.95E-01	2.90E-01	2.049	0.04	0.19
SEASON: Apr-June	-3.47E-02	1.07E-01	-0.324	0.746	-0.01
SEASON: July-Sept	-4.24E-02	1.05E-01	-0.406	0.685	-0.02
SEASON: Oct-Dec	-2.45E-01	1.03E-01	-2.387	0.017	-0.09
TIME	1.11E-01	3.39E-02	3.275	0.001	
$(TIME)^2$	-3.92E-03	7.26E-04	-5.399	0.000	
DUM93	-9.91E-01	2.54E-01	-3.894	0.000	-0.30
GWLEVEL	-8.53E-01	2.85E-01	-2.995	0.003	
$(GWLEVEL)^2$	3.42E-02	1.69E-02	2.02	0.043	
Ln(SS)*GWLEVEL	1.14E-01	3.56E-02	3.19	0.001	
$Ln(SS)*(GWLEVEL)^2$	-4.67E-03	2.15E-03	-2.166	0.03	
Ln(SALTSTORE)	-1.14E-01	8.82E-02	-1.289	0.197	
FARM SIZE	2.35E-02	7.87E-03	2.988	0.003	0.01
EDUCATION: yr 11/12	-9.92E-01	2.67E-01	-3.71	0.000	-0.35
EDUCATION: tertiary	-2.33E+00	4.06E-01	-5.743	0.000	-0.73
ASSESS: “no”	-5.07E-01	1.62E-01	-3.139	0.002	-0.19
ASSESS: “unsure”	-7.33E-01	3.06E-01	-2.398	0.016	-0.28
ASSESS: “no answer”	2.52E-01	3.09E-01	0.816	0.414	0.09
THREAT: “some”	-1.14E+00	4.35E-01	-2.618	0.009	-0.36
THREAT: “not much”	-6.01E-01	3.38E-01	-1.78	0.075	-0.23
THREAT: “none”	3.45E-01	4.73E-01	0.73	0.466	0.11
L/CARE: “fairly active”	-1.58E+00	3.83E-01	-4.126	0.000	-0.52
L/CARE: “not active”	-2.15E+00	3.91E-01	-5.495	0.000	-0.71
AGE: 31-40 yrs	-1.61E+00	5.71E-01	-2.821	0.005	-0.58
AGE: 41-50 yrs	-1.24E+00	4.95E-01	-2.501	0.012	-0.46
AGE: 51-60 yrs	-2.16E+00	4.95E-01	-4.373	0.000	-0.69
AGE: >60 yrs	-1.91E+00	7.04E-01	-2.709	0.007	-0.63
Constant	5.91E+00	1.05E+00	5.607	0.000	

Z is the ratio of coefficient to standard error, P the significance level. Standard errors corrected for clustering by bore. dF/dx is the change in probability of monitoring, for a discrete change of dummy variable from 0 to 1, or for a unit change in other variables, all other variables measured at their mean. Baseline CATCHMENT is Gairdner/Bremer, baseline SEASON is Jan-March, baseline EDUCATION is year 9/10, baseline ASSESS is “yes”, baseline THREAT is “considerable”, baseline L/CARE is “very active”, baseline AGE is younger than 30.

Although, as before, there have been changes to some of the catchment variables and changes to the values (but not the signs) of the parameters, the basic structure of the relationship between depth to water, salt store and monitoring is consistent with earlier models (Figures 6 and 7).

Figure 6: Relationship between probability of monitoring and time, by salt storage (model 3)

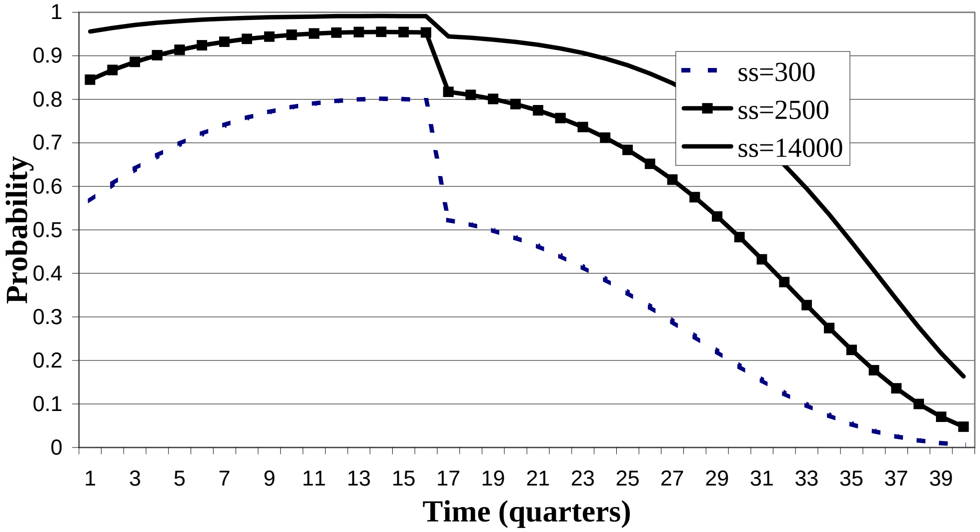
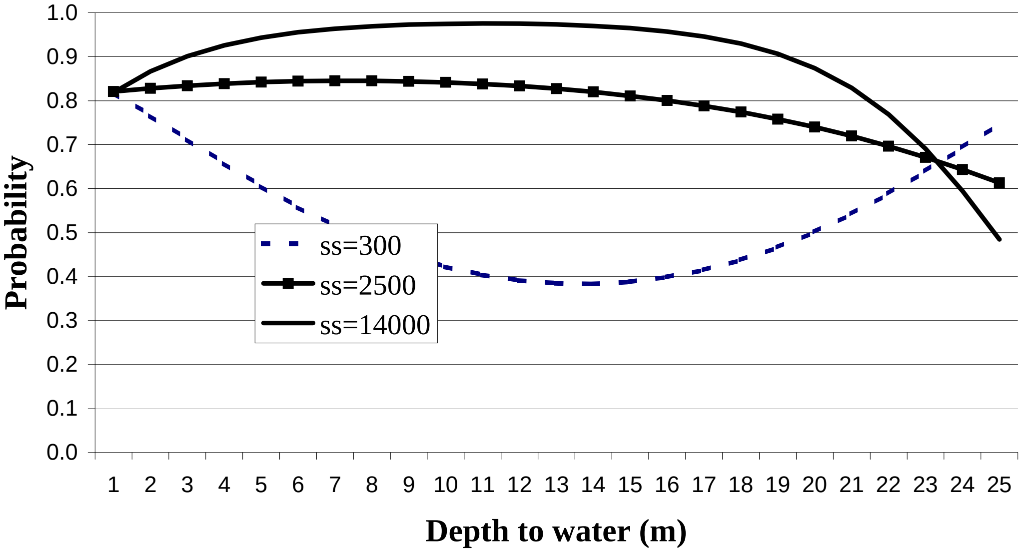


Figure 7: Relationship between probablity of monitoring and depth to water, by salt storage (model 3)



To generate these figures variables for TIME and GWLEVEL have been held constant at values as before. Other variables are included at levels which are most representative of the sample.: EDUCATION at year 11/12, THREAT at “some”, ASSESS at “yes”, AGE at 41-50 years and L/CARE at “fairly active”.

Table 11 reports the actual and predicted values, and reveals a substantial improvement in fit as compared to the previous model without the attitudinal and socio-economic variables: a value of $\sigma_n = 0.550$ is calculated.

Table 11. Predicted v. actual monitoring, restricted data set (model 3)

	Actual values	
	0	1
Predicted values		
0	**380**	125
1	177	**826**

4 Discussion

4.1 What is the value of monitoring groundwater levels?

For individuals the first value in monitoring lies in a greater awareness of the salinity threat and how it relates to their land and the district - *“they believe the data if they measure it”*. The monitoring carried out by farmers in the Jerramungup LCD, combined with the feedback and interpretation that was provided by AGWEST, allowed farmers to quickly become aware of the threat posed to the district by rising saline groundwater. The second value clearly evident is that groundwater monitoring can result in a substantial degree of learning, both of hydrological processes and also learning that can lead to monitoring being perceived as a useful management tool (see Marsh *et al.*, 1999). Monitoring can be used as a management tool in two different ways:

a) to assess the effect of a particular management treatment, and
b) as a indicator of when a particular management tool (e.g. lucerne phase of a rotation) needed to be implemented (i.e. as a tool to know when to act).

Seventy seven percent of the survey respondents said that their main reason for monitoring was that “they were interested themselves in the data and trends from the groundwater readings”. This result was supported by the relatively high percentage of respondents indicating that continued monitoring provided information of value (see Table 3). This was a surprising result to the authors who had expected that farmers would indicate that the information from the initial groundwater reading would be more valuable than information from continued monitoring, in line with the arguments concerning the economic value of information advanced by Pannell and Glenn (2000). However, a considerable number of the survey respondents said they were using data from their groundwater monitoring to assess management strategies that they had implemented. This suggests that, in this area and for this issue at least, some farmers have made a move from perceiving monitoring only as an awareness tool to perceiving groundwater monitoring as useful for ongoing evaluation of their farming system.

For catchments, groundwater monitoring has the potential to create a district awareness that is necessary to gather local support for district initiatives to obtain funding and support to address salinity issues. Once that funding has been obtained, continued monitoring serves a number of purposes. It provides information to funding bodies and government agencies that addresses accountability requirements, such as data that plots district trends, records the response to different management options, and contributes hydrological information to large scale projects. Further to this it helps in ‘creating an impression’ of awareness and willingness-to-act that attracts both outside expertise and further funds for a range of Landcare and production purposes. Thirteen percent of the survey respondents indicated that their main reason for monitoring was to provide “data that is needed for community and regional hydrology purposes”.

4.2 Why do farmers continue to monitor groundwater levels?

That bores with higher water levels and higher salt storage readings have a higher probability of being monitored indicates that farmers continue to monitor groundwater levels because they are concerned. This is further supported by our results from the analysis including socio-economic data which indicates that farmers who perceive that their property is more threatened by salinity will monitor more frequently. Interestingly, despite a positive correlation between salt storage (dependent on the depth to bedrock and expressed in tonnes per hectare) and both ground water conductivity and average salt storage (standardised for depth and expressed in kilograms per cubic metre), neither of the latter variables were significant if substituted for salt storage in the regression. We suggest that the high figures quoted for salt storage may have a powerful influence on a farmer’s perception of the potential salinity threat.

Discussions with farmers prior to surveying suggested that the most powerful reason to continue monitoring is if the monitoring is linked to management options, such as lucerne or surface water management. The results from our analysis support this: farmers who are using monitoring to assess management strategies they have implemented in an effort to reduce groundwater rise are significantly more likely to monitor. Associated with this is a desire in some cases to “prove a point”, especially if it is against conventional wisdom or the law. There are farmers who wish to clear further areas of their land (an action currently prevented by law) and who are anxious to demonstrate that tagasaste, lucerne or other perennial alternatives will substitute hydrologically for native vegetation.

Farmers also continue to monitor bores out of habit and/or a feeling of responsibility. Many have a genuine interest in the figures and are keen to discuss them with hydrologists and other professionals. Continued monitoring often provides links to expertise and individuals who wish to use the data for research reasons. Finally, there are peer and social reasons which influence farmers’ monitoring behaviour. Our analysis suggests that farmers who are more actively involved in land conservation activities monitor more frequently, as do younger and less educated farmers. The latter result, although surprising, might be linked to the inherent difficulties associated with using an indicator such as groundwater level, which is affected by many factors (e.g. rainfall), to assess the effect of different farming systems on groundwater levels (Pannell, 1999b). More educated farmers might be more inclined to question whether the monitoring is actually providing interpretable information about the effect of the farming system on groundwater level.

4.3 Why do some farmers fail to monitor groundwater levels?

There are a range of practical reasons why individual bores are not monitored (see Marsh *et al.*, 1999). Given that, our analysis indicates that bores in situations where the salinity threat is less serious (i.e. lower water levels, lower salt storage in the soil) are monitored less frequently, and also that farmers who perceive salinity as less of a threat on their property monitor less frequently.

Groundwater monitoring does appear to be a powerful awareness tool, but some farmers discontinue monitoring even though they have a rising saline water table. Pannell (1999a) suggests that the usefulness of information is related to its ability to reduce uncertainty. There are two possibilities in this situation. Firstly, uncertainty about the situation may be quickly reduced following a small number of readings of groundwater levels. Secondly, uncertainty about the relationship between groundwater levels and on-farm strategies may not be reduced by monitoring; that is, the information is not useful to farmers in a tactical sense. In that case there is little point (for farmers) in monitoring after initial awareness needs are met. The survey results, however, suggest that a considerable number of respondents do perceive groundwater monitoring as being tactically useful.

With regard to the first of these possibilities, awareness that groundwater was saline and rising was achieved within three to four years of the commencement of the project. It might then be perceived that there is no further need to monitor, or that monitoring may only need to be done infrequently (e.g. not quarterly or even yearly). Indeed, some survey respondents suggested readings less frequently than quarterly were sufficient This awareness may be the reason for the rapid fall-off in monitoring after 1992, and the significance of the 1993 dummy variable in the probit analysis. AGWEST personnel commented that farmers seem less interested now in feedback (e.g. of groundwater trends) than earlier in the project. Some survey respondents, however, commented that they wanted more feedback, e.g. *"(I) would be interested to see graph of results since 1989/90 perhaps"*.

Associated with the awareness of results from initial monitoring, there appears to be psychological reasons that dissuade some farmers from further monitoring (see Marsh *et al.*, 1999). There is a limit to how much "continual bad news" people can take, especially if they feel disempowered and unable to act to solve the problem. Even if alternative farming systems exist, the stress, learning and risk associated with changing farm practices can be substantial (Marsh, 1998; Pannell, 1999a).

Alternatively, the significance of the 1993 dummy variable could be related to farmer concerns about public release of information they considered to be sensitive. The survey asked farmers if they monitored but did not pass information on to the LCD coordinator, but perhaps not surprisingly no respondents replied that they did this. However, over 50 percent of respondents said that regional data from groundwater monitoring done by farmers should be publicly available "only in certain circumstances". We have no conclusive evidence that the public release of regional-level data affected bore monitoring in the Jerramungup LCD but suggest that the ownership of regional data that comes from farmer-bore monitoring is a key issue to address. Regional hydrological information has potential to be both commercially and socially sensitive. Ownership of data and conditions for its release have already been raised as issues in other catchments in WA (George, Agriculture Western Australia, pers.comm. 1999). Kenny (1998) suggests that permission should be sought for data to be disclosed, and our survey data indicates that over 50 percent of respondents would agree with this.

Finally, there are undoubtedly peer or social reasons that influence farmers' bore monitoring behaviour. We have not investigated this in any real depth, but our analysis has indicated some of the factors that could conceivably play a part. Additionally, there are social differences between the catchments that we have not attempted to explore in our analysis. For example, areas within the district were settled at different times, resulting in different social groups (see Marsh *et al.*, 1999).

Many piezometers are still being installed throughout agricultural areas with awareness issues and regional hydrology being perceived as providing the motivation for long-term farmer monitoring. It is important to consider exactly to whom the information is useful (Pannell and Glenn, 2000; Kenny, 1998)). It may be that the long-term monitoring of many bores situated on private land is of more interest to regional hydrologists than to individual farmers. If this is the case, then issues related to responsibility for continued monitoring need to be addressed.

5 Conclusions

The Jerramungup LCD has been recognised for their Landcare efforts, winning the National Landcare Award for Landcare groups in 1991. Despite the focus of this paper on reasons for failure to monitor, a very high level of bore monitoring has been achieved in the Jerramungup LCD. Key reasons for the success of the Jerramungup program have been the high degree of community ownership and involvement with the project since its inception, the commitment of AGWEST to providing support and feedback to the project, and the co-ordinating and motivating role played by the LCD coordinator.

Our analysis shows that the physical characteristics of bores (reflecting economic incentives for monitoring) do influence the frequency of monitoring. The key physical measures include groundwater level and salt storage, and the interaction between water level and salt storage is also significant. This makes intuitive sense as it is rising water levels in soils with high levels of salt that poses the most serious salinity threat.

Our analysis also indicates that farmers who are using monitoring to assess management strategies monitor more frequently. There is a clear economic incentive for monitoring when it is linked to the assessment of management strategies. Strong and clear links to management options mean that continued monitoring makes sense to farmers, as suggested by Pannell and Glenn (2000) and Kenny (1998). Farmers in the Jerramungup LCD who spoke enthusiastically about the value of continued monitoring were evaluating farming systems options such as lucerne, perennial grasses and surface water management. There is both a need and an opportunity to involve farmers in R&D related to the implementation of high water use systems on farms and linking this work with groundwater monitoring.

Social and psychological factors also appear to be important influences on monitoring behaviour. In particular, education level and involvement with land conservation groups significantly affected monitoring frequency. Additionally, farm size, age, and perception of the threat posed by salinity all influenced the probability of monitoring. These variables are, in a sense, social factors, but we believe that their effects on monitoring behaviour are most readily explicable in terms of their influence on the economic incentives for monitoring that farmers face.

Overall, the study provides strong empirical support for the view that economic incentives provide the main impetus for monitoring of groundwaters in this region, and that differences in monitoring behaviour can be well explained by actual or perceived differences in economic incentives. In addition, however, the study confirms that social factors, such as feelings of social responsibility and membership of land conservation groups, do also play a role.

The results have clear implications for efforts to promote monitoring by farmers of environmental indicators in general. When considering which types of indicators should be promoted, the indicators most likely to be successful will be those perceived by farmers to be practically relevant to their farm management. When considering which groups of farmers should be targeted, joint criteria are appropriate: farmers for whom monitoring is most likely to be economically beneficial, and farmers who are involved in land conservation groups. Pannell and Glenn (2000) provide considerable detail on the circumstances under which monitoring is most likely to be economically beneficial.

6 Acknowledgements

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