Chapter 5 Discussion and Conclusion

5.1 Introduction

Detecting environmental impacts in natural systems is challenging. This is widely acknowledged within the environmental impact assessment literature (e.g. Conquest 2000; Smith 2002; Stewart-Oaten *et al.* 1986). Detecting impacts in agricultural systems is harder still. Not only are the natural trends and variations embedded within the data, the data also reflect the management actions designed to produce a consistent yield and product. Sometimes these actions work in concert with natural cycles and variations, and sometimes they are designed to compensate for them.

Determining whether it is a management action or the natural cycle that is reflected with the structure of the data is difficult. Within this study, this has been apparent when considering both the on-ground EM38 and the satellite NDVI data. Whilst both the apparent conductivity and NDVI observations for vineyard A appear to have coincided with natural, climatic variations, these same observations for the 'control' block have not and the observations for vineyard B have been mixed in this regard. In the case of the 'control' block, this is suggestive of either management intervention or topographical factors (slope and hydrological considerations) although this is speculative. Regardless, these differences have implications for assessing the potential environmental impacts associated with longwall mining subsidence.

This chapter briefly reviews the broader issues and shortcomings highlighted throughout this thesis. It commences by reviewing the overall analysis with respect to the questions and hypotheses that were posited in Chapters 1 and 2 and it situates the results within the broader literature presented in Chapter 2. In doing so, this section further highlights limitations of the data and analysis. The next section explores some of the particular issues with the study design, the difficulties with applying standard BACI analysis to the data are discussed, and the implications this has on statistical modelling are noted. The chapter concludes with a brief discussion of recommendations as well as elucidating the contributions of this thesis to issues of monitoring above ground impacts of subsidence on agricultural productivity.

5.2 Review of Posited Hypotheses

In Chapter 1, questions into the nature of longwall mining impacts on viticultural productivity were posed. Does LMS impact upon viticultural productivity, vine yield in particular? If so, how, and what is the nature of LMS impacts? To address these questions, Chapter 2 suggested two null hypotheses that would be addressed by this study. These were:

- Longwall mining induced subsidence affects viticultural production in a localized, site specific manner; and

- Longwall mining induced subsidence has no significant (e.g. not moderate/severe) effect on viticultural production (vine yield).

Although there are still no reported cases in the literature purporting to examine LMS impacts on viticulture, these questions were formulated in response to the broader case-study literature where potential LMS impacts upon agriculture in general had been explored. How are the results from this study situated within this broader literature?

On the balance of evidence presented, it is clear that the hypotheses posited above cannot be rejected. That is to say, none of the evidence examined for this study suggests that for the vineyards in question longwall mining has had a systematic and significant impact. If there were evidence of such impacts it would have been expected that some, or all, of the following would have been observed:

- At the panel level, for each zone there would have been clear evidence of substantial differences in vine yields that coincided with the timing of mining. That is to say, the yields of the chain pillars would have been consistent both pre- and post-mining, whilst the transition and longwall zones would exhibited substantially lower (or higher, if effects were not negative) yield in the post-mining period. No such clear and substantial differences were observed.

- At the block level, for each zone there would have been clear evidence of substantial differences in apparent electrical conductivity that also coincided with the timing of mining. Furthermore, post-mining comparisons with the apparent electrical conductivity of the subsided blocks with the ‘control’ block would have shown consistent trends across the entire post-mining period. No such trends were observed. Quite simply, there were no consistent trends within the apparent electrical conductivity that suggest a zonal response to mining. Whilst an aggregated (e.g. averaged across the whole post-mining period) comparison of the pre- and post-mining apparent conductivity of the subsided blocks with the ‘control’ block suggested the possibility of an impact, this was directly influenced by the sharp increase in the control block’s apparent electrical conductivity towards the end of the study, and not a decrease within the subsided blocks as would have been the case if mining had impacted upon apparent electrical conductivity within the subsided blocks.

- At the vineyard scale, for each block that had been undermined, clear differences in NDVI for each of the various zones within each and every post-mining image would have been clearly evident. That is to say, starting with the image acquired in November 2005, the zones within subsided blocks would have exhibited substantially different NDVI values with respect to the other zones within that same block. These differences would then have persisted and be evident within the images captured in November 2006 and October 2007. Additionally, as these zonal differences would have ‘emerged’ within blocks that had subsequently been undermined. Such clear, significant and systematic differences were not evident within the post-mining images. Furthermore, the block-by-block comparisons of NDVI values during the *Before*, *During* and *After* mining time periods did not exhibit trends consistent with systematic and significant impacts across all subsided blocks.

Hence, on the basis of the weight of evidence presented, it is not possible to reject either of the posited null hypotheses. The findings of this study would then appear to support the assertion of Hinchilffe (2003), who suggested that where longwall mining did impact upon agricultural productivity, the effects were likely to be highly localized and site specific. Within the vineyards of the study area, some localized impacts were reported and there was evidence of cracks emerging in conjunction with the timing of mining (Figure 5.1). However, the random nature of these cracks and their emergence in areas that were monitored by panel sampling precludes any comments on the nature and magnitude of impacts that might have been associated with them.

From the literature, agricultural impacts associated with LMS have almost always been associated with an increase in surface water retention (e.g. ‘ponding’). This phenomenon has been reported by Darmody *et at* (1988, 1989), Hu *et al.* (1995) and Bell *et al.* (2000). Thus far, ponding has not emerged as an issue within the study area. Furthermore, the apparent electrical conductivity measurements collected to date have not suggested a consistent increase in water accumulation and retention within any of the subsided areas. Again, this suggests that in the absence of systematic ponding, any potential impacts on viticulture, such as reduced yield, associated with LMS are again likely to be localized.

Figure 5.1. Evidence of localized cracking within vineyards. Random cracking appeared in some areas near the chain pillars. Note the ballpoint pen used to indicate scale (145mm).

It should be noted however, that a failure to reject the null hypotheses does not preclude the possibility that mining has negatively impacted upon the productivity of vineyards within the study area. Whilst there was no evidence of systematic differences between the various topographic zones that form in response to longwall mining, there may nonetheless be a subtler, more global response to mining on subsided blocks. In spite of the fact that the areas above the chain pillars were initially envisioned as ‘unsubsided controls’ for the other zones, they are in fact subjected to minor subsidence (see Section 5.3).

However, if such subtle, global effects were present they would be difficult to detect with the data collected for this study. While the averaged panel data suggests that the data are heavily impacted by climate, it must be acknowledged that other data were collected at a fine enough scale that could be used to account for the observed behaviours of individual vines (e.g. vine sap flow, *in vivo* sugar phloem uploading, individual vine soil moisture). Without such data, it is impossible to account the observed behaviour of individual vines.

The QuickBird imagery could possibly be used to detect subtler effects, if they exist. Although the NDVI ratio is resistant to many forms of atmospheric noise, it is not resistant to all forms of said noise; additive effects associate with atmospheric path radiance (Huete *et al.*, 2002) could be responsible for the inter-image variability of NDVI values observed within the vineyards during the study. Although intra-image comparisons of vineyard blocks and zones (where effects of atmospheric path radiance are generally uniform across a given image) did not suggest systematic impacts associated with LMS, atmospherically corrected images might highlight a ‘global’ trend, as noted above. However, like the panel data, without additional measurements at the vine scale such data and ensuing analysis are likely to be confounded by vineyard micro-climatic variability.

It should also be noted that the method used to assign vines, apparent electrical conductivity and NDVI values into their associated zones may not be accurate within some areas of the vineyards. As previously noted, the zones were delineated from data collected along the subsidence monitoring transects indicated by the blue lines in Figure 3.2. It is important to note that the accuracy of these zones is likely to decrease with increased distance from these transects. That is to say, that accuracy of the zones decreased the further away one moves from these monitoring transects. As such, the results and analysis presented herein could have been skewed by such errors. However, given that the results using actual changes in elevations (from the pre- and post-mining DEMs) did not produce a significantly different result suggests that the method for delineating zones was, in fact, reasonably accurate.

5.3 Study Design Considerations

The results of this work highlight a number of potential limitations associated with the design of the environmental monitoring program. The first is with respect to the suggested use the chain pillar zones to act as un-subsided controls for subsided vines. As noted in the earlier review of subsidence mechanics (section 2.2.1), the subsidence associated with angle of draw means the areas above the chain pillars will be subjected to subsidence. According to the subsidence predictions of Waddington and Kay (2003) these zones will subside anywhere from 10 – 20 cm. Although it is unclear whether or not even this minimal subsidence can impede vine root function, clearly the areas of the chain pillars cannot be considered to areas of ‘no subsidence.’ As such, future studies examining the environmental impacts of LMS should use control blocks as reference zones.

Whilst it is true that impaired root function will lead to reduced growth and thereby eventually causing mean pruned cane mass to decrease, climatic conditions (e.g.

drought) can also significantly affect water and nutrient uptake. Several years of prolonged drought, like those most of Australia has experienced during the entirety of the study period, could also lead to a decline in average pruned cane mass. Even in the best circumstances it can be very difficult to differentiate anthropogenic environmental impacts from other natural, environmental trends and thereby attributing causality to the impact activity (Conquest 2000).

The results of this work demonstrate the need to commit to long-term monitoring, not only after a longwall mining event but also before the mining event. This will help to reduce the impact of climatic variability on the response data. The unfortunate reality is that, in this region, and particularly for the season's monitored, the three-year 'before mining' period and the three year 'after mining' period simply may not have been enough to elucidate any impact response over and above the noise of climate variability. Whilst it could be argued that the data at least can provide an upper limit to the potential magnitude of the response (i.e. limited to within the range of responses associated with climatic variability), it nonetheless begs the obvious question - just how long monitoring should be conducted? Clearly, there is no easy answer to this question.

5.4 BACI Designs

Although one of the recommendations for improving the study design was to use control blocks as the reference for 'no impact', it should be clear from the results and analysis presented here that this poses difficulties. As was particularly evident within the EM38 results and analysis, the behaviour of a single control block can sometimes skew BACI comparisons, suggesting that an environmental impact has occurred as a result of the human activity in question. Employing more than one control site could potentially prevent this from happening. Ideally, every impact block or paddock should have its own non-impacted control that has similar vines and spans similar topography to that of the undermined block. Clearly, these are challenging constraints from a viticultural perspective.

However without a one-to-one pairing between impact and control sites, statistical relationships between *Before* and *After* time periods are skewed. As noted in Section 4.3.2, no BACI statistical comparisons were undertaken to preclude this from happening. Whilst a series of paired t-tests between the control and impact blocks could have been undertaken, the statistical significance of such paired tests would have been overstated; most statistics texts are quite explicit in this regard (e.g. Byrkit *et al.* 1987). They make it abundantly clear that in such cases, the analysis of variance (ANOVA) statistical technique should be employed. However, for longwall mining operations, the progression of mining presents difficulties for ANOVA techniques, as discussed below.

5.5 Statistics of Repeated Measures

One of the problems with the ANOVA technique is that it requires an orthogonal set of comparisons to be accurate. BACI designs exploit this, because in general the date of the environmental impact, or treatment, is presumed to be known (Smith 2002; Stewart-Oaten *et al.* 1986). This fixed date is then used to ‘partition’ the data into periods corresponding with *Before* and *After* impact. Statistically significant differences between the magnitudes of these *Before-After* differences are then generally attributed as being indicative of an environmental impact.

However, with longwall mining it is generally not possible to account for mining progression in such a manner. As the mining progression figures presented herein (Figures 3.5 and 3.6) demonstrate, the assignment of a particular mining status (either *Before*, *During* or *After*) is dependent on the location of mining activity on the date of the survey in question. That is, in general there is no singular date that can be used to neatly partition longwall mining data into the variable for modelling. Whilst such partitioning may occasionally neatly separate any given pair of blocks (as was the case with yield surveys for blocks A4 and B22), in general this is not the case (as exemplified by the pruning weight, EM38 and QuickBird surveys for these same blocks).

This points to another, broader and potentially more intractable problem. BACI type analyses are related to statistical methods of ‘repeated measures’, they rely both upon a balanced study design and the fact that the same subjects (impact and control sites/blocks in this case) are repeatedly observed through time, both before and after the application of treatments (impacts). Violations of these conditions present problems for these types of methods. However, many of the surveying techniques employed in precision agriculture and viticulture do not meet these basic assumptions. Whilst particular blocks or paddocks (e.g. populations) may be the subjects of a particular study, the individual points and spatial locations (e.g. individuals) actually surveyed generally vary from survey to survey. ‘Repeated measures’ statistical techniques rely upon this sampling of the same individuals through time to detect statistically significant differences associated with particular treatments. As such, it is unclear how to adapt precision agriculture and viticulture techniques to account for this variation.

In the viticulture case, one alternative would be to simply sample every vine row. Thus, all vine row averages could then be treated as individuals and analysed across years. Alternately, the capabilities of the GPS can also be exploited, whereby a particular ‘sampling path’ is programmed into the device and followed every year.

This would ensure the same rows are surveyed from year to year, thus allowing for the appropriate statistical comparisons through time.

5.6 Recommendations and Summary

The reasonable correspondence between the modelling results for the *Zone* models and those of *Elevation* model were encouraging. Whilst an approach based on actual elevation differences is be preferred, the collection of such accurate and detailed topographic measurements pre- and post-mining can be expensive. Despite this expense, these methods allow for greater understanding of the topographic changes induced by LMS in areas generally not monitored by standard, on-ground surveying methods. Where the cost is prohibitive, methods based on mining zone can also be employed with reasonable certainty, though it would be useful to quantify how the accuracy of various zones declines as one moves away from surveyed monitoring transects. If required, additional subsidence observations could be obtained to minimise these errors across the various zones across the longwall panel.

Overall, the study also demonstrated the potential of precision viticulture tools to monitor responses at the block level. Whilst the average apparent soil conductivity across all the study blocks exhibited varying relationships with recent rainfall events, there may be reasons why this was so (e.g., different vineyard management approaches). Accounting for such differences would allow for the analytical partitioning of blocks into similar categorical groups, and thereby better account for the variability inherent in the data.

The relationship between block average NDVI values and two-monthly rainfall totals was similarly encouraging. As a measure of the amount of photosynthetically active biomass, the linear relationship implied between NDVI and rainfall is sensible, and intuitive; plant growth would be expected to follow rainfall trends within a growing season. Although not presented, there was a small, negative linear relationship between the average NDVI value and average block yield for both A4 and B22 (R^2 = 0.170). With further study, it might be possible to explain more of the sub-block variability evident with both the EM38 and satellite remote sensed data. Being able to account for these sub-block sources of variability would signify an even greater ability to monitor for potential mining induced impacts at a finer scale. As such, attention could be devoted to the time consuming process of atmospheric correction of QuickBird imagery. This would allow for better monitoring long-term changes in the NDVI of vineyard blocks through time.

In spite of these limitations, both the environmental monitoring and the analytical work presented in this thesis are important in that, prior to this work commencing, the literature contained very few studies that quantitatively examined the systematic impacts of longwall mining on agriculture. For viticulture there were none. The apparent lack of systematic impacts associated with the longwall mining of a single coal seam under these specific vineyards is obviously important in the context of the vineyards in question. In a general sense the results also serve to reinforce the original assertions of Hinchliffe (2003) related to the site-specific, localized nature of agricultural impacts associated with longwall mining

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Appendix A Rectification Processing

Table A.1. QuickBird image rectification accuracy for images captured from 26-10-2003 to 22-01-2006.

										Residuals					
		Sensor View Angle					RMS Errors			X			Y		
Date	Image Type	In Track	Across Track	Off Nadir	Point Type	Count	Mean	Range	Stdev	Mean	Max	Min	Mean	Max	Min
26-10-2003	Pan	0.2	-1.6	1.6	Control	23	.587	.834	.236	.000	.949	-.869	.000	.738	-.454
					Check	23	.479	.678	.228	.077	.647	-.772	-.063	.718	-.800
	MultiSpec	0.2	-1.6	1.6	Control	23	.147	.208	0.59	.000	.237	-.217	.000	.185	-.133
					Check	23	.129	.238	.065	.025	.205	-.193	-.007	.195	-.200
06-01-2004	Pan	2.3	-4.1	4.7	Control	22	.583	.765	.193	.000	.678	-.690	.000	.798	-.618
					Check	21	.644	.863	.218	.140	.919	-.558	.056	.709	.056
	MultiSpec	2.1	-4.1	4.7	Control	22	.146	.191	.048	.000	.170	-.172	.000	.200	-.154
					Check	21	.161	.209	.055	.035	.230	-.139	.014	.177	-.267
03-11-2004	Pan	12.5	-5.5	18.3	Control	22	.515	.811	.268	.000	.701	-.731	.000	.632	-.852
					Check	22	.656	.751	.191	-.224	.832	-.873	.009	.637	-.904
	MultiSpec	12.3	-5.5	18.3	Control	22	.124	.206	.064	.000	.181	-.187	.000	0.159	-.193
					Check	22	.171	.181	.051	-.057	.216	-.217	.005	.169	-.260
04-03-2005	Pan	-2.3	1.0	2.5	Control	22	.495	.835	.240	.000	.578	-.763	.000	.625	-.933
					Check	21	.541	.722	.237	.022	.774	-.802	-.122	.533	-.851
	MultiSpec	-2.5	1.0	2.5	Control	22	.129	.243	.062	.000	.143	-.197	.000	.160	-.269
					Check	21	.130	.197	.057	.003	.188	-.198	-.023	.131	-.203
11-11-2005	Pan	20.3	-12.3	23.6	Control	23	.531	.794	.232	.000	.567	-.633	.000	.947	-.914
					Check	23	.687	.746	.213	-.093	.781	-.803	-.257	.728	-.989
	MultiSpec	20.1	-12.3	23.6	Control	23	.130	.224	.064	.000	.149	-.161	.000	.259	-.211
					Check	23	.170	.171	.051	-.024	.202	-.206	-.059	.202	-.226
22-01-2006	Pan	18.1	-12.4	19.1	Control	25	.585	.793	.173	.000	.767	-.619	.000	.603	-.881
					Check	21	.571	.821	.251	-.227	.527	-.805	.025	.664	.025
	MultiSpec	18.0	-12.4	19.1	Control	25	.150	.201	.046	.000	.188	-.153	.000	.163	-.260
					Check	21	.144	.241	.064	-.057	.129	-.206	.012	.186	-.197

Table A.2. QuickBird image rectification accuracy for images captured from 14-11-2006 to 28-01-2008.

										Residuals					
		Sensor View Angle					RMS Errors			X			Y		
Date	Image Type	In Track	Across Track	Off Nadir	Point Type	Count	Mean	Range	Stdev	Mean	Max	Min	Mean	Max	Min
14-11-2006	Pan	-19.8	-7.3	21.0	Control	22	.586	.717	.169	.000	.703	-.683	.000	.837	-.779
					Check	20	.700	.624	.204	-.072	.870	-.907	.027	.831	-.733
	MultiSpec	-19.9	-7.3	21.0	Control	22	.155	.242	.053	.000	.171	-.168	.000	.242	-.220
					Check	20	.177	.159	.051	-.019	.214	-.249	.062	.210	-.173
12-01-2007	Pan	-3.4	-23.4	23.6	Control	22	.655	.753	.234	.000	.781	-.611	.000	.854	-.809
					Check	20	.663	.713	.219	-.358	.745	-.856	-.028	.729	-.963
	MultiSpec	-3.6	-23.4	23.6	Control	22	.335	.811	.210	.000	.289	-.235	.000	.825	-.564
					Check	20	.276	.634	.162	-.082	.218	-.360	.008	.631	-.295
19-09-2007	Pan	12.2	19.4	22.8	Control	20	.643	.645	.207	.000	.852	-.690	.000	.829	-.803
					Check	20	.661	.881	.228	.121	.893	-.898	.120	.810	-.647
	MultiSpec	12.0	19.4	22.8	Control	20	.158	.162	.048	.000	-.169	.212	.000	.178	-.205
					Check	20	.167	.233	.057	.028	.221	-.230	.038	.218	-.144
30-10-2007	Pan	-22.6	1.1	22.6	Control	20	.495	.846	.219	.000	.461	-.602	.000	.818	-.739
					Check	20	.543	.894	.258	.020	.786	-.981	.059	.641	-.977
	MultiSpec	-22.8	1.1	22.6	Control	20	.126	.221	.061	.000	.116	-.156	.000	.207	-.232
					Check	20	.136	.230	.067	.004	.192	-.250	.021	.176	-.248
23-12-2007	Pan	-2.2	-1.4	2.5	Control	20	.603	.837	.252	.000	.876	-.834	.000	.703	-.910
					Check	20	.670	.572	.173	-.285	.551	-.894	.016	.643	-.862
	MultiSpec	-2.4	-1.4	2.5	Control	20	.154	.207	.056	.000	.219	-.212	.000	.177	-.209
					Check	20	.172	.169	.046	-.072	.133	-.227	.010	.182	-.218
28-01-2008	Pan	-1.9	-3.2	3.7	Control	20	.423	.691	.198	.000	.597	-.548	.000	.674	-.680
					Check	20	.608	.725	.203	-.156	.570	-.730	-.054	.667	-.921
	MultiSpec	-2.1	-3.2	3.7	Control	20	.103	.176	.052	.000	.148	-.140	.000	.173	-.185
					Check	20	.159	.215	.053	-.040	.139	-.177	-.005	.185	-.234