Final Report: SRDC Project BPS001

Identifying management zones within cane paddocks: an essential foundation for precision sugarcane agriculture

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Sugar Research and Development Corporation

Final Report

SRDC Project BPS001

Project Title: *Identifying management zones within cane paddocks: an essential foundation for precision sugarcane agriculture*

Lead Research Organisation

- Burdekin Productivity Services Ltd, Ayr

Participating Research Organisations

- Soil Horizons Pty Ltd, Townsville
- Queensland Department of Employment, Economic Development, and Innovation, Mackay and South Johnstone
- Ag Data Solutions Pty Ltd, Ayr
- Mackay Sugar Cooperative Association Ltd, Mackay
- Herbert Cane Productivity Services Ltd, Ingham
- Independent Agricultural Resources Pty Ltd, Mackay
- Sucrogen Ltd, Ingham
- Terrain NRM, Ingham

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None of the Project BPS001 activities are of a commercial-in-confidence nature.

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Project commencement date: 1 July 2007

Project completion date: 1 August 2011

1. **Executive Summary:**

(Maximum 800 words. This should provide a non-technical overview of the project which could be used to communicate project outcomes in media such as the SRDC website. It should cover the following:

- Issue: What was the industry and/or community issue, what was its relevance, and how did the project address the issue?
- R&D Methodology: Succinctly explain the methodology, and indicate the extent of collaboration and/or partnerships, especially with end users.
- The project deliverables ie outputs (knowledge, skills, processes, practices, products and technology) and outcomes (impacts that benefit the industry and community);

The impact of the project findings on the sugar industry and the Australian community. Indicate actual/expected net benefits in terms of social, environmental and economic impact, and actual/expected adoption of outputs.)

Variability in plant growth across spatial zones within sugarcane crops arises from the complex interactions of soil nutritional status, soil physical properties (especially soil texture), surface and subsurface drainage, seasonal conditions, soil health, pests and diseases, cane variety adaptability to soil type, and paddock management practices.

BPS001 research has shown that no single GIS spatial layer is sufficient to identify and manage the variability inherent in sugarcane production systems. However, by comparing patterns within three key GIS layers, we have found a way to simplify the complexity among the factors controlling crop yields, and have found answers to the two basic questions driving the research:

- *How do satellite imagery and EM map patterns relate to variations in space and time in soils, soil properties, and sugarcane yield?*

- *Are there general relationships between image analysis, EM signals, yield, and soil properties that are widely applicable within and between regions?*

The three fundamental GIS layers are:

- *A soil layer (stable)*: based on technology such as deep soil electrical conductivity (ECa) responses where detailed soil maps are not available. The map patterns must be checked against actual soil profile data, especially soil texture and sub-surface drainage characteristics, at strategically located sites. We have shown that these spatial data are related to stable soil properties and may be relied on to produce similar, mappable, spatial patterns from year to year and, in the case of our study, over a 5-year cropping cycle.

- *A topography, or 'drainage', layer (stable within a crop cycle, but influenced by paddock earthworks)*: based on detailed topographic data that may be readily accessed during soil ECa surveys, or by tractors equipped with real-time kinematic global positioning systems (RTK-GPS). This layer defines water movement pathways in paddocks and characterises the drainage status of contiguous segments of the crop along each row within the paddock. The surface drainage patterns are closely related to the potential of a site to become waterlogged under wet conditions or to dry out rapidly under dry conditions; in either case, the paddock management zones will have a negative impact on crop yield. The patterns are likely to change if any earthworks are carried out in the paddock. Hence, the patterns are stable within a crop cycle but may change if drainage works or other land-shaping activities are carried out in the fallow period between successive crops in the paddock.

- *A crop yield layer (variable spatial responses to weather, pests and diseases, and paddock management strategies)*: reflects differences in soil and site parameters controlling the growing
conditions within yield zones in a paddock. Data may be derived from high resolution

satellite imagery captured before harvest or from harvester-mounted yield monitors. BPS001 has found that patterns in crop yield variability are closely related to the distribution of contrasting soil groups in relation to paddock topography. The repeatability from year to year of the definition of higher-and lower-yielding crop production zones, and the stability of the zone boundaries under different climatic and management regimes remain to be demonstrated.

Enhanced knowledge of relationships among these and other spatial GIS layers will drive progress and the wider adoption of precision agricultural techniques in sugarcane production.

The main benefits to flow from this knowledge include:

Industry
Knowledge of relationships among GIS layers will provide pathways for continual on-farm improvements embracing activities as diverse as soil preparation strategies, zonal ripping, applying plant nutrients, breeding adapted cane varieties, managing irrigation water, refining spatially-defined management techniques based on crop yield potential, and adopting relevant precision agricultural technologies.

Farm productivity
More efficient use of crop inputs (*e.g.* fertiliser, soil amendments, water, and pesticides) will result from applying only the input level needed to support crop growth on particular parcels of land and from minimising off-farm losses. Techniques for identifying cane varieties adapted to both soil variability and spatial positions in the landscape are likely to develop, and they will require a ‘variable variety planter’ to fully capitalise on the possibility of on-the-go planting of varieties that match specific soil conditions.

Environmental
Significant water quality improvements will be generated by paddock inputs based on site-specific management of spatially-defined zones of crop yield potential. It is likely that developments in this area will extend to the revision of State Government regulatory guidelines governing soil nutritional and plant protection inputs in the future.

Economic
Site-specific application of nutrients (e.g. ‘*Six Easy Steps*’), pesticides, and herbicides should be based on spatially defined management zones within paddocks including, but not limited to, the yield potential and key soil properties of the zones. To fully capture this benefit, the definition of the management zones will require a spatial analysis of the impact of seasonal growing conditions on the patterns of crop yield over long sequences of wet, dry, and ‘average’ years.

2. Background:

(Including technical information and existing knowledge concerning the problem or research need addressed by the project)

Precision agriculture is a farm management approach that underpins sustainable farm returns by selectively applying inputs and best management practices to spatially defined parcels of land (*i.e.* to management zones) within paddocks, farms, or catchments. Identifying and managing within-paddock spatial variability is regarded as a key component of precision agriculture.

The application of precision agricultural techniques in cropping systems depends on the recognition within paddocks of georeferenced zones whose locations are tied to known latitudes and longitudes. The zones provide a framework for growers who wish to make site-specific decisions in applying appropriate management practices to individual areas within paddocks. In this way, input levels can be targeted for cost-effective farm production, for minimised waste through over-use or mis-application of inputs, and thereby for reduced environmental impacts. The management decisions must be underpinned by sound knowledge of variations in the underlying soil properties. In the northern Australian sugar industry, however, there are few areas where detailed soil maps are available at a scale meeting the detailed requirements of precision agriculture. This basic constraint to the ready adoption of precision agricultural practices is discussed in Chapter 2 of Attachment 1 (the scientific findings and research results from Project BPS001), and provided a stimulus to find other ways to provide fundamental soils information in a timely manner and at an affordable cost.

The project has explored the utility of apparent electrical conductivity (ECa) mapping of the soil to detect variations in soil properties at a cane paddock and sub-paddock scale. With the developments pioneered in Project BPS001 and the use of accurate geo-positioning and computerised spatial data management technologies, soil ECa mapping has evolved into a tool for defining variations in soils on a sub-paddock scale. When combined with other georeferenced spatial information such as processed multispectral satellite imagery, detailed topographic information, and sugarcane yield mapping, the project has made significant advances in understanding the sources of paddock variability and managing its complexity.

Project BPS001 was initiated to provide a foundation for precision agriculture in sugarcane production by developing better understandings of the interactions of the factors that influence the variability in yields of sugarcane crops. This variability across spatial zones within paddocks arises from the complex interactions of soil types, soil nutritional status, soil physical properties (especially soil texture), surface and subsurface drainage, seasonal conditions, soil health, pests and diseases, cane variety adaptability to soil type, and paddock management practices. The project has identified that, while crop yield is influenced by complex interactions among these variables, the within-paddock variability is largely influenced predominantly by the physical properties of the soils (detected by soil ECa mapping and validated by soil inspection and analysis at strategic locations within key soil ECa mapping units) and their spatial locations within the topographical landscape (defined by digital elevation layer).

The results generated from the project will enable sugarcane growers to develop better practical management strategies to reduce yield variability, and to modify paddock inputs based on access to key spatial information. Progressing precision agriculture provides a pathway for maximising profitability and a means to enhance environmental integrity through improved quality of the water leaving sugarcane paddocks.

3. Objectives:

(As stated in the original proposal, and a statement of the extent to which the project has achieved them)

3.1. Objectives from the original proposal

The project will develop and promote techniques for establishing zones for targeted application of best management practices within cane paddocks. The zones will be identified by mapping features in satellite imagery, soil electromagnetic induction (EM) responses [known as ‘apparent soil electrical conductivity (ECa) responses’ when detected with a Veris

3100 soil conductivity mapping unit as in Project BPS001], *actual soil properties, and sugarcane yields. They will be georeferenced (assigned latitudes and longitudes) and viewed, queried, and analysed at various scales in a geographic information system, a process that will integrate data collected from different sites and at different times.*

The resulting map units will allow the subsequent development and promotion of variable rate, site-specific, best management practices for sugarcane production and improved environmental stewardship over and above the management of the crop or paddock as a single, homogenous entity.

The research will address two main questions:

- *How do satellite imagery and EM* [ECa] *map patterns relate to variations in space and time in soils, and in sugarcane yield?*
- *Are there general relationships between image analysis, EM* [ECa] *signals, yield, and soil properties that are widely applicable within and between regions?*

3.2 Achievement of the original objectives

The Project BPS001 has fulfilled its original objectives and has gone further (see Section 8.2 of Attachment 1). It has explored the relationships among the soils, soil ECa signals, paddock topography, and crop yield and has shown clearly that no single GIS spatial layer is sufficient, by itself, to identify and manage the variability inherent in sugarcane production systems. The major achievement of BPS001 has been to work out how to use three key GIS layers over a paddock soil ECa patterns (as a surrogate for detailed soil information), paddock elevation (as a surrogate for site drainage), and crop yield variations derived from processed multispectral satellite imagery or harvester-mounted yield monitors to understand the complexity of the patterns of crop production and their management in spatial zones in paddocks.

The project findings are reported on in detail in Attachment 1. They provide a new way to use currently available precision agricultural technology to apply the inputs necessary to manage most of the site-specific factors that give rise to paddock-scale variability in crop yield. The farm productivity and environmental benefits that will flow from the application of the BPS001 results are outlined in various sections of this report.

An economic analysis of a case study using real nutrient input costs was carried out (Section 8.3.2 of Attachment 1) to evaluate the advantages of adopting site-specific fertiliser applications (as proposed by Project BPS001) over the current method of a uniform blanket application of nutrients over the whole paddock. It was found that a saving of $60 / hectare could be achieved in a 3-zone, site-specific, variable rate application of nutrients which equated to a saving of $557 (13%) on the cost of a whole of paddock blanket dressing of the same nutrients. The regional implications of this finding are discussed below (*Section 4.3.1 Methodology - Evaluation: Impact of the project).*

4. Methodology:

(Include **activities and project management to deliver outputs and outcomes.** Where detailed methodology has been published elsewhere, it should be summarised here and the publications should be included as Appendices to the report.

- Clearly enunciate the project process and its links to the outputs. Include where appropriate details of stakeholder participation, systems integration, implementation/adoption strategies and enhancement of human capacity.
- Specify method(s) used to evaluate success in delivery of outputs and outcomes. In particular, clearly enunciate the method(s) of evaluation used within the project to assess:
  - the impact of the project,
  - the learning experiences/capacity building achieved from the project, and
  - the implications of the project in guiding future R&D.)

The **major project output** presented in Attachment 1 is a rigorous understanding of the scientific principles that underpin the use of a set of GIS layers (primarily soil, topography, and crop yield patterns) to develop a new approach to holistic farm management that can be implemented progressively within a precision agricultural system for sugarcane production.

The **project outcomes** are cutting-edge technologies for sugarcane production that go beyond current best management practices, and a strategy for their practical and progressive adoption by sugarcane growers. Awareness of the benefits of adoption of the project outcomes is being delivered to all levels of the sugar industry from farmers to political leaders, and to the wider community using established and respected local networks in Queensland's sugarcane lands.

4. Methodology:

(Include **activities and project management to deliver outputs and outcomes**. Where detailed methodology has been published elsewhere, it should be summarised here and the publications should be included as Appendices to the report.

- Clearly enunciate the **project process and its links to the outputs**. Include where appropriate details of stakeholder participation, systems integration, implementation/adoption strategies and enhancement of human capacity.

4.1 Methodology: Activities and project management to deliver project outputs and outcomes

4.1.1 Project management

The project involved ten investigators from nine research providers located in five regional centres across 500 km of coastal Queensland between Mackay and Ingham. Burdekin Productivity Services Ltd, Ayr, was the lead agency and oversaw the financial management of the project. Technical leadership of the project was provided by Soil Horizons Pty Ltd, Townsville. The affiliations and research interests of the investigators are set out in Section 2.5 of Attachment 1.

None of the investigators had a full-time commitment to the project; the total salary commitment by SRDC to the project was for less than 1.5 full-time equivalent staff. Only two of the investigators were involved for 50% of their time (Coventry, Hughes), one of the investigators was involved for 15% of her time (Anderson), and none of the other investigators was involved for more than 5% of their time.

Project Review Meetings of all project investigators, support staff, Grower Reference Group members, and local sugar industry extension officers, were held annually over two days to review progress to date, to debate the significance of findings, and to determine where those results should lead the next phase of the research program. As happens in all good projects, once an answer to a research question was found, many more questions were raised.

The project meetings were supplemented by frequent meetings of various subsets of investigators in the course of field operations at project study sites located near Mackay, Ayr, and Ingham, at special meetings aimed at resolving data analysis problems and interpretations, and at preparing and presenting project results to external bodies. Email and telephone calls sustained the basic working linkages between investigators.

4.1.2 Project activities

Five field study sites of 5 – 12 ha were selected on "typical sugarcane soils" in the Central, Burdekin, and Herbert Districts. They were located on the following farms:

- Site M1: A. and J. Bugeja's farm, Homebush (Central). Study area = 10.8 ha.
- Site B1: I. Haigh's farm, Brandon (Burdekin). Study area = 12.0 ha.
- Site B2: S. Lando's farm, Brandon (Burdekin). Study area = 10.2 ha.
- Site H1: A. Pace's farm, Mutarnee (Herbert). Study area = 5.3 ha.
- Site H2: G. and J. Morley's farm, Lannercost (Herbert). Study area = 11.1 ha.

All of the sites lie on very gently sloping alluvial plains across a climatic gradient with annual rainfalls ranging from 970 mm in the Burdekin to 2340 mm at site H2 in the Herbert. La Niña weather conditions prevailed throughout most of the four-year project and all the results relate to 'wetter than normal' years. Unusually heavy rainfall throughout the 2010 harvest severely disrupted farming and project operations across the region. It was followed by a prolonged wet season (2010-11) and extreme cyclonic conditions (Cyclones Anthony in January, and Yasi in February) during which the whole of North Queensland received exceptional rainfall. Other details of the sites are given in Chapter 3 of Attachment 1.

Apparent soil electrical conductivity (ECa) mapping was carried out at each study site using a trailer-mounted Veris 3100 soil ECa mapping unit that, just prior to planting the sugarcane crop, was towed at 10 m run spacings over cultivated fallow land. The soil ECa data were recorded by an on-board data logger as voltage changes in return electrical signals that had been transmitted through shallow (0 – 300 mm) and deep (0 – 900 mm) segments of the soil profile at georeferenced locations at one second intervals (about 5 m spacings) along each Veris mapping run. The spatial data sets consisting of discrete measurement points were converted to continuously graded maps by kriging using GIS software (the Manifold package) to produce surface layers for shallow and deep soil ECa values, and for the other spatial data collected. Details of the data collection and processing protocols are given in Section 4.1 of Attachment 1.

The soil ECa mapping was followed immediately by soil description and sampling from hand-augered boreholes drilled to 1 m depth at a total of 130 field validation locations for the ECa maps produced at the five study sites. The soil validation locations were selected from patterns evident in the soil ECa maps, satellite imagery, aerial photography, topography, topsoil properties, farmer perceptions of yield patterns, and other observable paddock features.

Key soil properties measured or analysed from each soil validation site (Section 4.2 of Attachment 1) were:

- field morphological properties (e.g. colour, texture, structure, consistence, etc),
- soil particle size characteristics and soil chemical data from 3 'standard soil layers' per site (topsoil: 0 – 25 cm depth, upper subsoil: 40 – 60 cm depth, and lower subsoil: 75 – 100 cm depth),
- surface soil bulk density and cone penetrometer resistance,
- gravimetric soil moisture in 10 cm layers to 1 m depth per site.

The very extensive soil analytical data set (more than 12,000 data values from 130 soil profiles x 3 or 4 sampling depths x up to 17 laboratory analytes as well as bulk density, particle-size, and gravimetric soil moisture analyses) was analysed statistically to determine which soil properties were most closely related to the shallow and deep soil ECa signals, and also to the crop yield, at the map validation sites (Sections 4.2, 5.4, and 6.4 of Attachment 1). The occurrence of well drained, sandy soils as low ridges across the paddocks or as infilled stream channels were readily detected by the Veris 3100 unit; at each of the study sites, the lighter textured, sandier soils produced lower soil ECa signals than did the heavier textured clays, as has been found by previous researchers. Similarly, the heavier clay soils were readily identified from their high soil ECa signals, especially where those clays were found to have relatively high exchangeable sodium percentages (ESP) and were either sodic (ESP > 5%), or strongly sodic (ESP > 15%). Subsoil moisture was an important driver of soil ECa signals in areas of non-saline and non-sodic soils.

Multivariate analyses of the data have been used to determine what soil properties explained the variability of soil ECa signals within paddocks. These revealed that soil physical properties related to soil compaction (in particular, the bulk density and percentage of coarse sand in the topsoil) to be the most important soil properties in explaining 48 – 78 % of the variance in the soil data from each site (Section 5.4 of Attachment 1).

Digital paddock elevation data were collected by differential GPS during the ECa mapping and, more precisely, by RTK-GPS units mounted on the Veris 3100 mapping unit later in the life of the project. The georeferenced data were processed using the same protocols as for the soil ECa data and were displayed as kriged, interpolated surface layers (Section 4.3 of Attachment 1).

Variations in crop yield were detected and mapped by harvester-mounted Techagro^{TM} yield monitors and, in the later harvests at some sites, by processing of high resolution (0.8 m resolution), multispectral satellite imagery. Normalised difference vegetation index (NDVI) maps were produced from satellite images that had been captured just before commercial harvesting operations began. The georeferenced NDVI values were calibrated to actual crop yields by regression analysis of manually-harvested data from reference sites in the crop. The number of sugarcane stalks in strategically-located, small plots (5 m long rows) of sugarcane were counted, manually harvested, and weighed in the field (Section 6.1 of Attachment 1). The soil ECa data processing protocols were used to prepare derived crop yield maps from the NDVI data for the 2009 harvest of plant cane at site H2 where the technique was developed, and for the 2010 harvest of first ratoon crops at sites B1 and part of M1 only, as a consequence of harvesting difficulties induced by the unseasonally heavy rainfall during the 2010 harvest.

The various georeferenced data sets (*i.e.* spatial layers of paddock-based information) were entered into Manifold GIS software where they were analysed spatially, interrogated, displayed, and stored. The spatial analysis of the data revealed that the within-paddock variability may be simplified, understood, and management strategies developed in a precision agricultural context by linking three key spatial mapping layers, namely:

- soil mapping data – accessible through stable, deep, soil ECa soil mapping surveys,
- digital elevation data – which can be obtained through tractors equipped with RTK-GPS technology or from soil ECa mapping surveys,
- crop yield data – from processed multispectral satellite imagery or yield monitors mounted on cane harvesters.

This important outcome has been demonstrated and discussed in case studies from two sites where all of the key data sets were available (Chapter 7 of Attachment 1). A strategy is set out in Section 7.4 of Attachment 1 for the progressive adoption of the project's outcomes by sugarcane growers intending to change their farm management practices to a precision agricultural base. An assessment of the savings to be made from site-specific fertiliser inputs is set out in Section 8.3.2.

4. Methodology:
(Include activities and project management to deliver outputs and outcomes. Where detailed methodology has been published elsewhere, it should be summarised here and the publications should be included as Appendices to the report.

- Clearly enunciate the project process and its links to the outputs. Include where appropriate details of stakeholder participation, systems integration, **implementation/adoption strategies** and enhancement of human capacity.

4.2 Methodology: Implementation and adoption strategies

The main outputs from Project BPS001 are the scientific understandings of a holistic approach to precision agricultural farm management, and cutting-edge technologies for implementing farming practices in sugarcane production that go beyond current best management practices.

A strategy for the progressive implementation of the research outcomes has been set out in four steps from entry-level precision agricultural operations (level PA4) to level PA1, which is the highest level of precision agriculture practice recommended (Section 7.4 of Attachment 1). The sugar industry is in the early stages of transition to precision agricultural practices and many growers are currently operating at levels PA4 or PA3 (partial application of proven technology). Only a few growers in any district are currently applying some of the level PA2 practices (application of proven technology); no sugarcane grower has yet adopted all the recommendations of level PA1 (the industry goal).

The more innovative outcomes delivered by Project BPS001 are:

- knowledge of how several key GIS layers may be used to understand and manage crop variability within a sugarcane paddock;
- a precision agriculture goal for sugarcane growers to aspire to;
- the technology necessary to achieve the aspirational goals;
- an implementation strategy that takes a grower progressively from entry-level precision agricultural operations to the highest level of operations that exceed the current best management practice of the Australian sugar industry.

Adoption strategies are currently in place to help ensure achievement of the BPS001 outcomes. But it will take time for the new technology to filter through the industry, and most of the strategies will continue beyond the completion of Project BPS001 on 1 August 2011.

The three main approaches to implementation and adoption set out below.

4.2.1 Adoption strategy 1: Communication of project outcomes to date

On-going, daily, informal communications between project investigators, growers, and industry extension officers have set in place an increasing ground-swell of support for the project through the progressive delivery of project findings over the last four years. BPS001 investigators have presented the project's outcomes across all levels of the sugar industry from individual sugarcane growers to the Federal Minister for Agriculture, Fisheries, and Forestry (discussed in Section 7.1.1, below).

In addition, BPS001 investigators have offered scientific support to two SRDC-funded Grower Group Innovation Projects that continue to offer excellent avenues for communication of BPS001 achievements directly to leading, innovative growers in the Central, Burdekin, and Herbert Districts:

Project GGP052: The next step for precision agriculture aimed to understand the interaction of the variables contributing to spatial variability within sugarcane paddocks and, in particular, the impact of traffic (soil compaction) and plant disease on crop yield.

Project GGP057: SECMAPPER (Soil Electrical Conductivity Mapper) developed a new, heavy duty machine for mapping apparent soil electrical conductivity patterns below green cane trash blankets and crop stubble.

Another GGIP proposal is currently under development in collaboration with Project BPS001 investigators to develop a smart GIS system to allow non-specialist operators to manage and interrogate spatial datasets (*e.g.* soil ECa maps, satellite imagery, georeferenced soil test sites, etc) and to produce predictive maps of management zones within paddocks.

Over the last four years, BPS001 investigators have participated in many meetings, made presentations of project plans and outcomes, fostered inter-regional visits by Productivity Services staff, and have discussed implications of the project with sugarcane growers, industry extension officers, cane productivity groups, and other land managers in North Queensland.

The formal meetings included:

- BPS001 Grower Reference Groups in Mackay, Burdekin, and Herbert: face-to-face contact with most group members at least twice a year, 2007-2011,
- Burdekin Productivity Services Ltd:
  - quarterly interactive briefings of the BPS Board of Directors, 2007 – 2011,
  - keynote address at the BPS Annual General Meeting, 24/08/2010,
- Herbert Cane Productivity Services Ltd and BSES, Ingham:
  - Soil Health Forums: 12/12/2008, 12/11/2009, 11/11/2010,
  - Sugar Productivity Forums: 22-23/02/2010,
- Mackay Area Productivity Services Ltd: quarterly project updates, 2007-2011,
- Agriserve (BSES and MAPS), Mackay: 14/10/2010,
- Plane Creek Productivity Services Ltd: March 2008,
- Australian Society of Sugar Cane Technologists conferences:
  - Ballina 2009: 3 oral papers and 3 posters presented,
  - Bundaberg 2010: 1 oral paper and 2 posters presented (Best Poster Award),
  - Mackay 2011: 1 poster presented,
- GIVE Day, Ingham: 25/03/2009,
- GREAT Day, BSES Brandon: 18/5/2009,
- Trial Information Days, BSES Mackay: 15/04/2008, 17/02/2010, 14/02/2011,
- Healthy Soils Workshop, Mackay: 28/08/2008,
- Healthy Soils Workshops, Home Hill: 27-30/04/2009,
- Tropic City Group: annual meetings in Mackay 2008 and Tully 2009,
- NQ Dry Tropics, Townsville: 24/01/2010,
- Project Catalyst Grower Forum: 21-22/02/2010,
- Reef Catchments NRM, Mackay: 5 presentations between October 2010 and April 2011,

- Queensland Department of the Environment and Resource Management (DERM), reef regulation staff:
  - Head Office, Brisbane: role of precision agriculture practices (BPS001 outcomes) in improving water quality leaving coastal catchments, 24/11/2010,
  - Regional Office, Mackay: educating DERM Reef Protection Officers, 01/03/2011,
- Briefing of the Federal Minister for Agriculture, Fisheries, and Forestry (Mr Tony Burke), Mackay, October 2009. The Minister's enthusiastic response is presented under *Section 7.1.1 Environmental and Social Impacts"* (see below).

4.2.2 Adoption strategy 2: On-going extension through Project Catalyst

Project BPS001 CIs occupy significant positions in the planning and operation of *Project Catalyst* that is supported by the Coca-Cola Foundation ($5 million), the World Wildlife Fund, and the Federal Government's *Reef Rescue Project*. It is administered by Reef Catchments, a Mackay-based natural resource management group, and operates in the Central, Burdekin, and Herbert-Tully Districts. The focus of *Project Catalyst* is on innovative management of sugarcane lands. It encourages the adoption of improved coastal land use practices by providing practical knowledge and sugarcane grower support for technological change in ways that are being increasingly supported by government and utilised by farmers.

The project aims to:
- improve sugarcane farming practices in the Mackay-Whitsunday region by reducing the losses of nutrients, agrichemicals, and fine sediments from farms to off-site, non-target areas,
- monitor the subsequently enhanced quality of waters entering the Great Barrier Reef lagoon in the region,
- boost and assess the economic viability of a pilot group of growers in the region whose farm management skills will be upgraded to the level of Reef Catchments Class A practices that will exceed the current best farm management practices in the region.

The precision agriculture component of *Project Catalyst* is underpinned by, and promotes the adoption of Project BPS001 outcomes, such as soil ECa mapping, multispectral satellite image analysis, crop yield monitoring, georeferenced sampling of soil profiles, and site-specific application of paddock inputs in spatially defined zones within sugarcane paddocks. The BPS001 results are being used in the further development of precision agricultural approaches to improved management techniques for increased productivity and enhanced environmental integrity of sugarcane production systems.

Three BPS001 investigators have been directly responsible for delivering *Project Catalyst's* strategies for improved plant nutrient, herbicide, and soil management practices on sugarcane farms across the region (T. Crowley in the Central District, P. McDonnell in the Burdekin, and L. Di Bella in the Herbert until his appointment as Manager, Herbert Cane Productivity Services Ltd, Ingham, in June 2011). The strong link between Project BPS001 and *Project Catalyst* provides a unique and exciting opportunity to connect agricultural management practices, increased farm productivity, and environmental icons such as the Great Barrier Reef, with scientific understandings from Project BPS001.

In this way, the extension component of BPS001 has been, and will continue to be delivered directly to all levels of the sugar industry, to political leaders, and to the wider community using established and respected local networks in Queensland's sugarcane lands. As *Project Catalyst* evolves, the potential to deliver BPS001 outcomes to a wider audience will also evolve, perhaps even reaching an international audience. All of this is being delivered at no cost to SRDC, or to Project BPS001.

4.2.3 Adoption strategy 3: Precision agriculture training courses

As the outcomes from Project BPS001 have become more widely communicated, there is an emerging recognition in the sugar industry and environmental managers in northern and central Queensland that there is more to precision agriculture than automated steering systems on tractors. Some natural resource management groups have supported the past purchases of specialised equipment (*e.g.* variable rate fertiliser boxes) for use in proposed precision agricultural practices. It is becoming evident that many of the farmers who have purchased such equipment lack awareness of the wider possibilities that precision agriculture offers their enterprises, and that specialised training in new farming practices is needed to allow them to capitalise more fully on their investments.

In March 2011, BPS001 investigators had been approached jointly by natural resource management group and productivity services groups to prepare and deliver precision agriculture awareness and training courses aimed at service providers and at farmers. At the time of the first meeting in Ingham on 1 June 2011 to discuss the details of this initiative, the participants were also involved in discussions with BSES staff seeking project linkages to develop, with SRDC support, a training course in precision agriculture. The proposal was followed up with another meeting in Townsville on 7 July 2011 that included most of Project BPS001 investigators and J. Panitz, BSES Bundaberg. A strategy has been developed to incorporate the BPS001 outcomes as core components in the BSES Training Program.

No matter what approach is used to deliver precision agricultural training, it is clear that a mechanism will exist beyond the completion of Project BPS001 to put the outcomes from the project into the hands and the minds of industry service providers and sugarcane farmers.

4. Methodology:
(Include activities and project management to deliver outputs and outcomes. Where detailed methodology has been published elsewhere, it should be summarised here and the publications should be included as Appendices to the report.

- Specify **method(s) used to evaluate success in delivery of outputs and outcomes**. In particular, clearly enunciate the method(s) of evaluation used within the project to assess:
  - the **impact of the project**,

4.3 Methodology: Evaluation of success in delivery of outputs and outcomes

4.3.1 Methodology - Evaluation: Impact of the project

- ***Adoption of BPS001 outcomes for enhanced economic return***

A case study made of nutrient inputs to a 9.3 ha sugarcane paddock at Mackay where the yield of the first ratoon crop (2010 harvest) varied from less than 70 t of cane / ha (TCH) to 120 TCH. An assessment was made of nutrient requirements of the second ratoon crop using the *Six Easy Steps* guidelines across three yield zones in the paddock (low: less than 70 TCH, medium: 70 – 90 TCH, and high: 90 – 120 TCH). It was found that a saving of $60 / hectare could be achieved by a 3-zone, site-specific, variable rate application of nutrients, which equated to a saving of $557 (13%) of the cost of a whole of paddock blanket dressing of the same nutrients (see Section 8.3.2 of Attachment 1).

An analysis of 26,000 sugarcane paddocks (average 2.8 ha/paddock) within the Mackay sugarcane growing area indicated that 30% of paddocks displayed within-paddock yield variability in excess of 40 TCH in the 2008 season (mill records from Mackay Sugar Ltd, 2011). This equates to approximately 22,500 hectares (8,000 paddocks) which potentially could be allocated high, medium and low yield potentials within defined management zones. Based on the results from the study case at site M1 set out in the previous section, a three-zone approach to crop nutrition represents a potential regional saving of $1,350,000 in nutrient inputs, or a potential reduction of 720 tonnes of elemental nitrogen (1,560 tonnes of urea). However, further research is required to determine the implications of reducing nitrogen inputs with a reducing yield potential associated with the aging of ratoons in a crop cycle.

The early results from Project BPS001 clearly show the potential for significant on-farm savings, and district-wide savings, from the adoption of site-specific nutrient inputs. We expect that growers will make money from adopting the outcomes of the project and, while doing so, will also be contributing to enhanced environmental outcomes that are discussed below (Section 7).

- ***Enhanced economic return – a more comprehensive analysis***

A more complete assessment of the commercial drivers for a grower to adopt the precision agriculture principles developed in project BPS001 is currently in progress. Technological change through the adoption of BPS001 outcomes is being supported by *Project Catalyst* with 30 leading sugarcane growers in the Central District and 10 (eventually expanding to 20) in each of the Burdekin and Herbert Districts. The pilot group of 50 - 70 growers is being supplied with tools to move towards adopting the BPS001 protocols for soil ECa mapping, georeferenced soil testing, paddock elevation mapping, and crop yield monitoring.

An economic assessment of the *Project Catalyst* outcomes is in progress with the Queensland Department of Employment, Economic Development, and Innovation, which is assessing the farm economics through 25% of the farmers undertaking a profit probe, and the rest doing economic assessments. Results of the economic analysis will not be available until 2012 because of the requirement to use a minimum of 2 - 3 years of data to provide an accurate assessment of the actual economics involved in adopting the BPS001 precision agriculture outcomes.

It is expected that, as more specific and targeted inputs are applied to spatially defined zones in paddocks, economic gains and environmental benefits will inevitably follow. This will have a direct positive impact on the adopters of the new technology. In addition to more efficient management of inputs at a sub-paddock scale following the Project BPS001 outcomes, the precision agricultural approach will assist growers to decide whether inputs should be boosted or reduced in certain parcels of land, or if land in marginal areas should, in fact, remain in sugarcane production.

- ***Acceptance of peer-reviewed scientific publications***

To date, the major publications of Project BPS001 have been in the Proceedings of ASSCT conferences (see *'List of Publications'* below) in order to keep the industry informed of progress. Now that the data and interpretations from the whole of the project have been brought together systematically in Attachment 1, several nascent scientific papers will be finalised and submitted for publication in the wider soils and agricultural literature.

- ***Invitations to speak about Project BPS001 at public meetings***

The part-time BPS001 investigators have been kept very busy meeting requests for public presentations over the life of the project (see *'4.2.1 Adoption strategy 1: Communication of project outcomes to date'*, above).

- ***Adoption of Project BPS001 outcomes in other projects***

The processes, practices, and interpretations developed in BPS001 underpin the evolving precision agriculture component of *Project Catalyst*, a land management project that has attracted significant public and private funding to establish improved farm management practices in sugarcane lands of the Central, Burdekin, and Herbert-Tully Districts (see *'4.2.2 Adoption Strategy 2: On-going extension through Project Catalyst'*, above*).*

Discussions have been held with senior officers in the Queensland Department of Environment and Resource Management, Brisbane, about the relevance of Project BPS001 outcomes for productive and environmentally sensitive land use; some of the project initiatives have potential for development into state-wide guidelines for coastal land management.

The role of BPS001 investigators in precision agriculture training programs, funded through a sugarcane productivity board - natural resource management – BSES alliance, with SRDC support, has been outlined above (see *'4.2.3 Adoption strategy 3: Precision agriculture training courses'*, above)

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  - the impact of the project,
  - the **learning experiences/capacity building achieved from the project**,

4.3.2 Methodology - Evaluation: Learning experiences / capacity building achieved from the project

The following criteria have been used to assess the learning experiences and capacity building aspects of the project:

- ***Scientific learning experiences***
  - *Soil sampling protocols*

    The soil sampling and analysis processes used in the field validation of the soils occurring in soil ECa patterns (Section 4.2 of Attachment 1) have resulted in the development of a modified protocol for collecting georeferenced soil samples, including both topsoils and subsoils. The new protocol has been adopted by productivity services groups and a number of agricultural consultants in the Central, Burdekin, and Herbert Districts.

  - *Yield assessments from satellite imagery*

    The project funded several BPS001 site visits by Dr A. Robson and Mr C. Abbott, Queensland Department of Employment, Economic Development, and Innovation, Kingaroy, to evaluate the application of spatial data analysis methods developed for the peanut industry to estimating sugarcane crop yields from NDVI analysis of multispectral satellite imagery (Section 6.2 of Attachment 1). This approach has been partly successful. It is now being refined and applied to different conditions in sugarcane crops in the Bundaberg area (Robson *et al.* 2010).

- ***Industry perceptions of variable rate application technology***

At the start of Project BPS001, there was industry-wide enthusiasm for the adoption of variable rate application of paddock inputs through the expectation that such an approach was likely to be profitable in higher value crops, including sugarcane (Bramley 2007). Some sugarcane growers, spurred by funding assistance through natural resource management agencies, put the cart before the horse: they bought equipment capable of variable rate applications of inputs, without having a clear idea of where in the paddock the variable inputs should be applied.

One of the stated reasons why BPS001 investigators have recently been invited to develop, or to participate in, precision agriculture training programs for the sugar industry is that knowledge of BPS001 outcomes for defining management zones in paddocks will result in the investment in equipment for variable rate application being much better utilised.

- ***Coping with State Government Reef Regulation requirements***

The results from Project BPS001 are already influencing the technological approaches for growers in transition from a 3-year to a 5-year nutrient management accreditation under Reef Regulation guidelines. BPS001 outcomes, especially the use of soil ECa maps, provide a simple, cost-effective basis for the site-specific application of inputs, which is a key component of the accreditation process.

- ***Industry perceptions: solving problems in the paddock***

BPS001 investigators have frequently received feedback from sugarcane farmers, individually or at group meetings. A common message has been that, until they began to appreciate that there are a number of issues driving paddock variability (see first paragraph of *'Executive Summary'*, above), their first reaction to an area of poor crop growth was to think of increasing the fertiliser inputs to that part of the paddock.

BPS001 outcomes have encouraged farmers to think about a wider range of soil and site properties that might be affecting crop growth responses. For example, Mr A. Bugeja, the owner of Rosella Farm on which the BPS001 study site M1 is located, has written in a letter of support (Attachment 3) that the project has been highly beneficial to his farming operations by providing a better understanding of the sources of variability in his crop yield, and by setting out strategies whereby he can manage that variability. As an early adopter of the Project BPS001 outcomes, he has also indicated a number of ways in which his new perceptions have changed his farming practices:

> *"Our association with this project has been very beneficial as we now have a distinct path for ongoing improvement in the way we manage our farms. We were very aware of the within-paddock variability in soil types through the ECa mapping programs but were concerned at the variability in yield that was indicated by the satellite yield maps. Our farming business has collected a lot of information about the nutrient levels in the topsoil but the project has now provided us with a good understanding of what is happening below the soil surface and how this influences the variability of sugarcane crop growth in our paddocks. The deep soil profile cores collected from the different ECa patterns at the trial block explained some of the reasons for the poor crop growth areas. We had always thought that poor yielding areas were due to nutrient problems but now have a better understanding that clay at depth and subsurface drainage problems can cause low yielding areas in the paddock, especially in wet years. This project has provided us with a good understanding of all the factors*

that can influence sugarcane growth and placed us in a better position to manage the variability that occurs in many of our paddocks.

… It is clear that a cane variety that yields well in the upper section of a paddock may not necessarily grow well in a badly drained section at the other end of the paddock. An innovation from this project is the possibility of planting two varieties in the same paddock based on their adaptation to the different soil types and to waterlogging. We also have the opportunity to create bigger hill-ups in low lying areas of the paddocks to keep the root zone out of standing water. An automated base cutter height adjuster has been fitted to our harvester which allows for variability in hill heights. In the future we aim to cultivate our paddocks at different times and at different intensities based on EC mapping and our knowledge of the different soils that occur within a paddock."

A more complete statement is included in Attachment 3: "Letter of support, A. Bugeja".

Similar changes in scientific and industrial perceptions arising from Project BPS001 have been identified by Mr R. Sluggett, an agricultural consultant, a grower-member of the Plane Creek Sustainable Farmers Group, and formerly an Extension Officer with BSES Sarina and agronomist with CSR Plane Creek. Mr Sluggett has written (Attachment 3: "Letter of support, R. Sluggett") that:

"The adoption of precision agricultural practices in the sugar industry is in its relative infancy when compared to other industries such as grain. ...

While we have developed some expertise and made progress, the progression of adoption of much of this technology and benefiting from the huge potential on offer has been hampered by the lack of fundamental research and knowledge of the drivers of variability of productivity within cane fields and their relative importance. Without this understanding, we can't begin to manage this variability in a precision agricultural sense. BPS001 has proved to be a valuable project by significantly improving this understanding, the project has investigated and evaluated the importance of a whole range of soil and site characteristics, management practices, inputs etc and their interactions and impacts on productivity.

… As a commercial provider of precision agricultural services, the findings of this project have been critical in providing the confidence in the integration of soil EM mapping, topography and yield mapping to better determine stable yield zones within cane fields and therefore more confidence in the development of management strategies for different zones within fields.

… The widespread adoption of precision agricultural practices promises huge environmental, economic and social benefits to the sugar industry. It is the next frontier. It is critical that research funding providers take note of the findings and recommendations of this project and see this as the first steps in a longer term program of knowledge enhancement and industry progression."

While Project BPS001 has focused on developing scientific knowledge, it has also addressed the issue of turning that knowledge into practical outcomes that may be used by agricultural service providers and sugarcane growers. Mr P. McDonnell, an agricultural consultant with Ag Data Solutions Pty Ltd, Ayr, has been an investigator on Project BPS001 and supplied the soil ECa maps for Burdekin and Herbert study sites. He has been involved with the project since its inception and has had early access to the protocols developed by BPS001 investigators. He has progressively adopted the emerging protocols into the work practices of his agricultural consultancy business, and has set out how those protocols have been implemented in practice in his commercial operations (see Attachment 3: "Letter of support, P. McDonnell").

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  - the impact of the project,
  - the learning experiences/capacity building achieved from the project, and
  - the **implications of the project in guiding future R&D**.)

4.3.3 Methodology - Evaluation: Guiding future research and development

The following criteria have been used to assess the implications of the project in guiding future research and development.

- ***Tools for managing soils***

Conventional sugarcane farm management decisions are usually made on the basis of soil tests on samples restricted to a depth of 0 – 20 cm in cultivated topsoils. This could lead to inefficient, limited, or wrong agronomic decisions where relatively uniform topsoils overlie subsoils with strongly contrasting characteristics as at site M1 (Sections 5.3.5 and 7.3.2 of Attachment 1). These differences may be greatly exaggerated where there are impediments to surface drainage, or poor subsoil drainage conditions prevail, also as at site M1.

Such situations can be readily and unambiguously addressed using spatial information a set of readily available sources (soils from deep ECa maps; topography and drainage from digital elevation models; crop growth from yield maps from processed satellite imagery or yield monitors on cane harvesters). The site interpretations must be validated using a combination of actual soil information from a few hand-augered boreholes located at well-chosen, strategic locations, and from observations of crop growth responses to weather conditions.

Emphasis on the importance of using information from both topsoils and subsoils by Project BPS001 (Section 8.3.1.1 of Attachment 1) has led to the adoption of a new soil testing protocol by some productivity services groups and agricultural consultants. The protocol includes observations and analysis (especially soil fertility and particle size parameters) of both topsoil and subsoil properties at georeferenced soil sampling sites related to deep soil ECa patterns within paddocks.

- ***Tools for managing poorly drained areas***

Ineffective paddock drainage and impeded farm drainage systems are constant problems at times of heavy rainfall in the almost flat-lying alluvial plains of the sugarcane lands of Central and Northern Queensland. A major output from Project BPS001 was the relationship between the elevation of a site within a paddock, the nature of its soil substrate, and the yield of sugarcane: lower areas of sugarcane paddocks with medium – heavy clay subsoils are likely to have low crop yields in wetter than average years. On the other hand, paddock zones in slightly higher areas and with lighter textured subsoils are likely to produce heavier crop yields, as was borne out in the two case studies reported in Chapter 7 of Attachment 1.

The tools suggested by BPS001 investigators (Section 7.3.2 of Attachment 1) to provide solutions to crop production problems related to poor drainage in spatially defined zones within a paddock are:

- techniques for identifying cane varieties adapted to both soil variability and spatial positions in the landscape. Hence, the development of a ‘variable variety planter’ to allow on-the-go changes along the row in sugarcane varieties during planting, and according to the potential for waterlogging at any particular location, would greatly assist in matching cane varieties to specific soil conditions.
- adoption of variable height hill-up operations after crop establishment to raise the height of the planted in potentially waterlogged areas in a paddock and an automated base cutter height adjuster fitted to the sugarcane harvester which allows for variability in hill heights (as has already been adopted by A. and J. Bugeja; see Attachment 3).

- ***Tools for managing crop inputs***

More efficient use of crop inputs (*e.g.* fertiliser, soil amendments, water, pesticides) will result from site-specific applications based on:

- applying the input needed to support crop growth on spatially defined zones within the paddock,
- minimising environmental risk from off-farm losses by applying only the level of input needed by the specific zones within the paddock.

- ***Tools for managing water quality***

Improved tools for zonal paddock management and more efficient and effective crop production will also prove to be very useful tools for water quality managers (Section 8.3.1.4 of Attachment 1). To be able to track water quality problems back to specific zones within a paddock, and to apply and monitor site-specific amelioration over the problem zone, would be a key environmental outcome. It would fill an important gap in current water quality science and provide an outstanding tool in helping to fulfill the Queensland Government's *‘Reef Plan’* for profitable and sustainable land management practices in sensitive coastal catchments.

5. Outputs:

(Including knowledge, skills, processes, practices, products and technology developed)

The major project outputs are set out in the scientific findings in Attachment 1. They consist of knowledge of processes and the development of understandings of how a new approach to holistic farm management. BPS001 outputs offer cutting edge technologies for sugarcane production that go beyond current best management practices, and can be achieved within a PA system.

A relatively simple model is presented (Section 7.4 of Attachment 1) and offers a rationale for the progressive implementation, expansion, and refinement over time of precision agricultural practices on any farm where spatial data are available at any level of complexity. The model lists the characteristics of increasingly higher levels of precision agricultural operations in sugarcane. It ranks the operations from PA 4, at a fundamental entry level, to PA 1 operations at the highest level of implementation.

A *‘Manual for apparent soil electrical conductivity mapping: a guide for the collection, analysis, and interpretation of soil ECa information’* (Attachment 2) has been prepared that sets out:

- reasons for soil ECa mapping,
- field operational issues,
- data processing protocols,

- stability of shallow and deep soil ECa patterns over time,
- field validation of soil ECa data,
- how to interpret and use soil ECa data in combination with other key data sets (e.g. topography, crop yield) to simplify and explain the complexity of paddock variability in sugarcane crops.

Training courses are in development for communicating basic PA skills to service providers and farmers.

6. Intellectual Property and Confidentiality:

(Detail any commercial considerations or discoveries made, and means of protection (eg patents) undertaken or planned Specify any information that is to be treated as confidential, to whom and for how long.)

All of the BPS001 Project activities have been in the public domain and none have been of a commercial-in-confidence nature.

7. Environmental and Social Impacts:

(Including any expected or actual adverse or beneficial environmental or social impacts of conducting the project and/or implementing its findings)

7.1 Environmental impacts

The identification of paddock management zones with site-specific management practice needs is becoming increasingly significant with Federal and State Government farming practice regulations being introduced to ensure satisfactory environmental outcomes (e.g. *'Reef Plan', 'Environmental Risk Management Plans')*. Some preliminary BPS001 outcomes were included in a presentation by *Project Catalyst* to Mr Tony Burke, the former Federal Minister for Agriculture, Forestry, and Fisheries, when he visited Mackay in early October 2009.

The Minister was interviewed a few days later in Cairns by Ashleigh Gillon, *Sky News*, and the following transcript is part of the interview broadcast on *Sky News Saturday Agenda*, on 17 October 2009.

> ***Ashleigh Gillon:*** *The Agriculture Minister, Tony Burke, has been up around these parts, touring the area and speaking with farmers, who have taken advantage of the Government's grant program through its Reef Rescue Scheme. I spoke with him earlier.*
>
> *Up to 90% of pollution on the Great Barrier Reef comes from farming. How realistic is the goal to cut that pollution by half in five years?*
>
> **Tony Burke:** *From the changes I have seen in the last few days, we appear to be on track to be delivering some incredibly amazing cuts. Some of these changes can happen quite quickly.*
>
> *The difference is that you go from sediments just waiting there, exposed, ready to make their way down to the reef, to being covered. You go from a situation where you had large amounts of runoff to something close to natural levels or zero.*

Ashleigh Gillon: *But cutting pollution by half? Farmers I have spoken to sound pretty doubtful.*

Tony Burke: *If you have a look at the work that I saw at a sugar farm just out of Mackay – how they connected GPS technology to their mapping of every paddock, to a regulated flow of chemicals.*

The nutrients that they put in had gone from a figure of 40 to a figure of 7. Now they are using less than a quarter because the technology is allowing them to completely target their use of chemicals and fertiliser.

When you get that sort of targeting, they have no loss in total production because the soil is still getting everything it needs. But less than a quarter of the nutrients are available for runoff now. Less than a quarter!

And because it is so well targeted, it is now finding its way into the soil so that you get an even smaller figure in actual runoff.

Now, these are figures that farmers are offering to us, that have purely been brought forward. They might have done it ten years down the track, but they have got it in place, on the ground, now – sharing the technology with four neighbouring farms. Now, that's a lot less than a half.

That's what I am seeing on the ground!

The Minister was very aware of the role of regional research outcomes in the success of the Australian Government's improved water quality program for Great Barrier Reef stream catchments. The differences noted by the Minister have resulted from the adoption by just a few leading sugarcane growers of higher level precision agriculture practices. The environmental benefits will continue to accrue as more growers adopt such outcomes, and as individual growers progress from entry-level PA4 precision agricultural practices towards the adoption of PA1 level practices that go beyond current best practice (see Section 7.4 of Attachment 1).

7.2 Environmental impact: Development of zonal management tools for water quality management

The quality of the stormwater runoff from a farm reflects the variety of soils, site characteristics, and management strategies applied at the farm. Similarly, the water quality of the runoff from a paddock reflects the variety of the soils, environmental niches, and management practices that have been applied to the paddock. Clearly, some spatial zones within a paddock will be more prone to soil erosion or leaching of agrichemicals than another. The outcomes from Project BPS001 suggest that it may well be possible to develop some tools for tracking water quality issues back to a particular zone within the paddock where a specific treatment may be applied to improve the quality of the runoff originating in that zone.

Significant water quality improvements may be generated by paddock inputs based on site-specific management of spatially-defined zones of crop yield potential. An example of reduced nitrogen application over low-lying potentially waterlogged paddock zones has been provided in Section 8.3.2 of Attachment 1. Further developments in this area will provide information that may be used in a future re-assessment of farm management regulations such as those of the *‘Environmental Risk Management Planning’* guidelines of the Queensland Government.

Improved tools for zonal paddock management and more efficient and effective crop production will also prove to be very useful tools for water quality managers. To be able to track water quality problems back to specific zones within a paddock, and to apply and monitor site-specific amelioration of the problem zone, will be a key achievement in helping to fulfill the Queensland Government's plans for profitable and sustainable land management practices in sensitive coastal catchments.

7.3 Social impacts

Entry into precision agriculture practices has been simplified by the outcomes of BPS001 where simple farming practices have been outlined for adoption by entry-level operators (Section 7.4 of Attachment 1). Improving knowledge of relationships among GIS layers will provide pathways for continual on-farm improvements and will embrace precision agricultural activities as diverse as soil preparation strategies, zonal ripping, zonal application of plant nutrients, breeding cane varieties adapted to both soil variability and spatial positions in the landscape such as potentially waterlogged areas, managing irrigation water, controlling weeds, and refining spatially-defined management techniques based on crop yield potential.

The step-wise progression into higher operational levels of precision agriculture practices that has been clearly set out by Project BPS001 will instill confidence in growers to use new tools in adopting the new farming system, and should encourage them to gradually work towards adopting higher level precision agriculture methods that have the potential to equal or exceed current best management practices.

8. Expected Outcomes:

(Including assessment of the likely impact for the sugar industry in Australia and elsewhere and where possible the cost and potential benefit to the Australian sugar industry and/or the community. Qualitative and/or quantitative baseline data collected in the early stages of the project and compared with data collected towards the end of the project should be analysed and presented to demonstrate impact, learnings and additional outcomes of the project.)

8.1 Crop yield mapping

Access to accurate and reliable crop yield maps is fundamental in progressing precision agriculture practices in sugarcane. High resolution processed IKONOS satellite imagery was used during the course of Project BPS001 to produce yield maps of study sites. Satisfactory results were achieved at the Mackay and Ingham sites (M1 and H2) where NDVI values matched reasonably well with small plot, manually harvested yield data (Section 6.2 of Attachment 1). However at the Burdekin sites B1 and B2 unfiltered correlations between NDVI values and manually sampled small plots were poor and were attributed to a number of factors including lodged cane (common in high yielding irrigated crops), weed invasion issues, sugarcane flowering, and possibly pixel saturation from the heavy yielding plant cane crop at the B2 site.

The value of satellite imagery for regional yield estimation is recognised when there is not a requirement for a high level of accuracy in every paddock. At this stage, Project BPS001 investigators have some concerns with the ability of satellite imagery to produce consistent and reliable crop yield maps for precision agriculture purposes using the NDVI methodology. An earlier image capture time may address some of these concerns but further research is required to improve the accuracy and reliability of yield maps if they are to be used extensively as a key component of precision agriculture.

All the project sites were harvested with machines fitted with Techagro™ yield monitors. Equipment failure at the Mackay site compromised the value of those data. Yield monitor technology is regarded as being the preferred mechanism for delivering yield maps in precision agriculture because the data is generated at the appropriate stage of the harvest period, and the integrity of the data is not compromised by the variables which affect satellite NDVI yield maps (*e.g.* crop lodging, weed issues, stool tipping, and flowering). A single algorithm is used to convert cane harvester monitor sensor signals into actual tonnes of cane per hectare. Research undertaken by Jensen *et al.* (2010) has indicated that Techagro™ yield monitors are able to produce reasonably accurate yield maps, but further work is required to provide the accuracy suitable for precision agriculture.

Both the processed imagery and harvester monitor systems for crop yield mapping require further research and refinement. In the future it is anticipated that precision agriculture will utilise both systems with the yield monitors generating the critical paddock-based yield map and satellite image captures during the growing season for defining agronomic and management issues such as impact of crop pests and disease, poor irrigation practices, weed infestations, etc.

The two approaches will enable a precision agriculture consultant to annually adjust nutrient inputs based on actual yield data and to predict the spatial locations of pest and disease incursions for site-specific application of pesticides and other inputs in subsequent crops. High resolution false- and true-colour satellite imagery as an additional spatial layer to fine tune crop yield interpretations (and resultant management decisions) has been successfully used at site B1 (Section 6.2.4 of Attachment 1) and its role in sugarcane production will increase as the cost of imagery reduces over time.

8.2 Accurate long-term weather forecasting

The role of accurate long term weather forecasting (12 month seasonal outlook) will contribute significantly to the rapid progression of precision agriculture in sugarcane, particularly in relation to nutritional inputs and variable rate applications. Project BPS001 has identified the likelihood of a soil with poor subsoil drainage characteristics positioned in a low lying area of a paddock having a poor yield potential in a wet year. However, in a drier year the yield potential of that zone would be significantly enhanced.

A precision agriculture consultant with access to the three key GIS mapping (soil ECa, paddock elevation, and archived yield maps), and an accurate seasonal forecast, is in a strong position to deliver variable rate nutrient programs for paddocks with inherent variability problems on an annual basis. The definition of the yield potential of stable paddock management zones that take into account soils, topography, and different seasonal conditions over a number of cropping cycles will provide a robust and reliable starting point for the variable rate application of crop inputs.

8.3 Variable rate application of nitrogen

Field observations and validation of crop yield patterns in Project BPS001 established that poorly drained soils located in low lying, waterlogged parts of Sites H2 and M1 are the main drivers of poor yields from zones within paddocks (see Section 7.3 of Attachment 1). However, it is unclear if the low yields in the poorly drained soils can be attributed to:

- a nitrogen deficiency due to denitrification in waterlogged soils;
- leaching losses of other plant nutrients from soils under prolonged wet conditions;
- the sugarcane root system being so compromised by extended waterlogged conditions that the plant is unable to extract nutrients when the soil dries out.

From a variable rate application of nutrients perspective, the foregoing scenario raises two critical paddock management questions whose answers are fundamental in determining the effectiveness of nitrogen applications after the paddock dries out:

- Should more nitrogen be applied to the previously waterlogged zone to offset the nitrogen losses through denitrification?
- Should less nitrogen be applied to the formerly waterlogged zone because the compromised root system of the crop is no longer able to extract any added nitrogen from the soil?

Further agronomic research is required to determine the most effective nitrogen management strategy in paddock zones subject to waterlogging and extended anaerobic conditions.

8.4 The role of the precision agriculture consultant

Project BPS001 has identified the need for sugarcane growers to work closely with precision agricultural consultants to identify and manage spatial zones with a paddock. Effective consultants will have high level GIS and computer skills, a thorough understanding of agronomic principles and practices and, in addition, a basic grasp of soil science and good communication and extension skills (see Section 8.3.1 of Attachment 1). Such support people are currently very rare in the Australian sugar industry, but the niche is guaranteed to expand as more growers seek specialised advice.

The sugar industry has to learn that precision agriculture is a specialised business and, like any specialised business, requires an investment in the best advice that is available. The days of providing a grower intending to adopt precision agricultural practices with a pocket manual to leave in the glovebox of the ute and a double-sided fact sheet are long since gone!

8.4 Potential benefit to the sugar industry

This issue was covered in section *'4.3.1 Methodology - Evaluation: Impact of the project'* (above) in which the BPS001 zonal approach to nutrient application within paddocks was shown to have the potential to return $1.6 million to sugarcane growers in the Mackay region alone. Reduced nutrient applications to waterlogged parts of paddocks also offer potential increases in water quality, thereby providing both economic and environmental benefits to the growers.

9. Future Research Needs:

9.1 Definition of paddock management zones in terms of crop yield potential

Australian sugarcane crop production is highly variable spatially within paddocks and across districts, and temporally from season to season. This variability is predominantly attributed to fluctuations in seasonal climatic conditions, soil interactions, crop age (ratoon number), and to a lesser extent, farm management practices. Poor understandings of the interactions among the variables controlling crop yield give growers similarly poor insights into which farming practices might be best used to maximise crop production. They also reduce the ability of sugar mills to form accurate regional yield forecasts prior to harvest. Both of these issues cost the industry millions of dollars in lost revenue.

The problems could be overcome if we knew how stable crop yield zones are over time and under changing seasonal conditions. Such knowledge could be gained by relating historical regional climate records over a sequence of cropping cycles (15+ years), to seasonal crop productivity and biomass variability mapped by satellite imagery, underlain by soil and landscape data, and integrated with yield data sourced from three sources: mill and grower paddock records (including variety and crop age), harvester monitors, and manually harvested plots. Much of this data is currently available through Mackay Sugar Ltd. Analysis of the spatial and temporal interactions among these parameters, would produce much more accurate crop yield estimates from spatially defined paddock zones that take into account climatic and site variability.

Should the boundaries of such zones prove to be stable over time (and under defined weather conditions), then it will be possible to define the yield potential of the crop management zones within a paddock. The definition of management zones in this manner will provide a reliable starting point for variable rate application of crop inputs.

9.2 Tools to manage the sugarcane crop to its zonal yield potential

Several research projects may follow from the definition of zonal yield potentials as discussed in the previous section. They include research to:

- define management zones within paddocks based on a spatial analysis of the impact of seasonal growing conditions on the patterns of crop yield over long sequences of wet, dry, and 'average' years;

- demonstrate the repeatability and stability of defined crop yield potential zones over time;

- determine the optimal number of crop yield potential management zones within a paddock;

- identify the influence of topography and soil properties (especially soil texture) on the stability of crop yield patterns under varying seasonal conditions;

- explore the impact of paddock irrigation on deep soil ECa signals and the potential for deep soil ECa mapping of subsoil moisture status;

- following the protocols available for nitrogen applications, develop new protocols for variable rates of application of other paddock inputs (particularly phosphorus and potassium) based on crop yield potential;

- match sugarcane varieties to specific spatial conditions (soil and topographic niches) within paddocks through the use of a 'variable variety planter' to allow on-the-go changes along the row during planting;

- ascertain the most effective inputs required to match crop nutrient needs to the ageing of ratoons in a cropping cycle;
- adjust crop nutrient inputs to potentially compromised sugarcane root system needs under waterlogged conditions;
- determine differences in nutrient losses through denitrification (and variations in nutrient inputs needed) in waterlogged soils of different soil texture.

10. Recommendations:

(Including activities or other steps to further develop, disseminate or exploit the Project Outputs, and/or to achieve benefits)

The research outcomes from Project BPS001 are currently being implemented by a small group of scientists with specialised skills, of which a deep appreciation of GIS processes is essential. A proposal is currently under development for consideration for funding by SRDC as a Grower Group Innovation Project.

The proposed GGIP Project aims to develop a smart GIS system to allow non-specialist operators to manage and interrogate spatial datasets (*e.g.* soil ECa maps, satellite imagery, georeferenced soil test sites, etc) and to produce predictive maps of management zones within paddocks.

11. List of Publications:

(Copies of substantive publications from the project should be included as Appendices. Where the project involves a student and the thesis is relevant to the project this should be referred to in the report and an electronic copy of the thesis sent with the report or as soon as it is available.)

Electronic copies of the substantive papers (*) are included on the CD-ROM in Attachment 4.

Coventry, R.J., Hughes, J.R., Di Bella, L.P., Crowley, A., and McDonnell, P. (2009).
Using EM maps to detect soil patterns in sugarcane paddocks.
Proceedings of the Australian Society of Sugar Cane Technologists, **31**, 587. (Poster).

* Coventry, R.J., Hughes, J.R., Reid, A.E., McDonnell, P. (2010).
Stability of spatial patterns defined by electrical conductivity mapping of soils within sugarcane paddocks.
Proceedings of the Australian Society of Sugar Cane Technologists, **32**, 397-409.

* Coventry, R.J., Pollock, D.C., Hughes, J.R., and Di Bella, L.P. (2009).
A role for soil EM mapping in precision agricultural practices for sugarcane production.
Proceedings of the Australian Society of Sugar Cane Technologists **31,** 265-273.

Di Bella, L.P., Coventry, R.J., McDonnell, P., Hughes, J.R., Parker, T., Ponce, E., and Sefton, M. (2010). Comparing precision agricultural tools and their usefulness in the Australian sugar cane industry.
Proceedings of the Australian Society of Sugar Cane Technologists, **32**, 701. (Poster)

* Di Bella, L.P., Coventry R.J., Sefton, M., Moody, P.W., Hanks, M., Stringer, J.K., and Kerkwyk, R.E. (2009b). The use of georeferenced soil test data in the Herbert District. *Proceedings of the Australian Society of Sugar Cane Technologists* **31,** 296-306.

* Di Bella, L.P., Sefton, M., Marrero, S., Ponce, E., Fernandez, F., Esquivel, M., and Coventry, R. (2009a). Sugarcane yield monitoring in the Herbert District. *Proceedings of the Australian Society of Sugar Cane Technologists* **31**, 274-281.

Hughes, J.R., Coventry, R.J., and Di Bella, L.P. (2009). GPS-guided zonal tillage: an option for managing soil compaction and yield variability in the Wet Tropics. *Proceedings of the Australian Society of Sugar Cane Technologists,* **31**, 585. (Poster).

Hughes, J.R., Coventry, R.J., McDonnell, P. (2011). Managing spatial variability in sugarcane production systems, *Proceedings of the Australian Society of Sugar Cane Technologists*, **33** (Poster, CD-ROM).

Parker, T., Savina, M., Sparkes, D., Morrison, D., Sorensen, K., and Di Bella, L. (2010). A practical application of PA tools in the Barron River Delta. *Proceedings of the Australian Society of Sugar Cane Technologists,* **32**, 700. (Poster).

Reid, A.E. (2008). Improving knowledge for statistical analysis of high resolution soil mapping data. *Final Report, SRDC Travel and Learning Project number: DPI019,* http://www.srdc.gov.au/UserImages/File/Final%20Reports/080501%20DPI019%20Fin%20rpt.pdf

Reid, A. E., Coventry, R.J., Hughes, J.R., and Di Bella, L.P. (2008). Precision agriculture in sugarcane production. *Australasian GenStat Conference 2008: Biometrics in Primary Industries and the Environment,* 2 - 5 December 2008, Marysville, Victoria.

Reid, A.E., Hughes, J.R., and Coventry, R.J. (2009). Environmental factors driving EM responses of soils. *Proceedings of the Australian Society of Sugar Cane Technologists,* **31**, 583. (Poster).

* Robson, A., Hughes, J., Coventry, R., Di Bella, L., Ponce, P., and Sefton, M. (2010). Using spatial mapping layers to understand variability in precision agricultural systems for sugarcane production. *Proceedings of the Australian Society of Sugar Cane Technologists*, **32**, 713. (Poster). **Received the Best Poster Award, Australian Society of Sugar Cane Technologists Conference, Bundaberg 2010.**

List of Attachments

ATTACHMENT 1 (hard copy and CD-ROM)
Project BPS001: Report on the scientific findings

The pdf file of the *'Project BPS001 Final Report. Attachment 1: Scientific Findings'* includes the following sections:

Chapter 1: Prologue
Chapter 2: Introduction and background
Chapter 3: The BPS001 study sites
Chapter 4: Methods for collecting and processing spatial data
Chapter 5: Understanding paddock variability: the soil GIS layer
Chapter 6: Understanding paddock variability: crop yield and elevation layers
Chapter 7: Simplifying the complexity of paddock variability
Chapter 8: Project BPS001: driving precision agriculture forward
Chapter 9: References
Chapter 10: List of publications

ATTACHMENT 2 (hard copy and CD-ROM)
Operations manual for soil ECa mapping: a guide for collecting, analysing, and interpreting apparent soil electrical conductivity information.

ATTACHMENT 3 (hard copy and CD-ROM)

Testimonials from sugarcane growers and industry consultants

The three following letters are included on the CD-ROM in a single pdf file:

- Letter of support from Mr A. Bugeja, sugarcane grower, Rosella Farm, Homebush.
- Letter of support from Mr R. Sluggett, agricultural consultant and sugarcane grower, Plane Creek.
- Letter of support from Mr P. McDonnell, agricultural consultant, Ayr.

ATTACHMENT 4 (included as a folder on the CD-ROM only)
Substantive publications arising from Project BPS001

The five substantive publications indicated in the Publication List (Section 11, above) are included as separate files in the Attachment 4 folder on the CD-ROM.